Part 2: Historical (Pre-1860) and Current (1860-2002) Forest and Landscape Structure

William H. Romme, Merrill Kaufmann, Thomas T. Veblen, Rosemary Sherriff, and Claudia Regan

Introduction

The term "landscape structure" refers to the configuration of vegetation and other land features over a large land area (usually an extent of many square kilometers). A landscape can be regarded as a mosaic composed of patches of different kinds— for example, different forest types, landforms, or human-built structures such as roads. The scientific discipline of landscape ecology is concerned with quantitatively describing the features of landscape mosaics, including, for example, the variety of patch types, the sizes and shapes of patches, and how different patch types are juxtaposed (Forman 1995). Landscape ecology also is concerned with understanding how the structure of a landscape influences its function – for example, what kind of habitat it provides for various plant and animal species, or how water and nutrients or pollutants move from place to place (Turner and others 2001). Another critical aspect of landscape structure is how it influences the spread of disturbances – including fire.

We address this question about historical and recent landscape structure in the area burned by the Hayman Fire in two parts. First, to put the Hayman Fire of 2002 into context, we characterize the historical range of variability (HRV – see the part 1 in this chapter) in landscape structure of the major forest zones of the Colorado Front Range, and compare these reference conditions with current landscape structure. This comparison of current to reference conditions permits an assessment of the magnitude, causes, and significance of changes that have occurred in the last century, and identifies generally where in the Front Range the changes have been great or small. We then focus on the Hayman area itself, to identify the nature, magnitude, and significance of 20th century landscape changes within the area where the 2002 fire occurred. We begin with a general assessment of the Front Range as a whole before treating the Hayman area in detail for two reasons: first, the general overview provides a context for understanding the unique features of the Hayman landscape, and second, future Front Range fires are likely to occur in other forest zones that are not well represented in the Hayman area per se.

Historical Range of Variability and 20th Century Changes in Landscape Structure of the Colorado Front Range

Historical landscape structure varied substantially among the major forest zones in the Front Range, and the nature and magnitude of changes during the 20th century also vary greatly. Four general causes for changes in landscape mosaics during the last century include fire exclusion, logging, exurban development (dispersed, low-density housing), and climatic variability. The relative importance of each of these four factors is different among the various forest zones of the Colorado Front Range, and explicit recognition of these fundamental differences among forest types is critical if we are to accurately assess the causes of the wildfire hazards that we face in our contemporary mountain landscapes. Therefore, we characterize landscape structure separately for each forest zone in the sections below. See table 4 for a general summary of these changes and mechanisms, and also see part 1 of this chapter for descriptions of each forest zone and its historical fire regime.

The Subalpine Zone – As described in part 1 of this chapter, the historical fire regime in subalpine spruce-fir and lodgepole pine forests of the Front Range and nearby areas was characterized by infrequent but large, high-severity fires. The result was a landscape mosaic composed of large patches of even-aged forests developing through natural succession after fire. The locations and ages of patches fluctuated over the centuries as stands became older and as new fires burned through the patch mosaic created by earlier fires (Romme 1982; Kipfmueller and Baker 2000; Sibold 2001; Kulakowski and Veblen 2002). In high-elevation wilderness areas and other portions of the Front Range where logging and development have not occurred, this fundamental landscape mosaic is still much in evidence. Because fire frequency and severity in these forest types are controlled mainly by climate and weather, rather than by fuels conditions, and because fires naturally occurred at long intervals even before the 20th century (see part 1 in this chapter), the fire exclusion practices of the last century probably have had only a modest impact on subalpine landscape mosaics.

However, spruce-fir and lodgepole pine forests in some areas have been altered by logging, including both selective cutting during the late 19th century and commercial clearcut logging during the mid-20th century. Logging probably has reduced the extent of older stands compared to what existed before the late 1800s, but the magnitude of this reduction is unknown. Logging of large old lodgepole pine probably accounts in

Table 4—General summary of the major changes in landscape patterns within forested portions of the Colorado Front Range during the past 150 years. Local exceptions are to be expected in every zone. See text for details and caveats.

Zone	Historical landscapes	Current landscapes
Subalpine zone	Pattern: Large patches of even-aged forest. Mechanism: Infrequent, high-severity fires followed by forest succession … fires occurred only in dry years and were little influenced by variation in fuel conditions.	Pattern: Unchanged from the historical pattern, except where logging and exurban development have created new kinds of forest patches. Mechanism: Fire regimes have changed little if at all, but new kinds of disturbance (human induced) have been introduced.
Lower montane zone	Pattern: Open ponderosa pine forests intermingling with dense ponderosa pine patches, openings, and shrublands Mechanism: Dry site conditions and relatively frequent, low-severity fires, maintained open pine forests in most of the area, but patches of high-severity fire also produced openings and patches of dense forest or shrubland.	Pattern: Generally more homogeneous landscape mosaics containing greater proportions of dense forest than occurred historically … extensive road systems and exurban development in many areas. Mechanism: 20th century fire exclusion, plus late 19th and early 20th century grazing, logging, and climatic conditions (all conducive to tree growth and survival).
Montane zone (including the Hayman landscape)	Pattern: Heterogeneous patch mosaics, containing variably-sized patches of even-aged forest resulting from high-severity fires, interspersed with relatively open, multiaged forests maintained by periodic low-severity fire … forests dominated by ponderosa pine except on moist sites (such as north-facing slopes and higher elevations) where Douglas-fir co-dominated. Mechanism: A complex, mixed fire regime, including significant components of high-severity as well as low-severity fire, plus variation over time in fire extent and severity.	Pattern: More homogeneous patch mosaics than were prevalent historically (at least in some areas, but not in all), consisting of large patches of dense forest and small patches of open forest. … Douglas-fir dominates or codominates on moist sites, as well as other sites where it was historically uncommon or absent … extensive road systems and exurban development in some areas. Mechanism: A complex mix of 20th century fire exclusion, coupled with late 19th century logging, late 19th and early 20th century grazing, and in some areas late 19th century burning (resulting in synchronous forest succession over large areas), and 20th century climatic conditions (conducive to tree growth and survival) … relative importance of each varies across the Front Range.

large part for the scarcity of stands older than 200 years in USDA Forest Service data-bases. Increased burning during the late 19th century (see part 1 in this chapter) also appears to have increased the abundance of 100 to140 year old stands in the Araphaho–Roosevelt National Forest. The net effect may be a more homogeneous age and size structure than existed before the late 1880s. In general, however, changes in the fire regime and in overall landscape structure, especially as they relate to wildfire hazard, are less significant in the subalpine zone than in any of the other forest zones of the Front Range.

The Lower Montane Zone – During the pre-1860 reference period, ponderosa pine forests near the lower forest/grassland ecotone apparently were predominantly low-density stands with well developed herbaceous or shrub strata. This open forest structure resulted in part from the low precipitation at the foot of the mountains but also was maintained by periodic low-severity fires (see part 1 of this chapter) that killed many of the tree seedlings that became established in openings between canopy trees. This interpretation is supported by fire history data (that is, fire scars indicating composite fire intervals less than 20 years), tree age data, and historical photographs (Veblen and Lorenz 1991; Sherriff and Veblen in prep.). The total area of open ponderosa pine forest maintained by periodic low-severity fire was relatively small. For example, for the portion of the northern Front Range in Arapaho-Roosevelt National Forest modeling of fire regimes in relation to environmental factors indicates that less than 20 percent of the ponderosa pine zone fits a model of model of moderately frequent, low-severity surface fires (Sherriff and Veblen in prep.; and see part 1 of this chapter).

Fire exclusion in the 20th century has allowed tree seedlings to survive, which has led to denser stands throughout much of the lower montane zone in the Front Range. However, fire exclusion probably is not the only mechanism that has promoted greater tree densities in the lower montane zone during the last century (Mast and others 1998). Studies of grazed and ungrazed ponderosa pine forests in Utah and Washington suggest that livestock grazing since the late 19th century also may have promoted increases in tree establishment by reducing competition from herbaceous plants and creating patches of mineral soil, and extensive grazing did occur in the Front Range during this period. Logging also can disturb the soil and create ideal seed-beds for establishment of conifer seedlings, and logging was intense in these accessible low-elevation forests in the late 19th century. Finally, the climate of the Front Range in the early 20th century was relatively moist and conducive to tree establishment and survival. However, studies of tree age structures in relation to climatic variability and local patterns in grazing and logging have not yet been able to confirm clear patterns of past tree establishment in relation to climatic variation or other causal factors (Mast and others 1998). More research is needed to tease out the relative importance of late19th century burning, 20th century fire exclusion, logging, grazing, and climate in producing the dense forests that characterize much of the ponderosa pine zone today.

Although the mechanisms are not yet fully understood, it is clear that many of the formerly open ponderosa pine forests along the base of the Front Range have developed a very different stand structure during the 20th century. Many stands now have higher total tree densities, fewer large trees and snags, and more homogeneous tree age and size distributions than existed between 1700 and 1900 (Veblen and Lorenz 1986, 1991; Kaufmann and others 2000). These areas now are generally more vulnerable to high-severity fire than they were during the reference period, and probably also are more susceptible to some pathogens. This change in forest and landscape structure constitutes a serious wildfire hazard, especially because of the great amount of exurban development that has occurred in the lower montane zone of the Front Range.

The Montane Zone – Historical photographs and stand structural data (on abundance of young stems) clearly indicate that many or most of the forests of ponderosa pine and Douglas-fir at middle elevations in the Colorado Front Range have increased in tree density during the past approximately 100 years. This generalization applies to areas that today are nearly pure stands of ponderosa pine as well as to mixtures of ponderosa pine with Douglas fir. Several ecological mechanisms and interactions have contributed to this increase in tree density, and the relative importance of each mechanism may be different in any specific area of the Front Range.

Twentieth century fire exclusion clearly is one important mechanism that has contributed to increased tree densities in the montane zone of the Front Range. Many photographs of this region from the late 1800s and early 1900s show low-density ponderosa pine stands and visual evidence of recent fire occurrence (Veblen and Lorenz 1991; Kaufmann and others 2001), and certainly many fires have been excluded during the last century that might have burned large areas if left unsuppressed (for example, in 1963 in the Cheesman landscape; see part 1 in this chapter). The moist climatic conditions of the early 20th century and of the decades of the 1970s and 1980s also were favorable for tree establishment, which may have been enhanced also by the effects of grazing. Prescribed fires in the 1980s and 1990s killed many of the trees that had established in the 1960s and 1970s, but these fires were of limited extent and did not affect landscape patterns. If more extensive fires had occurred during the 20th century, it is likely that many more young trees would have been killed throughout much of the montane landscape, and overall forest densities would not be as high as they now are.

However, other mechanisms also have clearly contributed to increasing forest density during the 20th century. Douglas-fir forests and mixed ponderosa pine/Douglas-fir forests were dramatically transformed in many parts of the Front Range by logging in the late 19th and 20th centuries. These forests today tend to have high tree densities but few old trees or snags and are generally less diverse in size and age structure than what we believe were the conditions before 1860. Naturally increasing stand density associated with forest regeneration after widespread 19th century fires (see part 1 in this chapter) also has contributed to the young, even-aged structure seen today in many ponderosa pine and Douglas-fir stands (Veblen and Lorenz 1986; Ehle and Baker in press). The extensive burning and logging of Douglas-fir forests during the latter half of the 19th century resulted in synchronized regeneration over large areas of the montane zone. The combination of these two early Euro-American settlement activities has produced what appear to be unusually homogeneous tree age and size structures across much of the mid-elevation portion of the Front Range.

Although we do not yet fully understand the relative contributions of 20th century fire exclusion and recovery from late 19th century logging and burning in creating the dense forests that characterize much of the montane zone today, most would agree that the diversity of stand structures at a landscape scale generally has been reduced in comparison with the pre-1860 reference period. Based on tree ages obtained from the relatively small area that escaped logging and recent burning, we know that the pre-1860 landscape included even-aged patches of trees resulting from previous stand-replacing fires, as well as patches of all-aged forest in which fires had repeatedly burned with lower severity (Veblen and Lorenz 1986; Kaufmann and others 2000; Ehle and Baker in press). The availability of spatially explicit data on past forest structures is insufficient to allow quantitative estimates of past vegetation structures for the montane zone as a whole. However, it is known that areas of meadow and relatively open, fire-maintained woodlands were juxtaposed with areas of dense ponderosa pine and Douglas-fir forest – a complex mosaic maintained in part by the complex mixed-severity fire regime that characterized this zone (see part 1 of this chapter). The increasing homogeneity of landscape structure in the montane zone during the last century, as a result of multiple and interacting ecological factors, probably has increased the chances of large, severe fires in Douglas-fir and mixed ponderosa pine/Douglas-fir forests of the Colorado Front Range. In addition, extensive outbreaks of mountain pine beetle (*Dendroctonus ponderosae*) and other native tree-killing insects have occurred periodically, most recently in the late 1970s and early 1980s, creating snags and dead woody fuels that further contribute to potential fire severity.

One additional significant impact on the landscape mosaics of the montane zone of northern Colorado is exurban development (Theobald 2000). The proliferation of homes and roads in some areas during the last half-century has been dramatic. The major effect of new roads and homes on the landscape mosaic has been to fragment the forests; that is, to create potentially smaller patches than characterized the pre-1900 landscape. Another effect of exurban development in the montane zone, of course, has been to put a great many people and homes into an environment that is naturally characterized by periodic fires, including high-severity fires.

Historical Range of Variability and 20th Century Changes in Landscape Structure Within the Hayman Fire Area

Most of the forest area burned in the 2002 Hayman Fire was ponderosa pine and Douglas-fir forest, which was characterized historically by a mixed-severity fire regime (see part 1 of this chapter). The landscape mosaic during the reference period in the area of the Hayman Fire and surrounding areas in the South Platte watershed included patches of even-aged forest developing after stand-replacing fires, as well as patches of multiaged forest affected by periodic low-severity fires, and small tree-less openings that resulted from locally severe fire events followed by poor tree regeneration (Brown and others 1999).

Fire exclusion within the South Platte Watershed began with the effects of logging and grazing in the late 19th century and continued with the addition of active fire suppression during the 20th century. Grazing was probably never as intense in this area as in other parts of the West because of limited understory production. Grazing continues in limited areas, but most grazing allotments ended during the middle of the 20th century. Logging tapered off during the 20th century and has been limited during the last few decades.

Historical documents from the Pike National Forest indicate that logging progressed up the South Platte watershed during the 1870s to 1890s, reaching the east boundary of the Cheesman landscape by around 1895 (Jack 1900; De Lay 1989). Tree age data near the Cheesman landscape (Turkey Creek study area just southeast of the Cheesman boundary) indicate that large numbers of trees became established during the 1890s (Kaufmann and others 2000), apparently in response to the opening of the canopy and the localized disturbance of the soil associated with logging. Grazing also may have favored high seedling survival after logging by reducing competition prior to active fire suppression, and favorable climatic conditions during the early 20th century also may have enhanced survival of the young trees that established during this time. The importance of these two mechanisms is still not certain, but fire suppression also clearly contributed to tree survival. Regardless of the exact ecological mechanisms, it is well documented that the late 19th century and early 20th century was a time when great numbers of ponderosa pine and other tree species became established in the Hayman Fire area, as well as throughout the montane zone of the Colorado Front Range and elsewhere in the West.

Our most detailed information on historical landscape structure in the area of the Hayman Fire comes from research within the 35-km2 Cheesman Lake property owned by the Denver Water Board (Brown and others 1999; Kaufmann and others 2000, 2001; Huckaby and others 2001; Fornwalt and others 2002; Kaufmann and others 2003). Logging in the Cheesman landscape actually was limited to a few small areas near several old cabin sites, and grazing was excluded by a six-strand fence completed in 1905, coinciding with completion of the dam. Nonetheless, tree densities increased within the Cheesman landscape during the 20th century, just as in surrounding areas where logging and grazing impacts were much greater. Douglas-fir, a fire-sensitive species, showed an especially striking increase in density (Kaufmann and others 2000). Indeed, forest densities were nearly as high at the end of the 20th century in the unlogged and ungrazed Cheesman landscape as they were in the nearby Turkey Creek area, which was intensively logged and grazed. Thus, fire suppression apparently is the primary reason for increasing tree densities during the past 100 years in the Cheesman area (Kaufmann and others 2001; Fornwalt and others 2002).

Canopy cover (percent of ground beneath tree crowns) was estimated for the Cheesman Lake and Turkey Creek landscapes using 1:6000 color infrared aerial photographs taken in 1996 (fig. 5). These estimates indicate that 45 percent of the Cheesman landscape and 53 percent of the Turkey Creek study area had canopy cover of 35 percent or higher in 1996. This level of canopy cover is adequate to support active crown fires (fires that spread both on the ground and in the canopy) under typical wildfire conditions. Canopy cover in the Cheesman landscape in 1900 then was reconstructed, using the Forest Vegetation Simulator (FVS) program, to assess how forest density had increased during a century of fire suppression. The 1900 canopy cover reconstructions were confirmed with historical photographs in the Denver Water archives. These studies indicated that 93 percent of the Cheesman landscape in 1900 had a canopy cover of 30 percent or less, and only 7 percent was dense enough to support a crown fire (fig. 5). If the landscape mosaic that existed in 1900 also was generally typical of earlier times in the reference period (which presumably it was, given the fire history of the area), then this reconstruction suggests that historical forests, influenced by mixed severity fire behavior patterns, were generally more open and less prone to large-scale crown fires than current forests.

Thus, the historical Cheesman landscape was dominated by open stands of ponderosa pine with lesser amounts of Douglas-fir (primarily on north slopes), and forests were interspersed with openings created by high-severity fires. Even at higher elevations, where remnant ponderosa pine trees now exist within dense stands of fire-sensitive species such as Douglas-fir, fire evidently occurred with enough frequency in the past to limit competition from the less fire-resistant tree species. Many formerly pure ponderosa pine stands in and around the Cheesman landscape now have been replaced with ponderosa pine/Douglas-fir forests or mixtures with other species

Conclusions: Changes in Front Range Forests and Wildfire Hazards

An extensively large area in the Colorado Front Range is included within the "Red Zone," identified by the Colorado State Forest Service as a region where the risk of substantial loss of property and even human life to wildfire is very high (Sampson and others 2000). The "Red Zone" encompasses portions of all the major forest zones in the Front Range, from the lower montane to the subalpine (see part 1 of this chapter). However, the reasons for high fire hazard are not the same in all places (table 5). In lodgepole pine and spruce-fir forests of the subalpine zone, recent large severe fires are *not* an artifact of abnormal fuel build-up during 20th century fire exclusion. The high fuel loads that characterize most subalpine forests are the normal result of high forest productivity and long intervals between disturbances; fires only occur during periods of extremely dry weather when variation in fuel characteristics has less influence on fire behavior and intensity than the effects of wind and low humidity. In contrast, the extent of dense ponderosa pine forests in the lower montane zone probably has increased substantially during the last century as a result of fire exclusion and other human activities. Frequent, low-severity fires formerly maintained open forest structure and reduced potential for severe fire behavior in these areas along the base of the Front Range, whereas today we have many unusually dense stands that can support unusually severe fires relative to the reference period. One factor is consistent across all forest zones: a major reason for serious damage and loss in recent and future wildfires is the presence of extensive exurban development and other vulnerable developments such as water storage facilities within ecosystems where fire has always been an important and recurring ecological process.

The relative importance of natural fire hazards vsersus augmented hazards resulting from past and current human actions (such as fire suppression) is much less clear in the extensive montane zone at middle elevations in the Colorado Front Range. This zone was characterized historically by a mixed-severity fire regime, which included significant components of high-severity as well as low-severity fire, and by a heterogeneous landscape mosaic, including dense stands as well as more open stands. The extent to which 20th century fire exclusion has altered this fundamental fire regime and the resultant landscape mosaic throughout the Front Range is uncertain. Moreover, the magnitude of change probably is different in different parts of the montane zone. New research is needed to better understand the spatial variability in historical and contemporary disturbance regimes and landscape dynamics throughout the Front Range.

With respect to the Hayman Fire that occurred in the southern portion of the Front Range in 2002, it is clear that the contemporary forest and landscape structure contributed to the size and severity of the fire. The relatively homogeneous forest structure of the contemporary landscape provided continuous fuels which facilitated fire spread in the Hayman and other recent fires in the montane zone of the Front Range. Under severe fire weather conditions, today's forests of ponderosa pine and Douglas-fir often do not

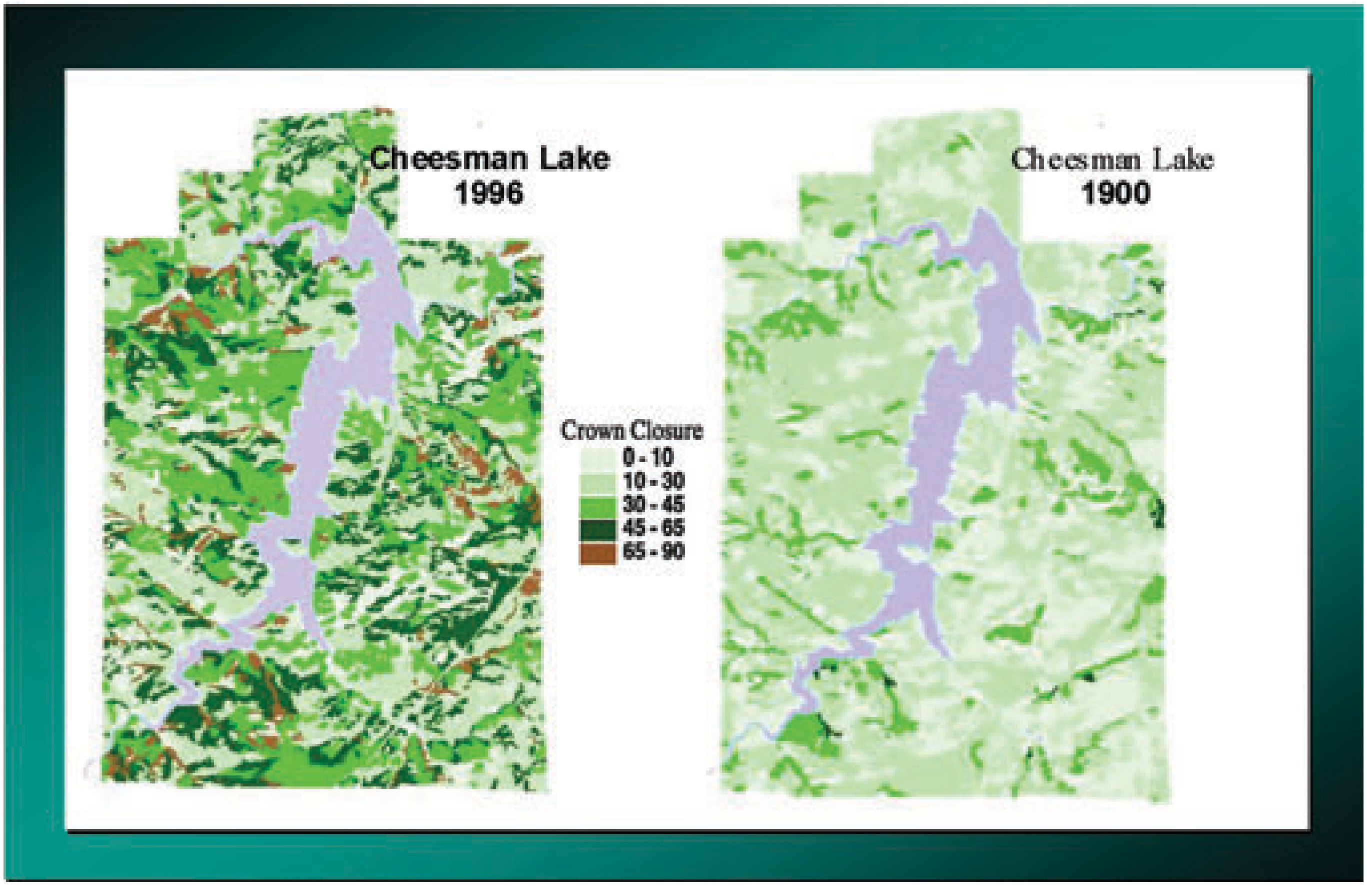

Figure 5. Recent and historical crown closure in the Cheesman Lake landscape (taken from Kaufmann and others 2001; also see Kaufmann and others 2003).

Table 5—General reasons for high wildfire hazard in the major forest zones of the Colorado Front Range. Local exceptions are to be expected in every zone; see text for details and caveats.

	Relative importance of factors contributing to current high wildfire hazard		
Forest zone	**Exurban development**	**20th century fire exclusion**	**Other late 19th and 20th centuries land uses (for example, logging and grazing)**
Subalpine	High	Low	Low
Lower montane	High	High	High
Montane	High	Moderate or variable	Moderate or variable

burn with the predominantly mixed-severity fire behavior that characterized historical fires in the Cheesman landscape, but tend to burn instead with predominantly intense fire behavior – much like that expected in higher-elevation lodgepole pine or spruce-fir forest (see part 1 of this chapter). This is evidenced by a series of fires since 1989 in the montane zone of the Front Range – Black Tiger, Buffalo Creek, Bobcat Gulch, Hi Meadows, Schoonover, and Hayman (see the chapter on fire behavior in this publication). Each of these recent fires had crown fire components that burned rapidly and with limited or no survival of trees over large areas, in contrast to historically more mixed fire behavior patterns reconstructed for the Cheesman landscape. As noted in part 1 of this chapter, the patch of severely burned forest created on June 9 was larger than in any fire in the Cheesman landscape from the early 1300s through 1880.

However, the extreme fire weather on June 9 also was an important contributing factor to the size and severity of the Hayman Fire, and other recent Front Range fires burned under extreme fire weather conditions as well. We need new research to better understand the relative importance of weather and fuels in controlling the behavior and impact of large fires in coniferous forests. Given the inherent complexity and variability of the mixed-severity fire regime that characterizes the montane zone, it is possible that large, severe fires comparable to the Hayman Fire did occur in Front Range forests of ponderosa pine and Douglas-fir during the pre-1860 reference period. For example, Elliott and Parker (2001) found geomorphic evidence for three severe, watershed-scale fire events that resulted in significant flooding and sedimentation – natural events that may have been similar to the severe sedimentation event that occurred after the severe 1996 Buffalo Creek Fire in the same area. The recurrence interval between these extreme events was long – 900 to 1,000 years — indicating that if fires like Hayman occurred in the Front Range montane zone during the pre-1860 reference period, they probably did not occur often in any particular watershed. However, no systematic search has been conducted for similar evidence of large severe fires in other watersheds during the historical period, so we cannot make any reliable inferences about the frequency or spatial pattern of such events.

What we can say with confidence is that the forests of the Cheesman study area and surrounding portions of the South Platte watershed were denser and more homogeneous in 2002 than they had been in the late 1800s, and that this landscape structure contributed to the severity of the Hayman Fire. Major uncertainties revolve around longer term variability of the landscape mosaic and the occurrence of extreme fire events in montane forests of the Front Range.

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