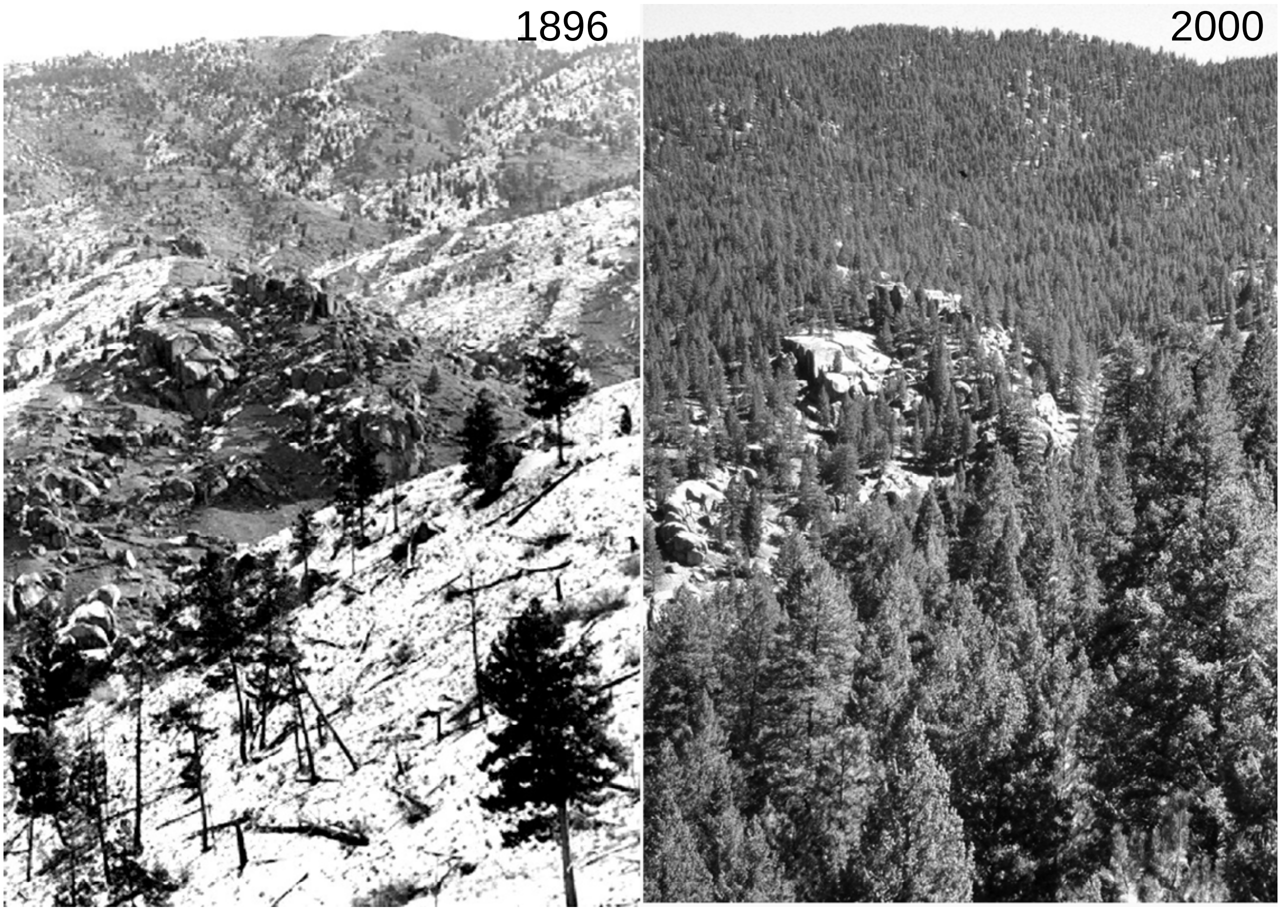
Historical Fire Regimes in Ponderosa Pine Forests of the Colorado Front Range, and Recommendations for Ecological Restoration and Fuels Management



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Introduction

At the request of The Nature Conservancy and the Front Range Fuels Treatment Partnership, we are developing brief summaries of the current state of our scientific understanding of historical fire regimes in the forested landscapes of Colorado's Front Range. The area of interest extends from El Paso and Teller Counties, near Pikes Peak, to Larimer County and the Colorado-Wyoming border. This article focuses on forests in which ponderosa pine is a dominant or co-dominant species. A subsequent article will deal with forests of lodgepole pine, spruce, and fir. M. Kaufmann and T. Veblen have conducted extensive studies of ponderosa pine forest ecology in the southern Front Range (mainly the Cheesman Reservoir area) and the central Front Range (mainly in and around Boulder County), respectively. This research has led to substantial agreement about the historical role of fire in shaping these forests, and we emphasize these points of agreement in this article, in the section entitled "Things We Know with Relatively High Confidence." Some disagreements and uncertainties also have arisen, and we identify these as topics of high priority for future research, under the section entitled "Things We Think We Know -- BUT with Relatively Low Confidence." We close with a brief summary of the implications of the science for current efforts directed at fire hazard mitigation and ecological restoration in ponderosa pine forests of the Front Range.

Ponderosa pine is a dominant or co-dominant forest species over a large portion of the eastern slope of the Colorado Front Range, growing in a wide variety of ecological settings. We have identified five major vegetation zones, extending from the plains grasslands at the foot of the mountains to the upper timberline, to provide a context for our interpretations (see Figure 1 and Table 1). The *Plains Grassland Zone* is predominantly non-forested, but small patches of ponderosa pine woodland with a grass or shrub understory are found. Piñon - juniper woodland also occurs south of about the Castle Rock area and in a small portion of Larimer County. The *Lower Ecotone Zone* represents the transition from predominantly non-forest to predominantly forest vegetation in the foothills. The elevation of this zone (and of all the other zones) varies from the southern to the northern portions of the Front Range, as

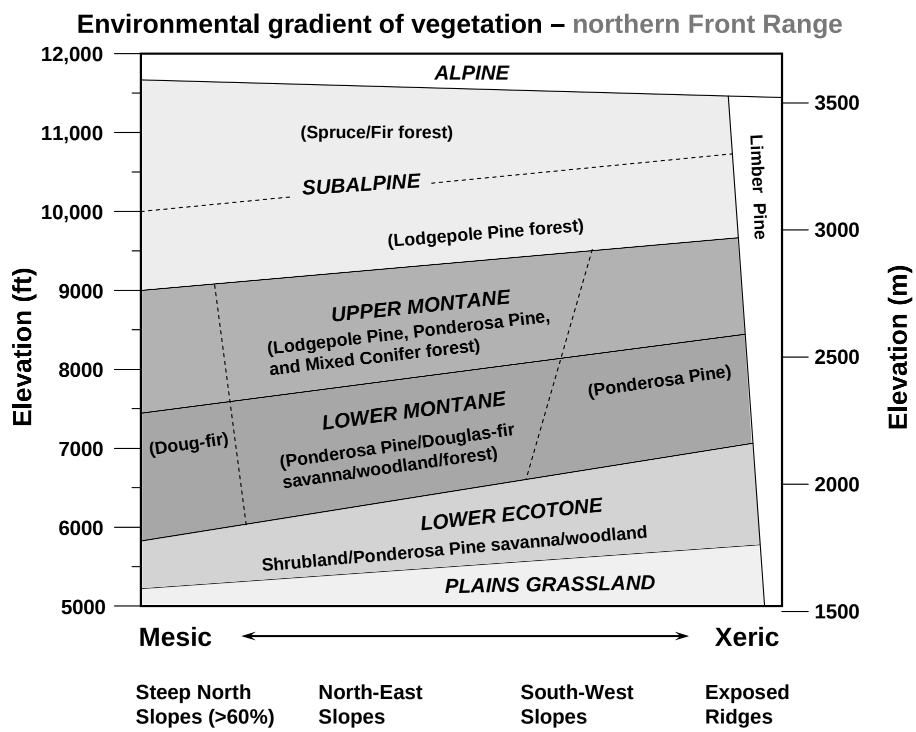

Figure 1. Major vegetation zones in the Colorado Front Range. See Table 1 for additional description of each zone.

Cover: Looking east from Cheesman Reservoir. 1896 photo courtesy of Denver Water Board, 2000 photo by M.R. Kaufmann.

Table 1. Forest area (acres) in major life zones in Colorado Front Range counties, reclassified from ReGAP data[1]. Major forest types listed in the table and key (below) account for at least 5% of the total forested area per life zone summed across all counties.

Front Range	***Southern***				***Central***				***Northern***	**Total Forested Area**	**Major Forest Types[2]**
Counties	**Douglas**	**El Paso**	**Park**	**Teller**	**Boulder**	**Clear Creek**	**Gilpin**	**Jefferson**	**Larimer**		
Subalpine / Alpine Life Zone											
Elevations	*>9500 feet*				*>9000 feet*						SF LP A
Forested Area	103	14,712	380,657	69,078	66,568	123,302	49,857	19,945	358,325	1,082,546	
Upper Montane Life Zone											
Elevations	*8500-9500 feet*				*8000-9000 feet*				*7500-9000 feet*		PP MC LP
Forested Area	25,889	61,308	197,440	143,927	74,630	34,616	27,962	85,053	336,167	986,991	
Lower Montane Life Zone											
Elevations	*6500-8500*				*6000-8000*				*5500-7500 feet*		PP PPDF
Forested Area	139,620	96,250	57,825	63,388	88,871	7,919	2,182	166,652	140,834	763,542	
Lower Ecotone Life Zone											
Elevations	*5500-6500 feet*				*5500-6000*				*5000-5500 feet*		PP PJ
Forested Area	13,014	18,960	0	0	3,599	0	0	1,976	499	38,049	
Plains Grassland											
Elevations	*<5500*								*<5000 feet*		PP PJ
Forested Area	31	50	0	0	95	0	0	27	2	205	
Total Forested Area	178,657	191,280	635,922	276,393	233,763	165,837	80,001	273,653	835,828	2,871,334	

[1]For a more thorough analysis of ReGAP data for the Colorado Front Range, see http://leopold.nmsu.edu/fwscoop/swregap/default.htm. ReGAP data for several forest types were grouped following general terminology used to describe Front Range forests: **SF** = S028 Subalpine Dry-Mesic Spruce-Fir Forest and Woodland and S030 Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland; **A** = S023 Aspen Forest and Woodland; **LP** = S031 Lodgepole Pine Forest; MC and **PPDF** = S032 and S034 Montane Dry-Mesic and Mesic Mixed Conifer Forest and Woodland; **PP** = S036 Ponderosa Pine Woodland; and **PJ** = S038 Southern Rocky Mountain Piñon-Juniper Woodland. Mesic and Dry-Mesic Mixed Conifer (ReGAP codes S032 and S034) in the Lower Montane Zone is almost entirely restricted to ponderosa pine/Douglas-fir. In contrast, the same types in the Upper Montane Zone tend to have a greater component of Douglas-fir, and one or more additional species (most commonly lodgepole pine, limber pine, aspen, Engelmann spruce, subalpine fir) are nearly always present.

[2] Listed in decreasing order of area in each life zone.

shown in Table 1. Generally a given zone occurs at lower elevations in the north than in the south, though there are several exceptions to this general pattern. The *Lower Montane Zone* contains a variety of forests and woodlands, with complex mixtures of tree species, understory species, local environmental conditions, and histories of natural and human disturbances. Ponderosa pine is the usual dominant tree in this zone, with Douglas-fir also present or co-dominant in many locations. The *Upper Montane Zone* represents a transition from montane to subalpine forests. Ponderosa pine is a component of this zone, and forms nearly pure stands in places. However, several other tree species also are common and may be co-dominant in places, including Douglas-fir, lodgepole pine, limber pine, aspen, and (in the south) white fir. Engelmann spruce, blue spruce, and subalpine fir are sometimes minor components of stands in the higher parts of the Upper Montane Zone. Vegetation patterns in this portion of the mountains are quite complex, and the controlling factors of topographic position, soils, and disturbance history are not fully understood. Above the Upper Montane Zone is the *Subalpine Zone*, dominated by lodgepole pine, Engelmann spruce, and subalpine fir. Because ponderosa pine is not a component, we do not deal with the subalpine zone in this article, but it will be the subject of a subsequent article. It is important to recognize the variety of plant associations and abiotic environments in which ponderosa pine occurs in Colorado's Front Range, because these different environments were characterized by important differences in their historical fire regimes. Consequently, the opportunities and constraints for community protection and ecological restoration also differ among these environments.

A “fire regime” is a summary of fire occurrence, behavior, and effects within a specified area, including specific parameters such as fire frequency, extent, seasonality, behavior (e.g., surface vs. crown fire), intensity (defined as heat release), and severity (defined as impacts on organisms and the abiotic environment). We focus in this report on fire frequency and severity during the historical reference period from about A.D. 1600 to 1900. This is a time for which we have relatively abundant data on fire and forest structure prior to many of the impacts of EuroAmerican settlement, and it therefore serves as a useful benchmark for evaluating the magnitude and significance of changes that have occurred during the last century.

<u>The Concept of Fire Severity</u>: Historical fires burned in a complex fashion, in response to variation in weather conditions, fuels, and topography. Within any individual fire, except perhaps the tiniest fires that failed to spread because of moist weather conditions or lack of fuel, there could be a continuum of fire behavior and fire effects from almost no change in forest structure to complete mortality of the canopy and understory. Moreover, a fire at a given site may burn severely one year, and then burn with very low severity the next time the area burns. Thus, in all of the vegetation zones of the Colorado Front Range, the historical fire regime would best be characterized as *mixed severity* or *variable severity*. Unfortunately, the term *mixed severity* has been used with a variety of meanings, some of which actually may be contradictory. Therefore, we wish to carefully define how we will use the term "fire severity" throughout this article. Our definition includes both the relative proportions of canopy trees killed by a fire and the consequences of this mortality for future development of stand structure, notably the opportunity (or lack thereof) for a new cohort of ponderosa pine trees to become established after the fire.

The continuum of potential fire effects is illustrated in Figure 2 for a small patch (an acre or so) of ponderosa pine forest having a sufficiently closed canopy that regeneration of this shade-intolerant species is impeded. At one end of the spectrum (point A in Figure 2), fire intensity is so slight that it produces essentially no change in stand conditions: perhaps a thin upper layer of litter is blackened, but the forest floor and surface fuels are only slightly altered and there is little or no mortality of canopy trees. Because the stand is not opened up by the fire to any significant degree, and mineral soil exposure remains limited, there is little opportunity for a new cohort of young trees of the relatively shade-intolerant ponderosa pine to become established as a

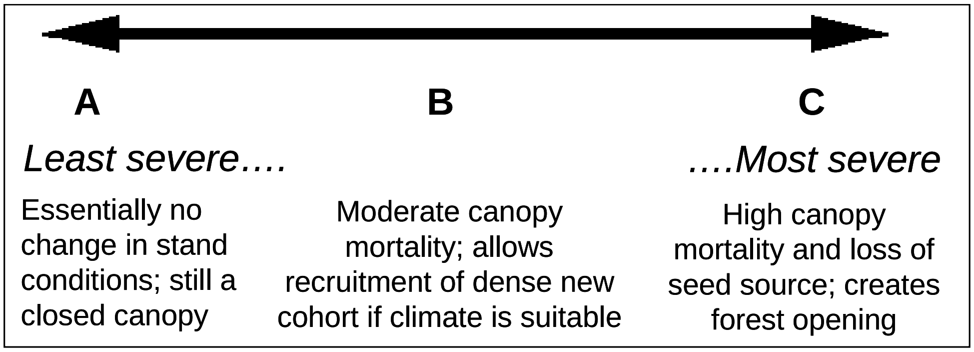

Figure 2. Continuum of potential fire severity and fire effects on forest structure in a small patch (an acre or so) of ponderosa pine forest having a relatively closed canopy before the fire.

consequence of the fire. (Of course, in initially dense stands, new trees could become established for other reasons, such as canopy mortality caused by wind, insects, or disease; or, in open stands with sufficient light, moister climatic conditions could trigger an episode of tree recruitment.) Near the middle of the spectrum (point B in Figure 2), the fire consumes a variable portion of the forest floor and kills a variable number of the dominant canopy trees – enough to create opportunities for a new cohort of trees to germinate and become established in the resulting canopy gaps, and to increase understory productivity. (Of course, no new trees would become established unless there was a seed source nearby and climatic conditions were favorable for tree seedlings, but nevertheless the fire created an opportunity for new trees if other factors were favorable.) Toward the other end of the spectrum of fire effects (point C in Figure 2), the fire kills so much of the canopy (maybe all of it) that it essentially eliminates the seed source. Even though the resulting open site conditions are favorable for new tree establishment, reforestation may be very slow as seed gradually disperses into the area from outside the severely burned patch. Here the size of opening created by fire, including consumption of any potential seed bank in the canopy or litter, becomes important in predicting subsequent vegetation development.

In our detailed descriptions of the historical variable severity fire regimes in ponderosa pine forests of the Colorado Front Range (below), we will be concerned especially with the proportions of the total burned area that were affected by various levels of fire severity as depicted by points A, B, and C in Figure 2. In other words, a given fire event that covered tens to thousands of acres would be characterized as *predominantly low-severity* if most of the patches were burned as indicated by the left end of the continuum near point A in the figure, while only a few patches were represented by points B or C. Alternatively, a given fire would be *predominantly high-severity* if most patches had fire effects resembling those of point B or C in the figure, recognizing that even here at least a few patches would likely be more similar to point A. If all three points in the figure were well represented by individual patches within the overall fire perimeter, then we would refer to these as truly *mixed severity* or *variable severity* fires.

Fires during the historical reference period exhibited complex behavior and complex effects in the Colorado Front Range. Because of this complexity, we cannot simply extrapolate results from the well known studies of fire in southwestern ponderosa pine forests (e.g., the "southwestern model" developed in northern Arizona) to the Front Range – even though ponderosa pine is the dominant tree in both areas. Instead, we need to understand how fire operated in different environments and different geographical regions of the Front Range.

<u>Things We Know with Relatively High Confidence</u>

(1) Factors in addition to fire and fire suppression have had major influences on historical and modern ponderosa pine landscapes.

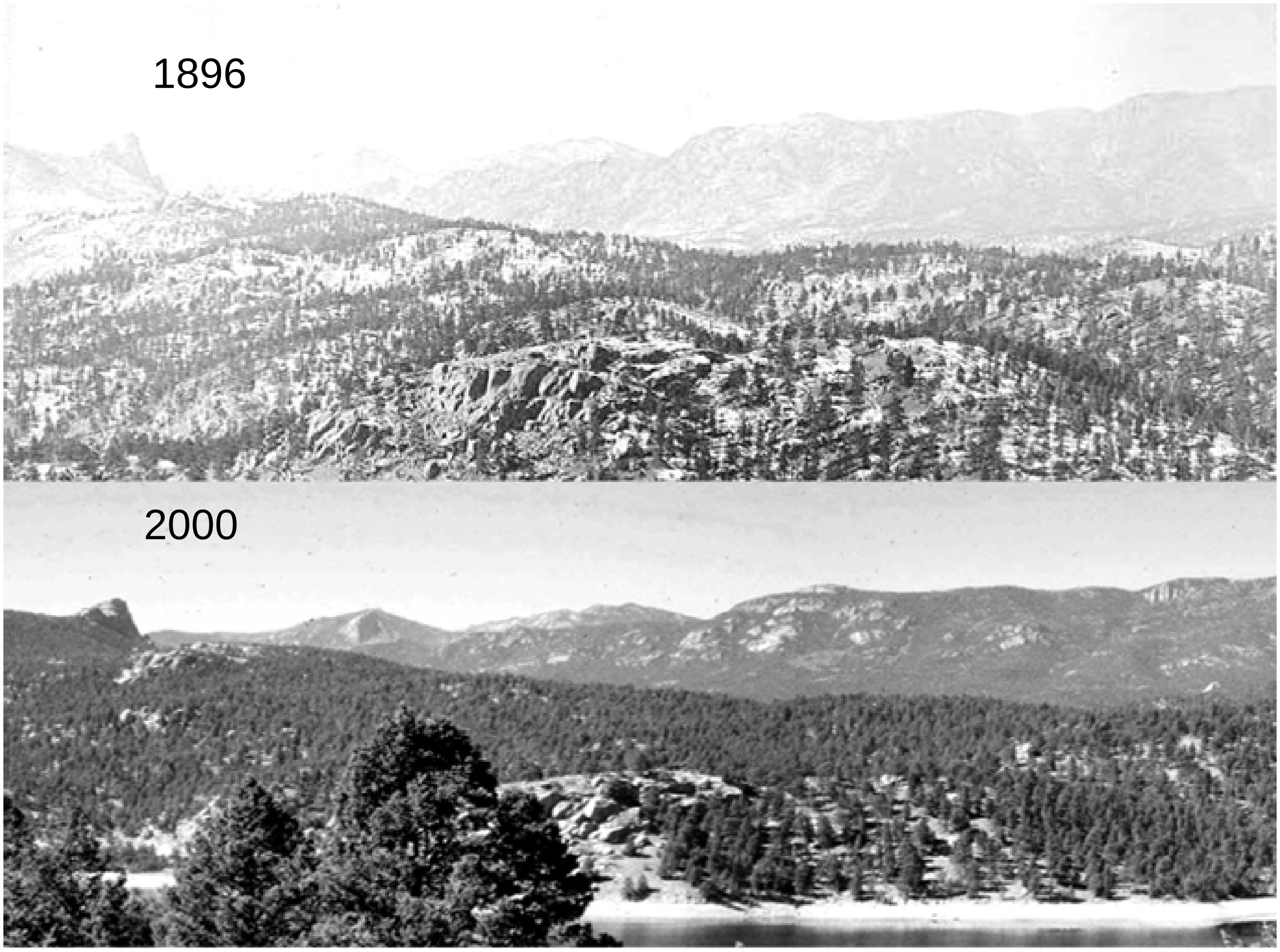

Figure 3. View across Cheesman Reservoir to the west, showing increase in number of ponderosa pine (and some Douglas-fir) trees, as well as increasing canopy cover (2000 photo by M.R. Kaufmann).

Although our emphasis in this article is on fire and potential ecological effects of fire suppression, it is important to stress that several other environmental factors (soils, topographic position, climate) and disturbance agents (insects, disease, drought, logging, grazing, tree planting) may have an equal or greater influence on forest stand structure and dynamics. For example, open stands with low tree density potentially may be maintained by periodic low-severity fires -- but such stands also may result simply from locally poor growing conditions, e.g., on shallow soils or on hot south-facing slopes at low elevations. Other disturbances also may cause substantial tree mortality, e.g., mountain pine beetles and severe drought. Ponderosa pine recruitment is driven not just by opening of the canopy and creation of bare mineral soil (as occurs with severe fire or logging), but also is dependent on the episodic availability of seed in conjunction with moist climatic conditions over periods of several years or decades. Fire frequency and severity also are controlled in large part by climatic variation, with more extensive and severe fire activity during dry years and less fire activity during wet years. Yet, the growth of herbaceous fuels during wet years is an important precursor to large fire years occurring one to several years later in the drier, low-elevation environments of the ponderosa pine zone. The climate of the Colorado Front Range appears to be influenced in part by very broad-scale atmospheric processes, such that local climate is statistically correlated with indices of atmospheric and oceanic conditions in the tropical Pacific (El Nino - Southern Oscillation),

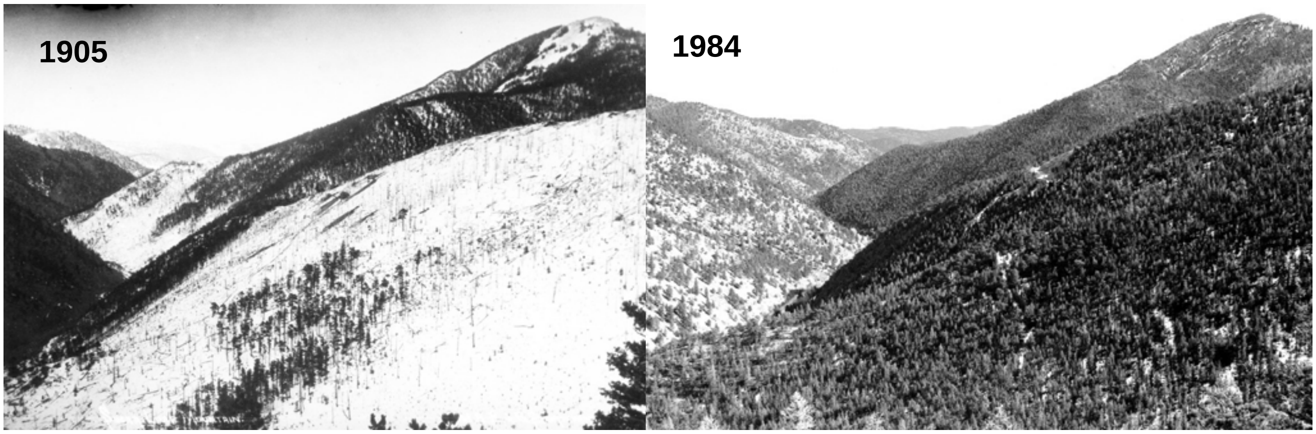

Figure 4. Sugarloaf area near Boulder. The forest on the north-facing slope (right side of the pictures) did not have a low-severity fire regime typical of southwestern ponderosa pine even prior to Euro-American settlement, but was characterized by a variable-severity fire regime, including a normal component of high-severity fire. Left photo: J.P. Sturtevant (courtesy of the Boulder Historical Society), right photo: T. Veblen.

the northern Pacific (Pacific Decadal Oscillation), and the northern Atlantic (Atlantic Multidecadal Oscillation). Climatologists are just beginning to fully understand the ways in which variability in these broad-scale atmospheric processes affect the climate of Colorado (and consequently fire occurrence) at time scales of a few years to centuries.

It is also important to recognize the effects of fire and land-use practices other than 20th century fire suppression on current forest conditions in the Front Range. For example, widespread burning and logging in the late 1800s is responsible for many of the young, even-aged stands that we see today. Similarly, livestock grazing in the late 1800s and early 1900s appears to have facilitated increases in tree density in some former grasslands. And finally, evidence exists that tree planting was emphasized in some areas during the 20th century when assuring sustainable timber production was a national goal. Some transplanting occurred even where historical forest densities may have been low or zero.

(2) Historical fires burned in a complex fashion, in response to variation in weather conditions, fuels, and topography.

We stress the complexity of historical fire behavior along topographic, moisture, and elevation gradients within relatively small areas (a few thousand acres) in the Front Range. This complexity of historical fire behavior was also influenced by broad-scale vegetation differences across the Front Range. For example, at low elevations south of the Denver area, Gambel oak shrublands adjacent to or mixed with ponderosa pine stands could have supported high severity shrubland fires, but oak is absent from the northern Front Range. Likewise, substantial topographic variation among different sectors of the Front Range may have significantly influenced historical fire regimes. For instance, rolling hills are quite extensive in the southern Front Range and in central and northern Larimer County, but in Boulder County the elevational gradient is steeper and the extent of rolling topography is substantially less than in these other areas. Likewise, the deep, and in places broad, canyon of the Poudre River creates a topographic setting that differs from much of the remainder of the Front Range.

(3) The idea that a historical fire regime of primarily low-severity fires maintained savannas and open woodlands applies only to portions of the lowest elevations of the Colorado Front Range, and generally does not apply to most of the middle and higher elevations.

Fire history and historical stand structures have been documented, based on extensive tree-ring evidence and historical photographs, in a study area centered on Boulder County but overlapping with adjacent counties. This research indicates that at low elevations near the Plains grasslands (primarily in the Lower Ecotone Zone, Figure 1), ponderosa pine stands in the 19th century were mostly open and were affected primarily by low- to moderate-severity fires (i.e., most of the burned area was affected by fires depicted between points A and B in Figure 2). These low to moderate severity fires burned with sufficient frequency to prevent the survival of most juvenile trees, and therefore tended to maintain open stands of mature trees. Although this is somewhat analogous to findings for dry ponderosa pine woodlands in Arizona, New Mexico, and some other parts of the West, the situation in the Colorado Front Range differed in two critical respects from these other areas. First, fire-scar evidence indicates that actual fire frequencies in this low-elevation ponderosa pine zone were substantially less than those reported for Arizona and New Mexico. Whereas a 150-250 acre tract of ponderosa pine forest near Flagstaff may have experienced fire every 3-10 years, a comparably sized area in Boulder County experienced fire only every 10-30 years. Secondly, patches of shrubland (especially mountain-mahogany and Gambel oak) in the Lower Ecotone Zone could have fueled locally severe fires that killed all of the trees growing within the shrubland patch, as has been observed in recent fires. The key similarity between the lowest elevation ponderosa pine zone of the Colorado Front Range and the ponderosa pine forests of the Southwest, is that during the 20th century both areas have experienced substantial increases in tree density. This increase in tree density appears to have been facilitated in part by exclusion of low-severity fires that formerly killed juveniles. However, other factors such as grazing, soil disturbance associated with logging and trail or road construction, and climatic variation probably also contributed to increased seedling establishment, even though long fire-free intervals during the fire exclusion period were essential to the survival of seedlings.

In this Lower Ecotone and in some of the lower portions of the adjacent Lower Montane Zone in and around Boulder County (Figure 1, Table 1) where historical fires were predominantly low-severity, fires generally killed tree seedlings but only rarely killed mature trees due to the lack of contiguous woody fuels. Nevertheless, at fine spatial scales, fuel accumulations from dead trees or small patches of live woody fuels would have resulted in some variability in fire severity. Patches of dense shrubs also would have provided fuels for locally severe fires, as described above. Thus, although there clearly was fine-scale spatial heterogeneity in fire severity, the *predominant* fire severity in this zone was low-severity that only rarely killed mature trees. These fires did kill some tree seedlings and saplings, but once a tree reached moderate size, it usually could survive most fires, and lived until it died from other causes, e.g., drought or insects. Thus, stands tended to have open canopies (less than 20% canopy cover), and, where soils and moisture conditions permitted, a well-developed herbaceous layer. Even here, however, fires occasionally were of moderate severity, killing a single tree or small clusters of canopy trees.

Just how extensive is this region in the Boulder County area where predominantly low-severity fires maintained an open, low-density forest structure, and where exactly in the Front Range should we expect to find this kind of historical fire regime? The precise geographical area in which this fire regime was important historically has been estimated from tree-ring data on fire history and fire effects (e.g., percentage of trees that survived a given fire) in a study area of 60,875 hectares (150,360 acres) in the ARNF in and around Boulder County. The analysis was applied to all cover types where ponderosa pine is a dominant or co-dominant, i.e., it encompassed portions of the Plains Grasslands, Lower Ecotone, Lower Montane and Upper Montane Zones (Figure 1, Table 1) in the northern Front Range. Ponderosa pine was mapped as dominant in approximately 75% of this area. Results of the analysis showed that, within this broad expanse of ponderosa pine forest, less than 20% of the area was characterized historically by mainly low-severity fires. In a separate analysis, using Boulder County as the base area and including both non-federal and federal lands, the same result was obtained: c. 20% for the area of predominantly low-severity fires. In the other 80+ % of the study area, evidence of moderate and high-severity fires also was prominent in the tree-ring record. The area of predominantly low-severity historical fires corresponds to those sites where, according to fire-scar evidence, fires burned at intervals of 10 to 30 years in sample areas of 150 to 250 acres, prior to fire exclusion. This zone in which pre-settlement forest structure was shaped primarily by low-severity fires (as well as soils and climate) is mainly at elevations below about 6900 to 7200 feet, although topographic factors also influence the elevational distribution of this fire regime type.

The study described above for Boulder County is the only study in the Front Range that systematically relates fire regime type to environmental factors across the full elevation range of ponderosa pine. Thus, it is difficult to estimate the area of the low-severity fire regime in other parts of the Front Range. However, we can infer that this zone of predominantly low-severity fires is found mostly on gentle terrain where the mountains meet the plains and in the lower foothills, mainly in the Plains Grasslands and Lower Ecotone Zones but also in the lower half of the Lower Montane Zone (Figure 1, Table 1). We stress that aspect, slope steepness, and proximity to grassland also influenced the location of this zone of low-severity fires, and that elevation alone cannot be used as a strict guide to its location. Although many of these low-elevation areas show increases in tree density during the fire suppression period, fire suppression is not the only reason for increased tree density; these are also areas where grazing and soil disturbances associated with roads and other construction have been widespread and may have triggered tree recruitment. We also note that tree densities have *not* increased in all of the low-elevation landscapes of the Front Range (though more research is needed to understand why tree density has increased in some areas but not others).

(4) In most of the Lower Montane Zone of the Colorado Front Range, the historical fire regime was a mixed or variable severity fire regime in which low-, moderate-, and high-severity fires all played an ecologically significant role.

With increasing elevation in the Lower Montane Zone, the model of primarily low-severity fire clearly does *not* apply, except perhaps in limited situations as described below. For example, in Boulder County this low-severity fire regime has not been documented at elevations above c. 6900 to 7200 feet. Instead, fires at higher elevations in the Lower Montane Zone (Figure 1, Table 1) were typically of variable severity, i.e., any individual fire could exhibit patches of fire behavior and effects spanning the entire continuum shown in Figure 2. Consequently, the effects of historical fires on stand structure were also very complex. In some places and at some times, fires simply maintained a relatively open forest structure (i.e., fire severity was between points A and B in Figure 2); in other places and at other times the fires killed most, or all, of the canopy (i.e., between points B and C in Figure 2). Thus, patches of high-severity fire killing a large proportion of canopy trees were important components (though not the only components) of the historical fire regime of middle and upper elevation ponderosa pine forests. In addition, dense stands of relatively even-aged ponderosa pine cohorts were a natural consequence of the moderate to high severity fires in this zone, though low-density stands with trees of all ages (including centuries-old individuals) also were common or even dominant in places, especially in the lower half of the Lower Montane Zone.

Although we are confident about this broad description of historical fire behavior and effects in ponderosa pine forests of the Lower Montane Zone in the Colorado Front Range, there are uncertainties about some of the details of the historical fire regime, notably the spatial extent of patches of different fire severity. In particular, we have an incomplete understanding of the spatial patterns of historical fires, e.g., the size and shape of patches of higher-severity fire vs. patches of lower-severity fire. The high degree of variability in fire severity over space and over time in this zone makes it difficult to determine meaningful averages for sizes of patches of different fire severity. Indeed, we expect that the idea of average patch sizes and severities actually is not particularly useful in this area. A

Figure 5. An open woodland of ponderosa pine in the foothills of Boulder County (left), on a site where the historical fire regime was dominated by low-severity fires; and a dense forest of ponderosa pine and Douglas-fir in Left Hand Canyon (right), characterized by a variable-severity fire regime, including a normal component of high-severity fire. Photos: T. Veblen.

broad range of sizes and severities was probably common, especially over time scales of centuries that included wetter and drier climate phases. Nevertheless, it is clear that the southwestern model of frequent, low-severity fires that maintained savanna-like stands does *not* apply to the Lower Montane Zone of the Colorado Front Range. On the contrary, this extensive region of ponderosa pine forests and woodlands was shaped by a complex fire history that included high severity as well as low severity fires, and this heterogeneous fire history (coupled with heterogeneous environmental conditions) resulted in a mosaic of naturally dense as well as open stands.

Things We Think We Know – but with Relatively Low Confidence

(5) The model of predominantly low-severity fires may apply to limited areas of more gentle topography in the upper part of the Lower Montane Zone and the Upper Montane Zone.

In localized areas of gentle, rolling topography, or near grasslands in the upper part of the Lower Montane and in the Upper Montane Zone, there may have been a greater incidence of low-severity fires than in surrounding areas of more rugged relief and greater forest cover. Examples might be the grasslands near Cardinal and Camp Frances in Boulder County, areas in Rocky Mountain National Park, and some of the country north of the Poudre River Canyon. Today, some grassland patches in the Lower and Upper Montane Zones appear to show encroachment by young ponderosa pine trees (although many other montane grasslands do not exhibit any tree encroachment). It could be hypothesized that grassy areas burned relatively frequently during the historical period, because their fuels were continuous and dried quickly, and fires ignited in the grassy places could have carried into surrounding forests, thus maintaining lower stand densities than were typical of forests remote from the grasslands. This interpretation makes intuitive sense, but we have relatively low confidence in it because we do not find as many fire-scarred trees adjacent to the grassy areas as we would expect if it is correct. We also note that many montane grasslands have been maintained by local site conditions inimical to tree establishment, rather than by fire. Furthermore, grass productivity in our region generally is much less than in parts of northern Arizona, so fire or herbaceous competition may not be as effective here in reducing tree density. In any case, we do not know whether these hypothesized areas -- of gentle topography at higher elevations that may have been affected by primarily lower-severity fires – were relatively extensive or very limited. And we stress that even if there were relatively extensive areas in the Lower Montane Zone where low-severity fires dominated the historic fire regime, those fires occurred far less frequently and with far more variable severity than in southwestern ponderosa pine forests such as those in northern Arizona.

(6) In ponderosa pine dominated forests of the Lower and Upper Montane Zones, stand structures in many areas strongly reflect the effects of pre-fire-exclusion fires that were of sufficient severity to kill large numbers of mature ponderosa pine.

In the Upper Montane Zone and at higher elevations of the Lower Montane Zone, for example at 8400-9100 feet in Boulder County, tree age data from many stands dominated by ponderosa pine, often in combination with Douglas-fir, show that present stand structures were largely determined by pre-20th century fires -- fires that killed high percentages of the tree population and triggered subsequent regeneration. Although forests in this region are still properly described as having a variable severity fire regime, it is the higher severity component of the fire regime that has largely shaped current stand structures by creating even-aged post-fire cohorts in many of these higher-elevation locations. Fire-scar and tree age data indicate that low-severity fire events comprised a far lower proportion of total fire events at higher elevations than at lower elevations, and similarly, that high-severity fire events were especially prominent in fire histories from higher elevation ponderosa pine forests. This pattern is very clear in Boulder County and nearby areas. However, we place this interpretation in the Low Confidence section of the article because of preliminary results from a study in progress in Larimer County by Laurie Huckaby and others. Preliminary results of that study suggest that low to moderate severity fires had a greater influence in Larimer County than in Boulder County on stand structure of Upper Montane mixed conifer forests . Therefore, we are unsure how widely we can apply the general principle that higher-severity fires became progressively more important with increasing elevation.

At least in the Boulder County region, under the historical fire regime, forest structures in the Upper Montane Zone appear to have been shaped largely by fires that were relatively infrequent (i.e., fire intervals of many decades or even a century or more) but severe (between points B and C in Figure 2). Some low severity fires also occurred in these stands, but tree population age structures indicate that it was primarily the severe fires that caused tree mortality and created opportunities for new establishment of the shade-intolerant ponderosa pine. These are environments where moist conditions probably prevented widespread fires except under conditions of extreme drought, and also provided for large quantities of spatially contiguous woody fuels. Thus, once ignited under extremely dry conditions, fires could be intense and burn over large areas. Age structures in these forests indicate that severe fires generally did not result in complete tree mortality over large areas, but did kill substantial numbers of canopy trees, and that high percentages of existing trees established soon after a documented severe fire. It is important to recognize that, although such sites have a relatively low probability of fire occurring in any given year, when fire does occur it has a high probability of being severe. When we reach the Subalpine Zone (Figure 1, Table 1), infrequent but extensive, severe fires are the primary shapers of forest structure, as will be discussed in a subsequent article.

Implications for Fire Hazard Mitigation and Ecological Restoration

(7) The two goals of community fire protection and restoring historical ecological conditions can sometimes, but not always, be attained in the same locations.

Although fuels reduction through thinning is sometimes consistent with ecological restoration, this is not the case everywhere in ponderosa pine forests. In the Colorado Front Range, historical fires maintained low-density woodlands, transient openings, and relatively sparse fuel loads in parts of the Lower Ecotone Zone and in some of the lower portion of the Lower Montane Zone (Figure 1, Table 1). In these areas, by reducing woodland densities and creating openings we can reduce the probability of severe, large-scale crown fires and also create stand structures that more closely resemble historical conditions. Thus, in the Colorado Front Range, the two goals of fire hazard reduction and ecological restoration converge most clearly in the lower-elevation portions of the ponderosa pine zone.

In most of the Lower Montane and Upper Montane Zones, however, historical stand densities were typically higher than near the grassland ecotone, and fire severity varied considerably over space and time. Notably, fires often were of sufficient severity to kill large numbers of canopy trees and were often (though not always) followed by development of dense post-fire cohorts (i.e., fire severity was between points B and C in Figure 2). This is a critically important aspect of the historical fire regimes of the Colorado Front Range, an aspect that cannot be overemphasized. This landscape probably was never characterized by large, homogeneous stands with low tree densities. On the contrary, variation in forest structure was important across the area, as were changes over decades and centuries. For these reasons, creating large landscapes with uniformly low tree densities probably would be unprecedented in the ecological history of this area.

We recognize, of course, that managers in the Front Range do *not* envision creating a uniformly low tree density across the entire region of ponderosa pine. Nor are we suggesting that the objective of restoration should necessarily carry more weight than other desirable ecological outcomes or fire hazard mitigation. Indeed, fuels reduction through thinning or creation of small openings and prescribed burning may be consistent with objectives other than restoration, such as protection of vulnerable structures from wildfire, enhancement of wildlife habitat, or preservation of threatened and endangered species. Rather, we are stressing that reduction in stand density does not always mimic the effects of historical fires and should not be uncritically equated with ecological restoration.

(8) In the Lower and Upper Montane Zones of the Colorado Front Range, where historical fire regimes and stand structures were highly variable, fuel treatments and restoration efforts should reflect that variability.

In most of the ponderosa pine forests of the Front Range, it may be appropriate for managers to implement a variety of fuel reduction treatments to protect structures and other vulnerable resources while also emulating natural ecological processes. Although there is

Figure 6. The lower ecotone in the Red Hill Valley northwest of Boulder in 1899 (left) and in 1984 (right). The 1899 photograph shows an open landscape characterized by low-severity fires in the foreground as well as in the distant background. The 1984 photograph shows an increase in ponderosa pine density coinciding with fire exclusion but also probably reflects tree establishment opportunities created by disturbances associated with ranching and later exurban development in this wildland urban interface. Note the substantial increase in stand density in the distant background creating the potential for more severe fire in the present landscape. Left photo: Paddock Collection (courtesy of Boulder Historical Society), right photo: T. Veblen.

much uncertainty about the extent of past fires of different severities, the historical landscape appears to have been characterized by a high complexity of stand structures. This implies that fuels treatments leading to a structurally complex landscape will not result in patterns fundamentally outside the historical range of variation. With prescribed burning (whether manager-ignited or wildland fire use), a wide range of fire severity should be tolerated, including at least some patches of relatively high severity fire (between points B and C in Figure 2).

(9) High tree density in itself is not a sufficient criterion for concluding that fire suppression has created an unnaturally dense stand.

Although many of today's dense ponderosa pine stands are an unnatural result of fire suppression and other human activities, this is not the case with all dense ponderosa pine stands in the Colorado Front Range. Some stands (particularly those in the Upper Montane Zone) are dense because of more mesic conditions. Many Lower Montane stands are now dense because of a sequence of anthropogenic effects, beginning with logging and grazing in the late 1800s and early 1900s that created conditions suitable for abundant regeneration of ponderosa pine and Douglas-fir, and finally by 20th century fire suppression that eliminated the key natural process for reducing tree density. It also must be recognized that many ponderosa pine stands in the Front Range are dense today because they are developing after severe fires that occurred *prior* to the period of fire suppression, i.e., fires in the 19th century or earlier. Thus, where ecological restoration is the primary management goal, or where emulation of natural landscape structure and ecological processes is an important secondary component of management that focuses primarily on wildfire hazard mitigation, not all of the dense stands should be thinned. To the extent feasible and consistent with primary management goals, at least some dense stands of ponderosa pine or ponderosa pine and Douglas-fir should be retained as important natural components of the historical forest landscape. Higher density stands probably were most prevalent at higher elevations and on mesic north-facing slopes.

(10) We cannot prevent all high-severity fires in Front Range ponderosa pine forests, and the likely effectiveness of mitigation will vary with elevation, and with other factors including extent of treatment, topography, weather, and climate.

With appropriate fuels treatments, it is feasible to substantially reduce the likelihood of high-severity fire, especially in the lower portions of Front Range ponderosa pine forests (e.g., in most of the Lower Ecotone and adjacent parts of the Lower Montane Zone). This is also where the greatest residential development is occurring, and thus the benefits of fuels reduction generally will be greatest in these lower-elevation areas. However, preventing high-severity fire in the highest-elevation portions of the ponderosa pine forest (e.g., in the Upper Montane Zone and adjacent parts of the Lower Montane Zone) will be more difficult. This is partly because these areas are generally more productive, i.e., relatively large quantities of biomass develop relatively quickly. It is also because the ecologically most important fires, i.e., the fires that have the greatest influence on stand structure, both here and in the adjacent subalpine zone, tend to occur primarily under conditions of extreme fire weather. Under those conditions, variation in fuels characteristics has less influence on fire behavior than when fire weather is less extreme. Effective reduction in fire risk at these higher elevations could potentially require more forest removal (and prevention of regeneration) than is either economically feasible or socially acceptable. Thus, we should not lead the public to believe that we can effectively or cheaply prevent all high-severity fires, either by fuels treatments or by suppression efforts. Nevertheless, even at the higher elevations, we can manage fuels and fires in such a way that, through Firewise and other practices, we substantially *reduce* the risk of damage to vulnerable structures from high severity fire – while acknowledging that the risk will never fall to zero.

(11) Although fuel reduction treatments can be effective in the short run, fuels management must be an on-going effort, or hazardous conditions will simply re-develop within one to several decades.

There is abundant evidence that logging (e.g., removal of larger trees or thinning of smaller ones) and associated soil disturbances may enhance establishment of new ponderosa pine seedlings. Thus, depending on initial stand structure, thinning could potentially result in a new stand structure in which surface fires are actually *more* likely to become crown fires. For example, in dense stands lacking an understory of young trees, seedling recruitment following thinning may produce a multi-story stand with dense ladder fuels. We do not fully understand how the kinds of thinning, logging, and prescribed burning now being conducted in the Front Range will affect subsequent tree recruitment, nor do we know how soon re-treatment may be needed to maintain a lower risk of high-severity fire. Nevertheless, management agencies should plan for on-going fuels treatments over the long term. Private land owners also must play a crucial role in reducing fire risk by treating their own lands to maintain stand structures conducive to fire control or to low-severity fire behavior.

Concluding Remark:

Ponderosa pine forests in the Colorado Front Range are as complex as anywhere else in the geographic distribution of the species. A great deal of knowledge about these ecosystems has been developed over the past two decades, much of it illustrating unique features not typically described elsewhere. Nonetheless, many details are not yet fully understood, and many of these details have important implications for getting the ecology right for the Front Range, for prioritizing where treatments are needed, and for clarifying more precisely what the treatments should be. Therefore, research must continue, to provide these details. Even without all the answers, however, a sufficient knowledge base is available to proceed with caution to restore more sustainable ecological conditions in some portions of the ponderosa pine ecosystem, and to protect human communities and values at risk. We stress that fire hazard reduction and ecological restoration are *not* always congruent, and that specific objectives therefore need to be clearly articulated for every treatment. We also stress that adaptive management is all about learning from research and from project experiences, including both our mistakes and our successes. It is imperative that the research and land management communities continue their pattern of frequent interaction and feedback. Maintaining this pattern of cooperation will assure the best ecological gains and the greatest community protection with the fewest mistakes and disasters.

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