Ecological Effects of the Hayman Fire

Part 1: Historical (Pre-1860) and Current (1860 – 2002) Fire Regimes

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Introduction

To address historical and current fire regimes in the Hayman landscape, we first present the concepts of "historical range of variability" and "fire regime" to provide the necessary conceptual tools for evaluating fire occurrence, fire behavior, and fire effects. Next we summarize historical (pre-1860) fire frequency and fire effects for the major forest types of the Colorado Front Range, to illustrate and emphasize the key point that the ecological role of fire is dramatically different in the various forest types that are found in and around the area burned by the Hayman Fire. We consider the magnitude by which these different kinds of fire regimes in the Colorado Front Range have been altered (or not altered) by human actions, notably 20th century fire exclusion. Finally, we focus on the Hayman Fire itself, to evaluate the extent to which this large, severe fire can be regarded as either a "natural" or an "unprecedented" event in this ecosystem.

Because future Front Range fires will likely occur outside the Hayman area, and because one purpose of this report is to provide a scientific basis for developing fire management policy, we believe it is important to place our assessment of the Hayman Fire into a broader context. For this reason, we discuss the role of fire in some forest types that actually are uncommon within the Hayman Fire perimeter per se (for example, spruce-fir), recognizing that the next big Front Range fire may well occur in these other kinds of ecosystems. Moreover, an understanding of the fire ecology of other ecosystems adjacent to the Hayman area helps clarify some of the unique features of the Hayman landscape. Thus, our treatment moves from basic concepts of fire and landscape dynamics in general, to a description of broad fire and landscape patterns in the Colorado Front Range, to a specific analysis of fire and landscape history within the specific area where the Hayman Fire occurred.

"Historical Range of Variability" (HRV)

Modern concepts of resource management that emphasize maintenance of ecosystem integrity while also providing commodities and services to society are encompassed under "ecosystem management." Ecosystem management (Christensen and others 1996) has been defined as: "Management driven by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on our best understanding of the ecological interactions and processes necessary to sustain ecosystem structure and function." An important component of the ecosystem management paradigm is explicit recognition of the dynamic character of ecosystems. Ecosystem management is not intended to provide maintenance of any status quo in ecosystem conditions but rather accepts that change is an inherent characteristic of ecosystems across both space and time.

For resource managers, it is important to know the range of critical ecological processes and conditions that have characterized particular ecosystems over specified time periods and under varying degrees of human influences (Christensen and others 1996). As applied to the management of forested ecosystems in the Western United States, an ecosystem management paradigm emphasizes knowledge of the range of ecosystem conditions prior to significant changes brought on by intensive Euro-American settlement and how these conditions have continued to change during the 20th century (Kaufmann and others 1994; Morgan and others 1994; Landres and others 1999; Swetnam and others 1999). The timing of major impact of Euro-American settlement on terrestrial ecosystems varies in the West from the middle 18th to early 20th centuries but generally begins in the latter half of the 19th century for most areas, including the Front Range of Colorado (but see part 5 of this report, "Historical Aquatic Systems"), where major impacts are described as early as the 1810s when beaver were extirpated. We refer to the range of ecological conditions and ecological processes (including disturbance processes such as fire) that characterized Front Range ecosystems for several centuries prior to significant impacts of Euro-American settlers as the ***historical range of variability*** or ***HRV***.

Understanding of natural variability in ecosystem conditions and processes provides operational flexibility for management actions and protocols (Landres and others 1999). Incorporating historical ecosystem patterns into management goals provides a strategy for dealing with sustainability of diverse and often unknown species requirements. Managing within the natural bounds of site variability and history, as well as maintaining major historical patterns and processes of ecosystems, is also probably easier and less expensive to achieve than trying to manage outside of constraints imposed by driving factors of the system (Landres and others 1999). Historical patterns of ecosystem conditions provide what may be the only viable model for how ecosystems have evolved and perpetuated themselves in the absence of significant human effects. Although anthropogenic climate change may alter ecosystems, natural climatic variation also has resulted in relatively rapid ecological changes in the past. In the absence of clear knowledge that historical ecosystem function is no longer an appropriate model, using the historical condition as a guide for evaluating current ecosystem conditions is warranted

Throughout this report, we compare ecological conditions in the aftermath of the Hayman Fire not only to conditions that existed just prior to the fire, but also to the natural range of conditions that characterized this ecosystem for hundreds of years prior to the arrival of Euro-American settlers. It becomes apparent that not all conditions just prior to the fire were "natural" or even desirable from an ecological standpoint. The HRV concept is most valuable when used as a reference against which to compare current conditions or trends. Where current ecosystem properties or trajectories are not much different from what would be expected under the historical disturbance regime, then the system probably is functioning normally, and ecological restoration is not needed. However, if current ecological conditions are dramatically different from historical patterns and trends, then careful assessment of the changes is warranted, and restoration of some or all of the historical ecosystem components and processes should be considered.

Historical Range of Variability in Fire Regimes of the Colorado Front Range

A "fire regime" is a summary description of the salient characteristics of fire occurrence and effects within a specified area (table 1). One of the most important aspects of a fire regime is the fire "severity" or impact of the fire on organisms and abiotic components of the ecosystem. The term "fire severity" is used with many different meanings, however (table 2), so we are careful in this report to define what we mean by fire severity. Fire regimes varied greatly throughout the Front Range during the historical period, as a result of underlying variation in vegetation characteristics and local climate (Agee 1998). Both vegetation and climate vary along gradients in elevation and topography (fig. 1).

As elevation increases, precipitation generally increases and temperatures decrease. This pattern is complicated by topography and soils, however, and the elevational zones in figure 1 depict only general trends. At any given elevation, the north-facing slopes tend to be cooler and moister than the south-facing slopes because the sun strikes south-facing slopes more directly. Fine-textured soils (derived, for example, from sedimentary rocks) generally retain more moisture than coarse-textured soils (derived, for example, from the granitic rocks that are prevalent in the Hayman area). Thus, vegetation zones extend to somewhat

Table 1—Components of a fire regime.

Component	Definition
Fire frequency	Number of fires occurring within a specified area during a specified time period, for example, number of fires in the Pike – San Isabel National Forest per year
Fire size or fire extent	The size (hectares) of an individual fire, or the statistical distribution of individual fire sizes, or the total area burned by all fires within a specified time period, for example, total hectares within the Pike – San Isabel National Forest that burned in 2002
Fire interval (or fire recurrence interval)	The number of years between successive fires, either within a specified landscape or at any single point within the landscape
Fire season	The time of year at which fires occur, for example, spring and fall fires, when most plants are semi-dormant and relatively less vulnerable to fire injury, or summer fires when most plants are metabolically active and relatively more vulnerable to fire injury
Fire intensity	Amount of heat energy released during a fire … rarely measured directly, but sometimes inferred indirectly from *fire severity*
Fire severity	Fire effects on organisms and the physical environment (see table 2)

Table 2—Commonly used synonyms and definitions of the concept "fire severity." The meanings differ depending on whether the focus is on fire effects on the forest canopy and understory or on the soil and soil surface. Note that the definitions may be inconsistent, for example, a *high*-severity fire from the perspective of the forest canopy may be *low*-severity from the soil perspective. However, high-severity effects on soils are almost always accompanied by high-severity effects on the canopy. The definitions used in the BAER process (burned area emergency rehabilitation) also are included.

Term	Definitions
Effects on the forest canopy and understory vegetation	**High severity** = **Lethal** = **Stand-replacing** … the fire kills all or most canopy and understory trees, and initiates a succession process that involves recruitment of a new cohort of canopy trees **Low-severity** = **Non-lethal** = **Non-stand-replacing** … the fire kills only a few or none of the canopy trees, but may kill many of the understory trees, and does not result in recruitment of a new canopy cohort but creates or maintains an open, low-density forest structure **Mixed-severity** = **Intermediate severity** … used in two different ways: *Within-stand* – the fire kills an intermediate number of canopy trees (less than high-severity but more than low-severity), and may or may not lead to recruitment of a new canopy cohort *Among-stand* – the fire burns at high severity in some stands but at low or intermediate severity in others, creating a mosaic of heterogeneous fire severity across the landscape
Effects on the soil and soil organisms	**High severity** … the fire consumes all or nearly all organic matter on the soil surface, as well as soil organic matter in the upper soil layer, and kills all or nearly of the plant structures (for example, roots and rhizomes) in the upper soil layer … results in possible water repellency and slow vegetative recovery **Low-severity** … the fire consumes little or no organic matter on the soil surface or in the upper soil layer, and kills few or no below-ground plant parts … results in limited or no water repellency, and to rapid vegetative recovery via re-sprouting
Definitions used by BAER	**High-severity** … areas of crown fire, i.e., leaves and small twigs consumed by the fire … always stand-replacing **Moderate-severity** … areas where the forest canopy was scorched by an intense surface fire, but the leaves and twigs were not consumed by the fire … may be stand-replacing or not, depending on how many canopy trees survive the scorching **Low-severity** … areas where the fire burned on the surface at such low intensity that little or no crown scorching occurred (may include small areas that did not burn at all) … never or rarely stand-replacing

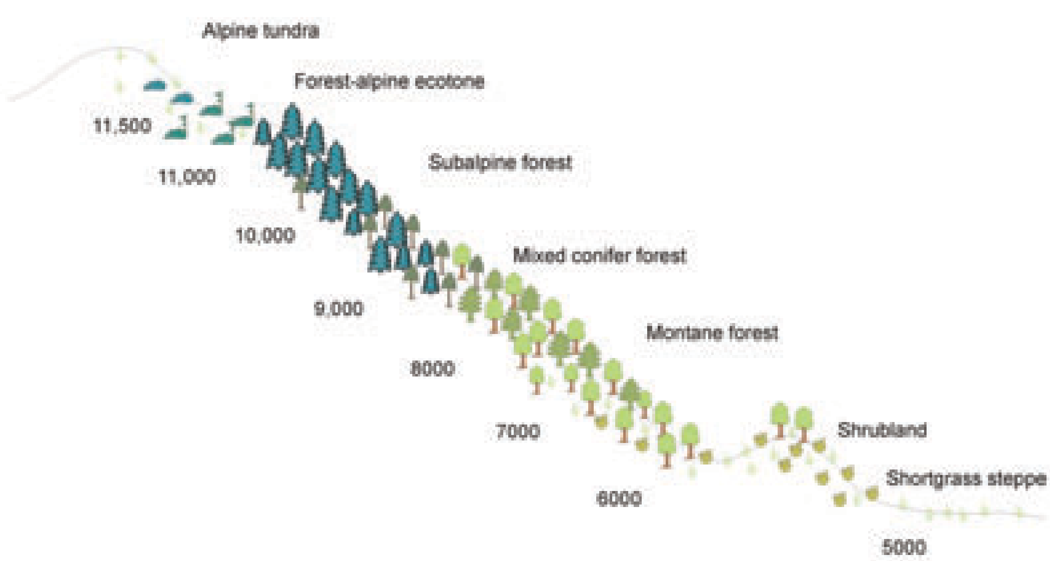

Figure 1—Major forest zones in the Colorado Front Range (provided by Laurie Huckaby).

higher elevations on south-facing slopes or where soils are coarse textured and extend to lower elevations on north-facing slopes or where soils are fine textured (Peet 1981).

Where the Great Plains meet the foothills of the Front Range (approximately 5,500 feet), the arid short-grass steppe gives way to dense shrublands of mountain-mahogany (*Cercocarpus montanus*) and other shrub species, intermixed with open forests of ponderosa pine (*Pinus ponderosa*). The open ponderosa pine forests are referred to as the "lower montane" zone, and they grow in the driest sites capable of supporting trees. Ponderosa pine becomes denser with increasing elevation, until in the "montane" zone (approximately 6,500 to 8,000 feet) it can form closed forests if undisturbed for long periods. Douglas-fir (*Pseudotsuga menziesii*) also grows with ponderosa pine in the montane zone. Douglas-fir tends to be more abundant on relatively cool, moist sites (for example, north-facing slopes and higher elevations), whereas ponderosa pine tends to be more abundant on relatively warm, dry sites (for example, south-facing slopes and lower elevations) within this broad vegetation zone. In the "mixed conifer" zone (approximately 8,000 to 8,500 feet), higher precipitation allows ponderosa pine and Douglas-fir to form dense stands in which both species codominate, along with a variable mixture of other tree species including aspen (*Populus tremuloides*), lodgepole pine (*Pinus contorta* var. *latifolia*), and limber pine (*Pinus flexilis*). Ponderosa pine and Douglas-fir drop out as one reaches the cool, wet "subalpine forest" zone (approximately 8,500 to 11,000 feet), and forests become dominated by a variable mixture of lodgepole pine, aspen, subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and limber pine. Above 11,000 to 11,500 feet, the growing season is too short for trees, and the vegetation is alpine tundra.

Within this framework of natural variation in vegetation and climate, we can recognize three general kinds of fire regime in the Front Range (table 3). We must emphasize that the distribution patterns described in table 3 are necessarily general and qualitative, and that many local exceptions are to be expected. Nevertheless, these three kinds of fire regimes provide a basic ecological context for evaluating fire occurrence and fire effects throughout the Front Range – including the Hayman Fire. All three fire regimes are powerfully influenced by weather and climate. Fuels conditions also are important in the frequent, low-severity, and mixed fire regimes, but are of far less importance in infrequent, high-severity fire regimes where weather conditions conducive to extensive fire occur only rarely (table 3 and below). Similarly, the importance of ignition frequency and ignition source (for example, by Native American peoples) varies greatly with elevation and geographic location (Baker 2002). We discuss changes in stand and landscape structure during the past 150 years in Front Range forests, and, later in this part 1, we discuss how these changes may influence fuels and fire behavior.

We cannot overemphasize the importance of these fundamental differences in natural fire regimes along an elevational gradient from lower montane to subalpine zones, not only in the Front Range but throughout the Rocky Mountain region of southern Wyoming and Colorado (Romme and Knight 1981; Peet 1988; Brown and others 1999; Veblen and others 2000, Kipfmueller and Baker 2000). Although fire ecologists have long recognized that fire regimes vary with elevation, topography, vegetation type, and geographic region (for example, Swetnam and Baisan 1996; Agee 1998; Heyerdahl and others 2001; Brown and Shepperd 2001; Allen and others 2002; Schmidt and others 2002), many recent policy statements portray all Western forests as a single, homogeneous entity (for example, President Bush's "healthy forests initiative" of 2002).

Infrequent High-Severity Fire Regimes – Continuous canopy fuels of dense Engelmann spruce, subalpine fir, and lodgepole pine forests, growing in cool, moist environments, permit widespread stand-replacing crown fires or severe surface fires – but only during conditions of low fuel moisture, low relative humidity, high temperatures, and winds. These kinds of weather conditions occur only a few times in several decades in the subalpine zone, and consequently most ignitions extinguish naturally without spreading. Low decomposition rates in the subalpine zone cause accumulation of fuels during the long intervals between fires and, therefore, intense fire behavior when extremely dry weather conditions eventually coincide with ignition (Clagg 1975; Romme and Knight 1981). Thus, subalpine forests generally are characterized by *infrequent, high-severity fires* (table 3).

For spruce-fir and lodgepole pine forests in the subalpine zone of northern Colorado and adjacent areas in the Rockies, stand-replacing fires are well documented as the kind of fires that have the greatest impacts on forest structure. In areas of continuous forest in the subalpine zone, vast areas have burned in single stand-replacing events as indicated by extensive even-aged tree populations (Whipple and Dix 1979; Romme and Knight 1981; Veblen 1986; Aplet and others 1988; Parker and Parker 1994; Sibold 2001; Kulakowski and Veblen 2002). Figure 2 depicts a portion of the area that burned in the extensive fires of 1851 – a regional drought year similar to 2002, in which fires occurred in almost every mountain range in Colorado, New Mexico, and Arizona. Large, high-severity fires in subalpine forests represent an infrequent but entirely normal event in subalpine forests. In contrast, low-severity surface fires in the subalpine

Table 3—Three general types of fire regimes in the Colorado Front Range. See table 2 for definitions of fire severity, and see the text for explanations and important caveats.

Type of regime	General characteristics	Major controlling variables	Distribution
Infrequent, High-Severity Fire Regimes	Fires recur within any stand at long intervals (100 to 500+ years), burning at high severity in the canopy and understory, and at variable severity to the soil	**Weather** and **Climate** are the primary controllers (most ignitions extinguish by themselves because of wet conditions; extensive fires occur only in very dry summers); variability in fuels usually has little influence on fire frequency, extent, or severity)	This type predominates at higher elevations (lodgepole pine and spruce-fir forests in the **subalpine zone**) in the Front Range and throughout the Rocky Mountains
Frequent, Low-Severity Fire Regimes	Fires recur within any stand at relatively short intervals (5 to 50 years), burning at low severity in the canopy and soil, and variable severity in the understory	**Weather** (fires occur during dry periods), **Climate** (extensive fires tend to occur in dry years that follow 1-3 wet years), and **Fuels** (fuels gradually accumulate during the intervals between successive fires)	Within the Colorado Front Range, this type apparently is restricted to ponderosa pine forests in the **lower montane zone** … it is more widespread in ponderosa pine forests in Arizona, New Mexico, and southern Colorado
Mixed Fire Regimes	These fire regimes are intermediate between the Frequent, Low-Severity and the Infrequent, High-Severity Fire Regimes … fires occur at variable intervals (10 to greater than 100 years), and burn at variable severity (patches of high severity intermingled with patches of low or intermediate severity)	**Weather**, **Climate**, and **Fuels** all influence fire frequency, extent, and severity, in complex ways that are not well understood, with enormous variability over time and space	This type predominates at middle elevations (ponderosa pine and Douglas-fir forests in the **montane zone**) in the Front Range and probably also characterizes middle elevations throughout much of the Rocky Mountains and Southwest

zone are relatively restricted in extent and probably have less ecological importance than the stand-replacing fires (Veblen 2000; Sibold 2001; Kulakowski 2002; Sherriff and others 2001; Kipfmueller and Baker 2000). In some of the driest sites at high elevations, where limber pine is the dominant tree species, fire-scarred trees are sometimes common, indicating a local history of surface fires (Sibold 2001). Overall, however, spruce-fir forests growing on cool, moist sites at high elevations commonly exhibit long fire intervals of more than 400 years between extensive crown fires (Romme and Knight 1981; Veblen and others 1994; Sibold 2001; Kulakowski 2002).

Frequent Low-Severity Fire Regimes – Fires in open ponderosa pine woodlands of the lower montane zone, where grass and other herbaceous fuel types are well developed, tend to be surface fires of relatively low intensity and high frequency. Weather conditions that dry fuels sufficiently for fire spread are more common at lower elevations and result in widespread fires during dry years (Veblen and others 2000). Thus, lower montane ponderosa pine forests generally were characterized by *frequent, low-severity fires* prior to the mid-1800s (table 3). This historical fire regime along the lower forest ecotone in the Colorado Front Range is similar in some respects to the historical fire regime of Southwestern ponderosa pine forests, for example, in northern Arizona (Covington and Moore 1994; Fule and others 1997; Veblen and others 2000; Brown and Shepperd 2001). Fires were less frequent in this habitat in the Front Range than in most Southwest sites, but ecological effects were similar in the sense that surface fires were sufficiently frequent to prevent open woodlands from developing into dense stands. Because many resource managers believe that ponderosa pine forests in the Front Range had historic fire regimes similar to the frequent, low-severity fire regime of many Southwest ponderosa pine forests, it is important to estimate how applicable the low-severity

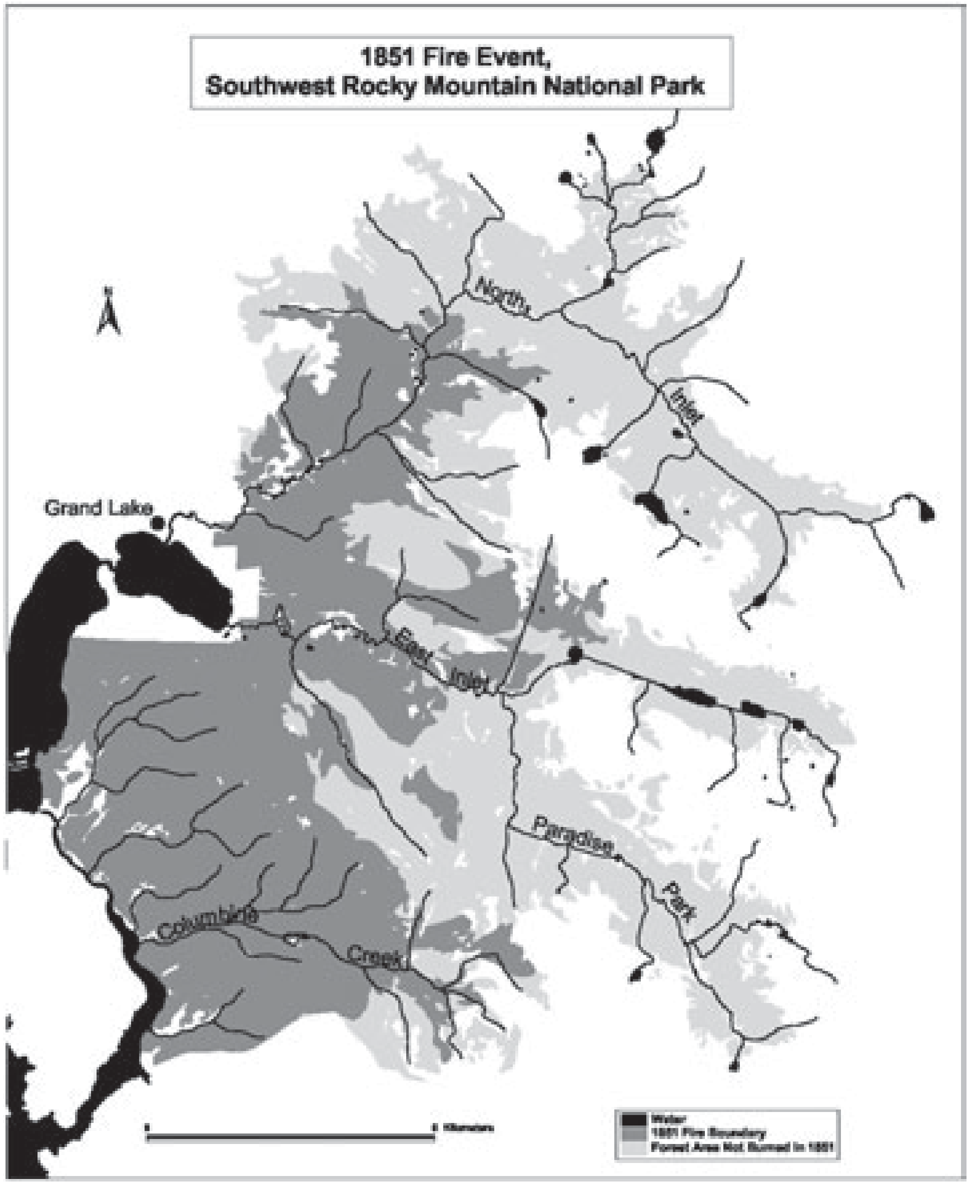

Figure 2—Map showing the extent of burning in 1851 in the southwestern sector of present-day Rocky Mountain National Park. The 1851 fire burned approximately 5,200 ha in the 11,000 ha area sampled for fire history. Fire extent was reconstructed from approximately 1,000 tree ages and 150 fire-scar wedges and field observations in all vegetation patches greater than 8 ha in the Park's GIS vegetation layer as described in Sibold (2001). Data are from J. Sibold and T. Veblen, unpublished.

fire regime is to ponderosa pine forests throughout their elevational distribution in the Front Range.

In the northern Front Range a study is currently under way that maps historic fire regimes in the ponderosa pine zone based on empirical models derived from 54 fire history sample sites (approximately 100 ha each) that relate fire regime type to environmental site conditions. The focus of the study is on discrimination of areas of relatively frequent fires (that is, return intervals to the same approximately 100 ha stand of 5 to 50 years) as opposed to infrequent fires (return intervals of many decades or even a century or more). Each of the 54 fire history sample sites was classified as having a fire frequency type of high, moderate, or low; the former approximates the Frequent-Low-Severity regime, and the latter two correspond to Mixed Fire Regimes in table 3. Environmental conditions at each site were classified in terms of the mean elevation, slope steepness, aspect, proximity to grassland, distance to ravine and the associated fire frequency type (high, moderate, and low fire frequency). Logistic regression and decision tree classification were used to model the relationship between each fire frequency regime type and the predictor environmental variables. These empirical models were developed for all cover types in the Arapaho-Roosevelt National Forest (ARNF) on the eastern slope of the Front Range that include ponderosa pine in a 71,224 ha study area. Using the ARNF Integrated Resource Inventory (IRI), the cover types and percent areas included were: ponderosa pine (29 percent), ponderosa pine-Douglas fir (25 percent), Douglas fir-ponderosa pine (10 percent), and mixed conifer (36 percent). In the mixed conifer type, ponderosa pine was the dominant species in 57 percent of the area. Thus, in the area of analysis ponderosa pine was dominant over 75 percent of the area.

Both the logistic regression and decision tree classification techniques indicate that lower elevations are more favorable to high fire frequency than higher elevation areas, and both models consistently predict the same low elevation areas as having high fire frequency regimes. According to these models, less than 17 to 18 percent of the ARNF ponderosa pine forests (where ponderosa is either the dominant species or a subdominant but significant component of the stand) would have had high fire frequency regimes. Conversely, 62 to 74 percent of the ponderosa pine study area would have had low fire frequency regimes (three or fewer fires between 1750 and 1915). The areas with reconstructed high fire frequencies are clearly limited by elevation. Elevation may be a proxy for other factors such as proximity to grasslands, given that the lowest elevations are adjacent to the plains-grassland ecotone, where the highest fire frequency sites occur. The low fire frequency sites tend to occur on more mesic north-facing aspects farther from ravines and on steep slopes.

This study is based on empirical fire history data from the northern Front Range where topographic and other differences may have resulted in a somewhat different historic fire regime than in the ponderosa pine zone of the southern Front Range. Given that caveat, the percentage area of estimated fire regime type for the ponderosa pine zone cannot be directly extrapolated outside of the area of study in the northern Front Range. However, this study in the northern Front Range clearly documents the following points: (1) The total amount of area now dominated by ponderosa pine that supported a frequent low-severity fire regime in the northern Front Range was relatively small and generally restricted to the lowest elevations along the mountain front. (2) Even within the cover type mapped as "ponderosa pine," where stands are often monospecific, approximately half of the area was not characterized by a frequent low-severity fire regime. Although this study is still in progress, these initial findings for the northern Front Range indicate that presence of a ponderosa pine cover type does *not* necessarily indicate a history of formerly frequent surface fires.

Mixed-Severity Fire Regimes – Most of the ponderosa pine and Douglas-fir forests within the montane and mixed conifer zones of the Colorado Front Range were characterized by a ***mixed-severity fire regime***. This is a complex fire regime that contains elements of both the frequent low-severity and the infrequent high-severity types (Agee 1998). Neither the Southwestern ponderosa pine model developed for northern Arizona (Covington and Moore 1994; Fule and others 1997) nor the boreal/subalpine forest model (for example, Johnson 1992; Veblen and others 2000) is appropriate in itself to describe this mixed-severity fire regime. Mixed-severity fire regimes in general are perhaps the most complex and poorly characterized of all historical fire regimes in Western North America, but they were widespread historically and were distinct from other types of fire regimes (Agee 1998).

Mixed-severity fire regimes in forests of ponderosa pine and Douglas-fir in the Colorado Front Range can be characterized as follows (from Brown and others 1999; Kaufmann and others 2000a,b, 2001; Veblen and others 2000; Ehle and Baker in press): Fires recurred at highly variable intervals, ranging from a decade to a century, and varied in size from very small (less than 1 ha) to very large (tens of thousands of hectares). Within the perimeter of any individual fire were areas where all of the canopy trees were killed, areas where many but not all of the trees were killed, areas with little or no canopy mortality, and unburned patches. These mortality patterns were produced by a mix of active crown fire, passive crown fire, severe surface fire that scorched tree crowns, and low-intensity underburning that did not scorch tree crowns. Proportions of total burned area in each of these categories of fire severity varied greatly among individual fire events. The largest, most severe fires tended to occur in extremely dry years, especially dry years following one to three wet years. Some large fires burned over a period of several months, dying down during moist days but flaring up again on dry windy days. However, not every watershed necessarily burned in every dry year, because of random variation in locations of ignitions as well as local variation in weather, disturbance history, and fuels characteristics.

We have good empirical evidence for both the stand-replacing and non-stand-replacing components of this mixed fire regime in Front Range forests of ponderosa pine and Douglas-fir. For example, centuries-old ponderosa pine trees with multiple fire scars, as well as all-aged structure in extant stands, testify to recurrent low-severity surface fires (for example, Rowdabaugh 1978; Skinner and Laven 1983; Goldblum and Veblen 1992; Brown and others 1999; Kaufmann and others 2000a,b; Donnegan 2000; Veblen and others 2000; Huckaby and others 2001; Brown and Shepperd 2001). In addition, around the year1900, photos of severely burned areas and young regenerating forests, as well as current even-aged stand structures, document the occurrence of stand-replacing fire (Veblen and Lorenz 1986, 1991; Hadley and Veblen 1993; Brown and others 1999; Kaufmann and others 2000a,b; Ehle and Baker in press).

Climatic Variation: a Key Influence on Front Range Fire Regimes – At an interannual scale, synchronous occurrence of fire-scar dates from sample sites separated by tens or hundreds of miles is strong evidence that regional climate is influencing fire regimes. For the area from southern Wyoming to southern Colorado, widespread burning in 1880 was recorded in early, albeit fragmentary, documentary sources (Jack 1900; Plummer 1912; Ingwall 1923), as well as in tree-ring studies of fire history (see Skinner and Laven 1983; Zimmerman and Laven 1984; Goldblum and Veblen 1992; Kipfmueller and Baker 2000; Veblen and others 2000; Brown and others 1999). Other individual years that recorded fire scars at disjunct locations over this large area include 1654, 1684, 1809, 1813, 1842, 1851,1859 to 1860, 1871 to 1872, 1879 to 1880, and 1893 to 1894 (Kipfmueller and Baker 2000; Alington 1998; Brown and others 1999; Veblen and others 2000; Donnegan 2000; Sherriff and others 2001; Sibold 2001). Such synchrony of fire years suggests that at a regional scale extreme weather increases fire hazard over extensive areas from southern Wyoming to southern Colorado. Indeed, tree rings sampled at numerous sites in northern Colorado (Cook and others 1998; Veblen and others 2000) indicate that all of the major fire years listed above correspond with significant drought during the year of the fire and/or the year immediately preceding the fire year. Over the period from 1800 to 1900, reconstruction of the Palmer Drought Severity Index indicates that the three driest years were 1842, 1851, and 1880 (Cook and others 1998), which were years of widespread burning in the Front Range (see fig. 2). The tree-ring record of drought and fire occurrence indicates that over the past several hundred years, fire years of similar extent to the year 2002 have occurred numerous times.

A comparison of fire occurrence and climatic variation from 1600 to the present, based on tree-ring records collected from ponderosa pine and associated conifers, indicates that fire is strongly associated with interannual climatic variation in the montane zone of the northern Colorado Front Range (Veblen and others 2000). Warmer and drier spring-summer seasons, indicated in instrumental climatic records (1873 to 1995) and in tree-ring proxy records of climate (1600 to 1983), are strongly associated with years of widespread fire. Years of widespread fire in the ponderosa pine cover type also tend to be preceded by 2 to 4 years of wetter than average spring conditions. Thus, years of widespread fire tend to occur during dry years closely following years of above average moisture that increase the production of fine fuels (Veblen and others 2000). Alternation of wet and dry periods lasting 1 year to a few years is conducive to the occurrence of large fires and is strongly linked to El Niño-Southern Oscillation (ENSO) events. The warm (El Niño) phase of ENSO is associated with greater moisture availability during spring, resulting in abundant production of flammable herbaceous material that burns in a subsequent dry year. Conversely, dry springs associated with La Niña events were followed by more widespread fire during the same year (Veblen and others 2000). There is a highly similar pattern of ENSO influences on fire occurrence in Pike National Forest (Donnegan 2000). A similar pattern of ENSO and fire for Arizona and New Mexico (Swetnam and Betancourt 1992, 1998) indicates a regionally extensive association of fire and ENSO activity in the Southern Rocky Mountains. Because regional weather patterns are driven by other circulation features in addition to ENSO, which has only a relatively weak influence on the Front Range (Woodhouse 1993), not all major fire years are directly linked with ENSO events. Nevertheless, many of the years of most widespread fire in the past are associated with ENSO events.

The period from about 1780 to 1830 was a time of reduced ENSO activity, which is manifested as reduced year-to-year variability in tree-ring widths in the Southwest (Sweetnam and Betancourt 1998) and the Colorado Front Range (Donnegan 2000; Veblen and Kitzberger 2002). During this interval, the difference between El Niño and La Niña extremes may have been damped or such events may have occurred less frequently. In the Colorado Front Range this time period of reduced alternation of wet and dry periods coincides with reduced fire occurrence in the montane zone (Veblen and others 2000; Donnegan 2000; Donnegan and others 2001; Brown and others 1999). Fewer or less extreme ENSO-related cycles of wet, fuel-producing El Niño events closely followed by dry La Niña events may explain this period of reduced fire occurrence. In contrast, the second half of the 19th century was a time of increased ENSO activity (Michaelsen and Thompson 1992), and in the Colorado Front Range, of increased variability of tree-ring widths and of fire occurrence. Based on tree-ring evidence from sites widely dispersed in the Front Range, after 1840 there is a gradual increase in the variability of tree-ring widths in the late 1800s (Donnegan 2000; Donnegan and others 2001; Veblen and Kitzberger in 2002). Increased variability in tree-ring widths may indicate greater ENSO variability at that time and in conjunction with increased ignitions by humans (see below) probably accounts for the increase in fire occurrence during the latter half of the 19th century. The mid- and late-19th century was also characterized by numerous years of severe drought (Cook and others 1998), whether related to ENSO activity or not, and widespread fires are recorded by fire scars in the Front Range during this period.

The increase in fire occurrence during the second half of the 19th century, associated with climatic variation, is evident in both montane and subalpine forests of the Front Range. However, there are important differences between the montane and subalpine zone in the sensitivity of fire to climatic variation. In montane forests of ponderosa pine, years of widespread fire generally are dry years that follow years of above-average moisture availability with a lag of 2 to 4 years (Veblen and others 2000). In contrast, at high elevations major fire years are dependent only on severe drought and do not require prior periods of fuel-enhancing increased moisture availability (Sherriff and others 2001).

Changes in Fire Regimes of the Front Range During the Past 150 Years

A key question underlying much of the current debate on fire management policy has to do with the extent to which the large, severe fires of 2000 and 2002 should be attributed to unnatural fuels build up during the 20th century period of fire exclusion. The answer is different for different forest types, different geographic regions, and different historical fire regimes. Therefore, in this section we assess the magnitude and significance of changes in fire *frequency* (number of fires per year in a region, or interval between successive fires in a single forest stand) and fire *severity* (table 1) for each of the three historical fire regimes described above for the Colorado Front Range (table 3).

Tree-ring records document a pattern of reduced fire frequency (table 1) during the 20th century in the lower to middle-elevation forests of the Front Range and nearby areas (Rowdabaugh 1978; Laven and others 1980; Skinner and Laven 1983; Goldblum and Veblen 1992; Alington 1998; Brown and others 1999; Veblen and others 2000). The modern fire exclusion period began in the early 1900s as a result of two key changes: suppression of lightning-ignited fires and cessation of widespread burning by humans (intentional as well as accidental ignitions by early settlers and Native Americans). Reductions in herbaceous fuels due to heavy grazing in the late 19th and early 20th centuries also contributed to the decline in fire frequency near the turn of the century, which in many studies predates effective fire-suppression technology by one or several decades (Veblen 2000).

The magnitude and significance of the 20th century decline in fire frequency varies significantly with forest type and elevation. In general, the impact of 20th century fire exclusion on fire frequency has been greatest at the lowest elevations in open forests dominated by ponderosa pine. In these ecosystems, where fires formerly were frequent but generally of low severity, 80-plus years of fire exclusion during the 20th century generally has permitted a buildup of woody fuels, which in turn may lead to greater severity in today's fires. However, the importance of 20th century fire exclusion in altering fuel conditions and fire severity becomes progressively less with increasing elevation, because natural fire intervals generally increase with elevation. Twentieth-century fire exclusion generally has had the least impact in subalpine forests dominated by spruce, fir, lodgepole pine, and limber pine. In mid-elevation forests with a large component of ponderosa pine (including forests codominated by Douglas-fir), the reduction in fire frequency also is more pronounced at lower elevations than at higher elevations (Veblen and others 2000). Consequently, changes in fuels conditions as a result of fire exclusion are likely to be greatest at the lowest elevations, where historical fire regimes were dominated by frequent low-severity fires, and least at the highest elevations, within infrequent high-severity fire regimes.

Although frequent low-severity fire regimes at the lowest elevations in the Front Range clearly have been altered by 20th century fire exclusion, it is questionable whether fire exclusion really has changed the fire regime of subalpine forests in the Front Range in any ecologically significant way. It is true that numerous small fires have been suppressed in the last century. However, these fires likely would have remained relatively small even without fire suppression because large subalpine fires occur only under severe fire weather conditions – conditions in which fires generally cannot be suppressed even with modern firefighting technology. Fires igniting at lower elevations probably burned into high-elevation forests in the past, and such fires have now been largely eliminated; however, just like locally ignited fires, fires spreading into the subalpine zone from below would be unlikely to cover much area except under severe fire weather conditions – conditions that occur rarely in this moist, high-elevation environment (Sheriff and others 2001; Sibold 2001). A large part of the spruce-fir cover type in the Front Range has not been significantly affected by fire for more than 400 years (Sibold 2001; Kulakowski 2002). Consequently, even if fire suppression were effective, there has not been a long enough period of fire exclusion to move the fire regime far outside of its historical range of variability. Moreover, periods of 80 to well over 100 years of no widespread (that is, more than 100 ha) fires in study areas of 4,000 ha or more are typical of the pre-1900 historical fire regimes of the spruce-fir cover type of the Front Range (Sibold 2001; Kulakowski 2002). Given these naturally long intervals between widespread fires in spruce-fir forests, the paucity of high-elevation fires since the onset of fire exclusion around 1910 is not outside the historical range of variability for this cover type.

Fire severity in subalpine forests also does not appear to have been altered significantly by 20^{th} century fire exclusion because these forests are naturally characterized by infrequent but high-severity, stand-replacing fires occurring under severe fire weather conditions. For example, the severe fires that occurred in 2002 in spruce-fir forests in the Park Range, on the White River Plateau, and in the San Juan Mountains of Colorado probably were well within the historical range of variability for fire severity and fire size in these ecosystems. Indeed, it is important to stress that severe and widespread fires are a natural feature of lodgepole pine and spruce-fir forests of the Colorado Front Range and elsewhere in the Southern Rocky Mountains. Thus, the premise that fire exclusion has created unnatural fuel buildup in spruce-fir forests of the Front Range is *not* supported.

We can make a reasonable generalization that 20^{th} century fire exclusion has significantly altered the frequent low-severity fire regimes at the lowest elevations but has not significantly altered the infrequent high-severity fire regimes at the highest elevations in the Front Range; however, no such simple interpretation is possible for the mixed-severity fire regimes of middle elevations. Given the inherent complexity and variability of mixed-severity fire regimes, we need more detailed, site-specific analyses to assess the impact of fire exclusion on fire frequency and severity. The Hayman Fire occurred within a landscape that historically was dominated by a mixed-severity fire regime, so with the conceptual background just developed, we now take a close look at the fire history and recent fire effects in the landscape where the 2002 Hayman Fire occurred.

Historical Fire Regimes and 20th Century Changes in the Hayman Area

Most of the Hayman Fire burned in montane ponderosa pine/Douglas-fir forest, with a small amount of mixed conifer forest on Thunder Butte and some subalpine forest in the Lost Creek Wilderness Area. Thus, the Hayman Fire occurred within an area where the historical range of variability was characterized primarily by a mixed fire regime (table 3). The other two types of historical fire regimes described in table 3 (frequent, low-severity fires and infrequent, high-severity fires) probably are *not* well represented in the Hayman Fire perimeter, though they characterize some small areas within the Hayman burn. However, these other types of fire regimes cover extensive portions of the Front Range, and one or both of them likely would have been major components of the burned ecosystem had the fire occurred just a few miles farther north in the Front Range or had it burned farther to the east.

Human impacts and land use patterns in the Hayman Fire area are similar to those in the ponderosa pine/Douglas-fir vegetation zone throughout much of the Colorado Front Range. Sources of information include fire history studies at Cheesman Lake (described below); fire history at other South Platte watershed locations (Donnegan and others 2001; Huckaby and others unpublished data); the Jack (1900) report on forest resources; a historical summary of human activities in the South Platte watershed (Pike National Forest historical review); General Land Office field notes recorded during the 1870s and 1880s (USGS, Lakewood, CO); and fire histories and assessments of historical human impacts in other Front Range locations (Veblen and Lorenz 1991; Veblen and others 2000; Brown and Shepperd 2001). As with nearly the entire Front Range montane zone, fire exclusion has affected the Hayman area and the surrounding South Platte watershed, beginning with the effects of logging and grazing in the 19^{th} century and continuing with fire suppression policies during the 20^{th} century. Grazing continues in limited areas, but most grazing allotments ended in the mid-1900s. Logging also tapered off during the 20th century and has been limited during the last few decades. Changes in stand structure and landscape structure of Front Range forests during the past 150 years are discussed in more detail in the next part of this chapter.

Historical and Recent Fire Frequency in the Hayman Area

We have detailed information on pre-1900 fire regimes in the 35-km^2 Cheesman Lake landscape and an adjacent study area along Turkey Creek in the Pike National Forest, both of which lie largely within the perimeter of the Hayman Fire (fig. 3). Both areas are dominated by ponderosa pine/Douglas-fir forest and probably are representative of much of the area burned in the Hayman Fire. The Cheesman landscape, owned by Denver Water, had never been logged, and grazing had not occurred since 1905 (Kaufmann and others 2000a,b). Thus, the Cheesman studies done prior to the Hayman Fire provide exceptional insight into historical fire regimes and other factors affecting historical landscape conditions in the Hayman Fire area. Fire history was studied at more than 150 sites in the Cheesman and Turkey Creek landscape. The earliest fire scars observed were formed in 1197, and coarse woody debris over 1,000 years old was found (Brown

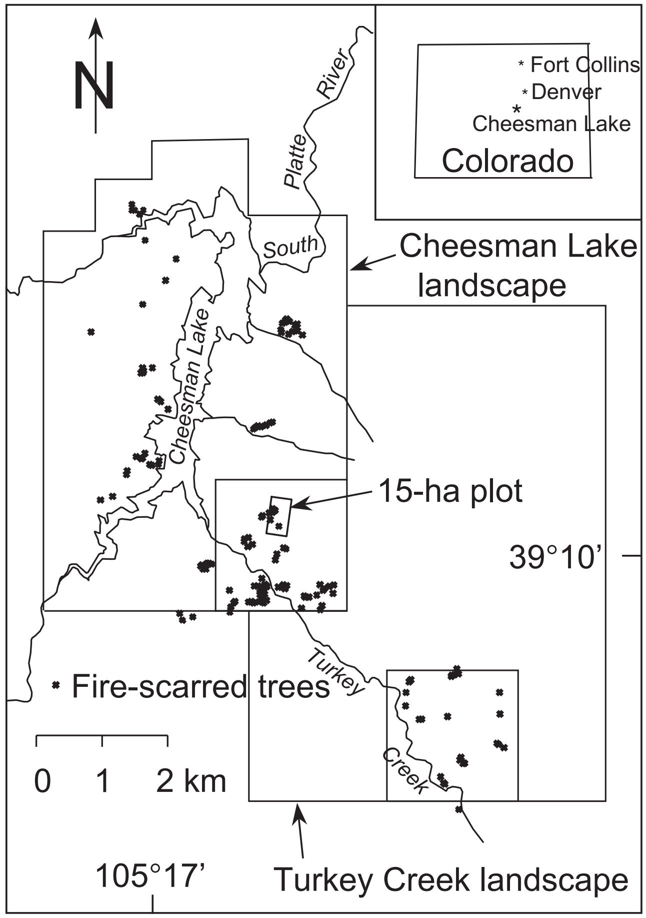

Figure 3—Map of Cheesman Lake and adjacent area in Turkey Creek (taken from Kaufmann and others 2000a).

and others 1999). Ages of live trees dating to the late 1300s were measured (Huckaby and others 2001).

During the six centuries prior to 1880, for which good fire history records were available from fire scars, fire intervals at Cheesman Lake varied from relatively frequent fires to moderate fire intervals to one long interval (fig. 4). During the 1300s and 1400s, the mean fire interval in an old-tree cluster near the south end of the Cheesman landscape was 16.8 years (Brown and others 1999). From about 1500 to the late 1800s, a series of widespread fires (5 km^2 or larger) occurred with longer intervening periods, each burning portions of the Cheesman landscape (Brown and others 1999). These fires occurred in 1534, 1587, 1631, 1696, 1723, 1775, 1820, 1851, and 1880. When the Cheesman fire history data for this period were analyzed for individual 0.5 to 2.0 km^2 portions of the landscape, the mean fire interval was 50 years (Kaufmann and others 2001). A limited number of fires in intervening years scarred one to several trees. It is unknown how many such fires occurred without scarring trees, or how large such fires might have been, but tree age data (below) suggest that the effects of these fires on the forest structure were relatively minor.

Since 1880, only one fire is known to have killed trees in the overstory – a 25 to 40 ha fire in the dry summer of 1963. In addition, a Cheesman caretaker reported an unsuppressed low-intensity fire during the summer in the early 1950s, burning in the northwest portion of the Cheesman landscape, but apparently this fire had limited effect on the overstory. The complete absence of large fires during the 20th century was primarily the result of fire suppression: in recent years, 10 to 12 ignitions were suppressed annually, some under dry weather conditions that could have supported a moderate to large fire (Bill Newbury, personal communication). Had there been no fire suppression, it is likely that at least one extensive fire

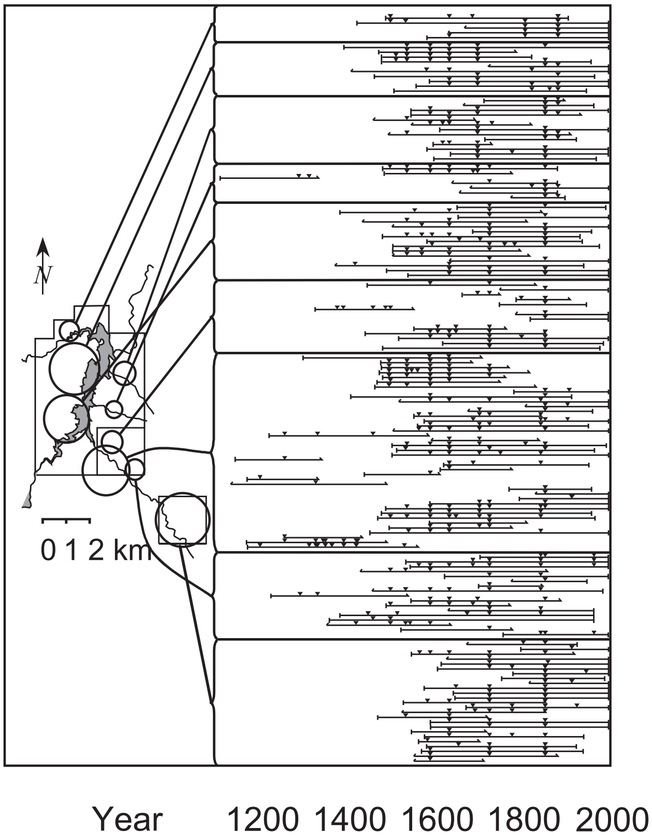

Figure 4—Cheesman Lake fire history (taken from Kaufmann and others 2000b).

would have affected this area during the 20th century (in 1963), and possibly two or more extensive fires would have occurred (for example, the questionable 1950s fire, and possibly others that were suppressed). Thus, there seems little question that fire exclusion affected the 20th century fire history of the Cheesman landscape; however, the number of fires effectively excluded in this area probably was far fewer than the number of fires excluded in some other ponderosa pine ecosystems, for example, in northern Arizona.

The long period of no fires or only minor fires ended abruptly with the 2002 Hayman Fire, which burned as an active crown fire over nearly all of the 35-km^2 Cheesman Lake landscape. Prior to the Hayman Fire, the most recent widespread fires had occurred in 1851 in the southern portion of the landscape and in 1880 in the northern portion (Brown and others 1999). The intervals between these historical fires and the 2002 fire were 151 and 122 years respectively – substantially longer than the average 50-year interval between large fires during the pre-1900 period.

Historical and Recent Fire Sizes

The spatial extent of the larger historical fires at Cheesman cannot be determined, because locations of fire scars extended to the edge of the sampled area. Nonetheless, it is clear that several fires exceeded 5 km^2, some exceeded 10 km^2, and at least one (1631) burned in all areas sampled (nearly 40 km^2; Brown and others 1999).

The Hayman Fire was large (550 km^2) but probably not unprecedented in the fire history of the Colorado Front Range where disjunct fire history samples show fire occurrence in the same year over similar extents of the montane zone of ponderosa pine-dominated forests (Veblen and others 2000). Several of the fire years at the Cheesman Lake study area also were prominent throughout the Front Range and Western United States, including 1631 and 1851 (fig. 2), indicating extensive, landscape-scale fires. Thus, the Hayman Fire probably was not unusually large in comparison with large historical fires. However, the patterns of fire severity within the overall perimeter of the Hayman Fire were unlike the patterns in pre-1900 fires within the Cheesman study area.

Historical and Recent Patterns of Fire Severity

Tree age data can indicate the severity of past fires. Where extant trees predate a known fire, it is clear that the fire was not completely stand-replacing. However, where all trees postdate a past fire, it is likely that the fire had killed all trees existing at that site (Kaufmann and others 2000a,b). Pre-1900 fires at Cheesman were stand-replacing in places but burned through the forest floor without causing significant tree mortality in other places, demonstrating that this ecosystem was characterized by a mixed-severity fire regime (table 3).

For the period of more frequent fires in the 1300s and 1400s, tree age data are too limited to evaluate fire severity, but it is likely that these fires, recurring at relatively short intervals, were predominantly low-intensity surface fires that left behind many surviving trees in the overstory. During the period from 1500 to 1880, however, extensive tree age data from more than 200 randomly sampled forested patches (Huckaby and others 2001; unpublished data of M. R. Kaufmann), coupled with the spatial heterogeneity of the landscape, indicate clearly that fires during this period were mixed in severity, having both a lethal component that created openings and a nonlethal component that left many surviving trees (Kaufmann and others 2000a,b; 2001). The 1851 fire created treeless openings in the forest that were still present in 2002. Old dead trees found on the ground in those openings were charred by fire, and dating of the outermost tree ring indicated that they had been killed in the 1851 fire. In some places within the 1851 burn area, patches of trees all postdated the1851 fire, indicating they had germinated after the fire killed the canopy that was present at that time. But in other patches, some extant trees predated 1851, indicating that the fire was not lethal to all trees in those locations.

In the Cheesman study area, the largest persistent opening created by past fires was no more than about 1 to 1.5 km^2, and the greatest distance to 300 to 400 year old trees was no more than 500 to 600 m (unpublished data of Kaufmann, Huckaby, Stoker, and Fornwalt). The tree age data indicate that on average, less than 20 percent of each fire was stand-replacing, and that stand replacement occurred as small patches dispersed in the fire area.

In the 2002 Hayman Fire, severity also varied spatially, but the patterns were dramatically different from the patterns created by historical fires in the Cheesman study area. Roughly half of the total Hayman Fire area (28,000 ha) burned at a severity great enough to kill all trees either by crown fire or lethal scorching of tree crowns. In other portions of the Hayman Fire, severity was low and overstory mortality was limited, and some areas within the fire perimeter did not burn at all. Nevertheless, both the total acreage and relative proportion of the Hayman Fire that produced lethal effects on the forest canopy far exceeded anything documented historically in the Cheesman landscape. During the five centuries for which we have historical fire data for the 35-km^2 Cheesman landscape, the largest area of complete mortality was no more than 1 to 1.5 km^2. In the Hayman Fire, however, most of this 35- km^2 area burned severely in just 1 day. Almost no trees survived within this exceptionally large patch of severe fire, and only small, widely spaced patches of surviving forest now remain.

Historical and recent Fire seasonality

Most large historical fires scarred numerous individual trees in different portions of their annual ring growth that represent different portions of the growing season or the spring/fall dormant period (Brown and others 1999). This indicates that large historical fires typically burned over an extended period, perhaps several weeks or even months, creeping slowly or residing in logs or litter most of the time, but increasing in intensity for brief periods during which trees were killed. In dramatic contrast to the pattern exhibited by historical fires, the major high severity portion of the Hayman Fire burned in a single day – an event of a spatial and temporal scale unprecedented in the fire history at Cheesman Lake.

Conclusions: Was the Hayman Fire a "Natural" Ecological Event?

Comparing the 2002 Hayman Fire with the historical fire record developed in the Cheesman Lake study area and elsewhere in the Front Range, we conclude that there is no simple answer to the question whether the Hayman Fire was a "natural" or unprecedented fire event in the ecological history of this region. We do conclude that the size of the Hayman Fire – that is, the total area burned – was not unusual either for the Cheesman landscape or for the Front Range in general. Many historical fires that occurred during extremely dry summers (for example, in 1851) appear to have been as large as the Hayman Fire or even larger. The fact that portions of the Hayman Fire were high-severity and stand-replacing also was not unusual for the Cheesman landscape or the Front Range; many pre-1900 fires contained a significant stand-replacing component wherever historical fire regimes were of either the infrequent high-severity or the mixed-severity type.

However, two features of the Hayman Fire are unprecedented in the historical record of the Cheesman area. First is the size and homogeneity of the patches of high-severity, stand-replacing fire in 2002. None of the fires documented from the early 1300s through 1880 created such a large contiguous patch of severe stand-replacing fire as was created on June 9, 2002. Second is the seasonality of fire: large fires before 1880 usually burned for several weeks or months, encompassing a wide range of weather conditions and fire behavior; whereas nearly half of the area burned in 2002 was burned in a single day of extreme fire weather, and the entire Hayman area burned in a period of only 3 weeks during early summer.

Placing the Hayman Fire into the context of the entire Front Range, the size of the severely burned patch created on June 9 is less unusual. Indeed, large, contiguous patches of stand-replacing fire are typical of subalpine forests characterized by an infrequent high-severity fire regime. However, the Hayman Fire was not in the subalpine zone; it was in the middle-elevation zone where a mixed-severity fire regime prevailed historically. Given the great variability of this type of fire regime, it is possible that similarly large patches of stand-replacing fire have occurred in other portions of the Front Range montane zone in the last several centuries. We have no direct evidence of such a large severe patch elsewhere in the Front Range montane zone, but neither has such a patch been explicitly searched for. Therefore, all that we can definitively conclude about patch sizes is that such a large patch of severe stand-replacing fire is unprecedented in the past 700 years within the 35-km^2 Cheesman landscape that is situated near the center of the Hayman Fire.

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