FINAL REPORT TO CITY OF BOULDER OPEN SPACE AND MOUNTAIN PARKS

THE HISTORIC RANGE OF VARIABILITY OF FIRE IN THE LOWER MONTANE ZONE OF BOULDER COUNTY: PAST FIRE TYPES AND FIRE EFFECTS

Rosemary L. Sherriff

Thomas T. Veblen

Department of Geography
University of Colorado
Boulder, CO 80309

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ABSTRACT

Most information regarding disturbance history and stand development of ponderosa pine forests has come from the southwestern United States. The results and interpretation of studies in southwestern ponderosa pine forests have been synthesized into a general model of fire suppression and ecological change known as the "Southwestern Ponderosa Pine Model" (SPPM). However, recently the applicability of the SPPM has been questioned for some ponderosa pine ecosystems. Although previous studies in Colorado recognize the importance of stand-replacing fires in the montane zone, some studies suggest that prior to fire suppression in the early 1900s most of the montane zone was less dense with more openings and had fewer stands mixed with Douglas fir. These studies acknowledge that their study areas do not fit the Southwestern Ponderosa Pine Model (SPPM); however, they also infer that most of the ponderosa pine zone in the Colorado Front Range may be currently outside of the historic range of variability of fire and stand structure. Our study objective was to examine the effects of fire occurrence in montane habitat types on City of Boulder Open Space land and explore generalizations that can be made about the natural fire regime in different habitat types. Age structure and fire history were examined at four sites to compare fire type and fire effects in different site conditions of the lower montane zone. In the Eldorado Springs area, the lowest elevation ponderosa pine stands were historically characterized by high fire frequencies. After the dramatic decline in fire occurrence in the late 1800s and complete cessation of fire after 1916, tree establishment rose sharply in this area likely due to the decline in fire occurrence. Historically there were few fires in the Long Canyon area, with only four fires recorded in the fire-scar record from the late 1700s to present. The Southwestern Ponderosa Pine Model (SPPM) appears to be applicable in the lower montane zone at the grassland-montane ecotone near Eldorado Springs. Frequent non-lethal, surface fires formerly maintained open, park-like stands of ponderosa pine, and the past century of fire exclusion has resulted in much denser ponderosa pine. However, age structure data suggest that few, if any sites, beyond areas adjacent to grasslands would support a high frequency-low severity fire regime in the northern Colorado Front Range. Sites only slightly higher in elevation show a dramatic decrease in the historic fire frequency compared to the lowest elevation montane-grassland sites. These four lower montane sites on Open Space land will help to determine what environmental factors allow for a high frequency-low severity fire regime throughout the entire elevational range of ponderosa pine in the northern Front Range.

INTRODUCTION

Most information regarding disturbance history and stand development of ponderosa pine forests has come from the southwestern United States. The results and interpretation of studies in southwestern ponderosa pine forests have been synthesized into a general model of fire suppression and ecological change known as the "Southwestern Ponderosa Pine Model" (SPPM; Covington and Moore 1994). The SPPM is a "fire regime-stand development" model, which is implicitly used in much of the management of ponderosa pine forests across the western U.S. According to the SPPM, frequent non-lethal, surface fires formerly maintained open, park-like stands of ponderosa pine, and the past century of fire exclusion has resulted in much denser ponderosa pine stands along with the well known changes in hazard of crown fires and forest health (Covington and Moore 1994).

The SPPM is well supported by data from many ponderosa pine ecosystems from Arizona to Oregon. However, recently the applicability of the SPPM has been questioned for some ponderosa pine ecosystems. For example, Shinneman and Baker (1997) believe that the high fire frequencies assumed in the SPPM prior to the 20th century do not apply to the ponderosa pine forests of the Black Hills National Forest and to many other areas. Although their study certainly did not quantitatively resolve the question of how extensive past stand structural types or past fire regime types were in the Black Hills ponderosa pine forests, Shinneman and Baker (1997) did draw attention to some critical questions about the management of ponderosa pine forests. For the northern Colorado Front Range these questions are:

-In what montane habitats does the SPPM apply?

-Which habitat types that today are characterized by ponderosa pine-montane forest were formerly subject to primarily surface fires, primarily stand-replacing fires, or a mixture of both?

The main objective of this study was to address the first question: To what montane ponderosa pine habitats does the SPPM apply on City of Boulder Open Space and Mountain Parks land? It may apply to the lowest elevational zone at the grassland-montane ecotone, but how well does it apply to higher elevation stands of ponderosa pine? For the City of Boulder Open Space and Mountain Parks land, this question is addressed in four lower montane forest stands ranging from open stands dominated by pure ponderosa pine to mixed conifer stands often dominated by Douglas fir and ponderosa pine.

COMPARISON OF FIRE HISTORY STUDIES IN THE FRONT RANGE

Previous work on fire history in ponderosa pine forests in the northern Colorado Front Range describes changes in fire frequency over the past several hundred years in relation to human activities and climatic variability (Veblen et al. 1996, 2000). The lowest elevation ponderosa pine stands were historically characterized by high fire frequencies (e.g. often 8-10 year return intervals to the same small stand or tree) that maintained an open park-like forest structure prior to the early 1900s. However, in higher elevation ponderosa pine forests, much lower fire frequencies (e.g. often > 60 years) have been documented by fire-scar analysis (Veblen et al. 2000). Historical photographs and age structure data document that many ponderosa pine stands were dense and had cohort age structures indicating that they had originated after stand-replacing fires (Veblen and Lorenz 1986, 1991). These patterns are supported by this study and studies in other Front Range ponderosa pine forests from Rocky Mountain National Park south to Pike National Forest (Rowdabaugh 1978, Goldblum and Veblen 1992, Brown et al. 1999, Donnegan 1999, Ehle 2000, Kaufmann et al. 2000).

In Colorado, there is abundant documentation that prior to 1900 many ponderosa pine ecosystems, especially those of the upper montane zone (Marr 1961), were characterized by dense stands and had at least some incidence of stand-replacing fires (Peet 1981, Veblen and Lorenz 1986, 1991, Hadley 1994, Alington 1998, Mast et al. 1998, Ehle 2000, Kaufmann et al. 2000, 2001, Huckaby et al. 2001). Although these studies recognize the importance of stand-replacing fires in the montane zone, some of these studies suggest that prior to fire suppression in the early 1900s most of the montane zone was less dense with more openings and had fewer stands mixed with Douglas fir (Kaufmann et al. 2000, 2001, Huckaby et al. 2001). These studies acknowledge that their study areas do not fit the SPPM; however, they also infer that most of the ponderosa pine zone in the Colorado Front Range may be currently outside of the historic range of variability of fire and stand structure.

SPECIFIC STUDY OBJECTIVE AND QUESTIONS

Our study objective was to examine the effects of fire occurrence in montane habitat types on City of Boulder Open Space land and explore generalizations that can be made about the natural fire regime in different habitat types.

Research Questions:

-How do fire regimes (e.g. high frequency-low severity fires vs. low frequency-high severity fires) relate to topographic position and elevation?

-What generalizations can be made about fire regimes and habitat type on City of Boulder Open Space land?

-In what habitats does the SPPM apply?

STUDY AREA

The original purpose of this field study was to characterize changes in stand structures and fire regimes in the northern Colorado Front Range along the environmental gradient from the lower ecotone to the upper limits of the ponderosa pine distribution; these four sites on City of Boulder Open Space and Mountain Parks land (3 sites near Eldorado Springs, 1 site in Long Canyon) were the lowest elevation sites of 20 identified for study.

The study areas are located on City of Boulder Open Space and Mountain Parks land at the base of Eldorado Springs (~1900m) and in Long Canyon (~2100m) on Flagstaff Mountain (Fig. 1). Montane forests extend from approximately 1830 to 2750 m (Marr 1961, Peet 1997). Vegetation of the montane zone varies from open park-like stands of ponderosa pine (*Pinus ponderosa*) at the forest-grassland ecotone to denser stands mixed with Douglas fir (*Pseudotsuga menziesii*) in more mesic sites and north-facing slopes. Our two study areas (Eldorado Springs and Long Canyon) in the lower montane zone range from open park-like stands at the forest-grassland ecotone near Eldorado Springs to a denser stand composed of ponderosa pine and Douglas fir trees at the Long Canyon site (Table 1). Fire history was previously sampled in these areas by Veblen et al. (1996; Site 15-Eldorado Springs, Site 11-Long Canyon).

The lowest elevation study area near Eldorado Canyon is on a north-south ridge on the northern side of Eldorado Springs (Fig. 1). Three different slope aspects (north, east and west-facing slopes) on the ridge were sampled for age structure as separate sites at the base of Eldorado Canyon to investigate local variation in age structure and fire history due to slope aspect. The west-facing site was located in a large meadow and had considerably higher herbaceous cover compared to the other two sites. The north-facing and east-facing sites were located higher on the ridge and are steeper than the west-facing site. Numerous rock outcroppings were observed in the east-facing site and at the top of the west-facing site. Long Canyon was sampled for age structure and fire history for a slightly higher elevation lower montane site and is dominated by a dense ponderosa pine-Douglas fir stand.

Precise historical records of grazing were unavailable, although within the last few decades the intensity of grazing in the Boulder area has been reduced (Mast et al. 1998). Logging has occurred at all sites, though the small number of stumps recorded in the Eldorado Springs area indicates the activity was low (Table 1). In contrast, the Long Canyon site has been heavily affected by human disturbances such as logging and recent thinning, which made the interpretation of the historical effects of fire on stand structure difficult to distinguish from more recent human disturbances (see Table 1 and Table 3 for stump information).

STAND DEVELOPMENT AND DISTURBANCE HISTORY METHODS

Age structure and fire history were examined at four sites to compare fire type and fire effects in different site conditions of the lower montane zone. Fire history for these sites is documented in Veblen et al. (1996; Site 15-Eldorado Springs; Site 11-Long Canyon). The sites were sampled for forest age structure in areas ranging from 20 to 50 hectares (50 to 124 acres, respectively). Over these relatively large areas, two to four equal subareas were sampled depending on the size of the site for tree size and age structure with the point-quarter method (Barbour et al. 1987). All trees > 1.4 m in height were included in the sample of size structure along belt transects (10x200m transects), and trees > 4 cm in diameter were cored as close to the root-shoot boundary as possible (i.e. 20 cm above ground) every 20m on transects using the point-quarter method. For the purposes of this study, twenty-year tree age classes were sufficient to interpret the effects of past fires on tree regeneration.

To estimate the ages of trees too small to core (< 4 cm in diameter) and to estimate the number of rings missed due to coring height (approximately 20 cm above the root-shoot boundary), existing data was used for seedling ages from nearby areas (Veblen and Lorenz 1986, Mast et al. 1998). An age estimate of 5 years was used for ponderosa pine following values reported for Boulder County at 40 cm above the root-shoot boundary (range 5-10 years) by Mast et al. (1998). Although Mast et al. (1998) did not report Douglas fir and Rocky Mountain juniper values for Boulder County; the authors found a slightly longer and similar age-to-coring height relationships compared to ponderosa pine, respectively, from Rocky Mountain National Park measurements. Based on this, an age estimate of 8 years was used for the age-to-coring height for Douglas fir and juniper.

RESULTS

Eldorado Springs Area

In the Eldorado Springs area, the lowest elevation ponderosa pine stands were historically characterized by high fire frequencies (e.g., often 8-10 year return intervals to the same small stand or tree, but highly variable) that maintained an open park-like forest structure prior to the early 1900s (Veblen et al. 1996, 2000). The fire-scar record indicates an historic fire regime of frequent surface fires with 17 fire years occurring from 1703 to the latest fire in 1916 (with a criteria of a minimum of two fire-scarred trees indicating a fire year). After the dramatic decline in fire occurrence in the late 1800s and complete cessation of fire after 1916 (Fig. 2), ponderosa pine establishment rose sharply in this area across all three slopes likely due to the decline in fire occurrence (Figs. 3-5).

Although most of the trees established after 1900 (on all three slope aspects), prior establishment pre-dates (1880-1900) fire suppression efforts on the east-facing slope (Fig. 3). This pulse of ponderosa pine establishment is likely due to regeneration after the last major fire in the late 1800s (last major fires in the late 1800s, with a minimum of 2 fire-scarred trees, were 1870 and 1886). The east-facing and west-facing slopes have pulses of establishment in the early 1800s (east-facing slope) to the mid 1800s (west-facing slope) (Figs. 3-4). The temporal variation in establishment may be due to differences in local fire occurrence on the east-facing and west-facing slopes. Both slopes show a decline in establishment during the late 1800s that is likely due to the increase in fire occurrence during that time period (Fig. 2A). Douglas fir and juniper establishments are not evident until the early 1900s, and neither species are prominent on the east-facing slope to present-day (Figs. 3-5, Table 1). Currently, saplings constitute a large fraction of the total number of trees, particularly on the east-facing and north-facing slopes (16-32% of all trees are presently saplings comparing all three sites at Eldorado Springs; data include trees and saplings/hectare, Table 1).

Stem density is highest in the north-facing slope and lowest in the west-facing slope (Fig. 6; Tables 1-2). A study using aerial photography in the Eldorado Springs area (Mast et al. 1997) found that north aspects had the highest tree cover and highest rate of tree cover increase. Our study found the east-facing and west-facing slopes dominated primarily by ponderosa pine, whereas the north-facing slope is dominated by both small diameter Douglas fir and ponderosa pine trees and saplings (Fig. 6; Table 1). A considerable number of ponderosa pine and Douglas fir trees established on the north-facing slope during the early to mid-1980s, while fewer trees established on the east-facing and west-facing slopes during the last 20 years (Figs. 3-5, Table 1 saplings). The east-facing slope is currently dominated by trees in the 20-35cm classes, while the west-facing and north-facing slopes have smaller diameter trees dominating the stand structure, indicating a substantial increase in tree density during the last few decades (Fig. 6).

Long Canyon

Historically there were few fires in the Long Canyon area, with only four fires recorded in the fire-scar record from the late 1700s to present (Fig. 2B). Although there seems to be a reduction in fire occurrence during the latter 20th century, the decline in fire occurrence is not as striking as at the forest-grassland ecotone because of the low number of fires that occurred historically in the Long Canyon area (Fig. 2). There is a marked increase in ponderosa pine establishment during the early 1900s (Fig. 7); however, the mechanism for the increase in establishment is difficult to decipher because of major logging and recent thinning activities (Table 1 and 3). Douglas fir establishment has substantially increased during the last 30 years (Fig. 8; Table 1) and the Long Canyon site is currently dominated by smaller diameter trees of both ponderosa pine and Douglas fir (Fig. 8). Continual establishment of ponderosa pine and Douglas fir during the 20th century is likely due to recurrent human disturbances at the site (e.g. thinning of smaller diameter trees).

DISCUSSION AND CONCLUSION

At the grassland-montane ecotone on Open Space land, the high grass component would have supported frequent, low severity fires. The Eldorado Springs area shows an obvious increase of tree establishment on all slope aspects with the onset of active fire suppression during the early 1900s; however the beginning of the increase in tree establishment pre-dates fire suppression efforts in some areas and is likely due to the last major fire in the late 1800s. Earlier pulses of establishment due to fire occurrence are also evident in the early to mid 1800s on the east-facing and west-facing slopes. The different age structure behavior among the three slope aspects near Eldorado Springs may be due to local variation in fire spread or other disturbances. Site specific information on grazing in the late 1800s is not available and could have been an important influence on the peak of establishment. For instance, grazing may have decreased fire intensity and spread after the late 1800s. It is likely that changes in climate and grazing intensity were similar among the slope aspects. Although climate undoubtedly plays a role in tree establishment, other factors such as soil texture, slope aspect and steepness, competition from grasses, and grazing pressure influenced tree germination and survival.

The Southwestern Ponderosa Pine Model (SPPM) appears to be applicable at the grassland-montane ecotone near Eldorado Springs. Frequent non-lethal, surface fires formerly maintained open, park-like stands of ponderosa pine, and the past century of fire exclusion has resulted in much denser ponderosa pine stands along with the well known changes in hazard of crown fires and forest health (Covington and Moore 1994). Environmental factors such as topographic position may be inconsequential for determining fire regime type (high frequency-low severity vs. low frequency-high severity) in areas adjacent to grasslands and at low elevation. This pattern of fire reduction followed by a sharp increase in stand density fits well with the SPPM. Current management plans are guided by the recognition that in this habitat (near Eldorado Springs) fire frequency during the past century is outside the historic range of variability, and so is the current stand density.

However, fire history and age structure data suggest that few, if any sites, beyond areas adjacent to grasslands would support a high frequency-low severity fire regime in the northern Colorado Front Range. Sites only slightly higher in elevation show a dramatic decrease in the historic fire frequency (Fig. 2B) compared to the lowest elevation montane-grassland sites (Fig. 2A and Site 14 in Veblen et al. 1996). In the lower montane stand of Long Canyon there is no evidence that frequent surface fires played a detectable role in the history of this stand over the past several hundred years. This type of fire history clearly does not fit the SPPM. Although the effects of fire occurrence on stand structure are unclear due to recurrent human disturbances in Long Canyon, management efforts to restore this site to an open, park-like woodland would not be consistent with the fire history at this site.

The lowest elevation areas adjacent to the grassland ecotone show a substantial change in the fire regime allowing for tree invasion into the grassland; however, many of the montane forests in the northern Front Range show even-aged pulses of establishment indicating a low frequency-high severity or -mixed severity fire regime (preliminary results; Sherriff and Veblen unpublished). Further analysis will examine fire regimes and stand development across the elevational range of ponderosa pine, and will include areas of mixed conifer forest type. At all four of these City of Boulder Open Space sites (3 sites at Eldorado Springs and 1 site at Long Canyon) we plan to examine the spatial heterogeneity of fire severity using the fire-scar and age structure data. A classification of "severity type" also needs to be established using site-specific fire-scar and age structure data. These four lower montane sites on Open Space land will help to determine what environmental factors allow for a high frequency-low severity fire regime throughout the entire elevational range of ponderosa pine in the northern Front Range.

Table 1. Forest stand information for each site.

Site	Species	Area Sampled (hectares)	Number of Trees Sampled for Age	Tree Density/ hectare	Number of Saplings[a]/ hectare	Number of Logs[b]/ hectare	Number of Stumps[b]/ hectare	Number of Snags[b]/ hectare
Eldorado Springs								
East-facing		25						
	Ponderosa		115	133	30	17	18	
	Douglas fir		2	2	1			
	Juniper			1				
West-facing		50						
	Ponderosa		92	62	12.5	5	2	
	Douglas fir		4	3	2			
	Juniper		4	12	1			
North-facing		20						
	Ponderosa		86	322	72	12	11	3
	Douglas fir		33	212	176			
	Juniper			11	6			
	Aspen				1			
Long Canyon		24						
	Ponderosa		112	208	54	28	70[c]	5
	Douglas fir		20	86	24			
	Juniper		2	17	6			
	Aspen		2					

[a]Some saplings may be suppressed and more than 20 years old.
[b]Most of the dead material was identified as ponderosa pine.
[c]Stumps primarily from one sector of sampling area near Flagstaff Road.

Table 2. Total live trees (>4cm DBH) sampled along 10x200m belt transects for forest structure in 5cm DBH classes for each site. Actual numbers should not be compared across sites because only 6 transects were sampled on the north-facing and east-facing slopes of Eldorado Springs due to the smaller sampling area in contrast to 12 transects sampled on the west-facing slope of Eldorado Springs and at Long Canyon. Table 1 should be used for comparison with the number of stems/hectare. The trend across all sites shows small diameter trees dominate the forest structure, particularly on the west-facing and north-facing slopes of Eldorado Springs and at Long Canyon.

		DBH class (cm)													
Site	Species	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	Total
Eldorado Springs															
East-facing	Ponderosa	12	10	11	31	23	31	23	9	5	2	2	1		160
	Douglas fir	1			1										2
	Juniper								1						1
West-facing	Ponderosa	17	24	23	29	20	13	8	6	2	3	1	1	1	148
	Douglas fir	2	1	1	1	1	1								7
	Juniper	2	5	1	3	2			1						14
	Aspen								1						1
North-facing	Ponderosa	74	83	66	53	41	31	17	15	5		1			386
	Douglas fir	108	80	34	18	6	8	1		1					256
	Juniper	2	5	3	2	1									13
Long Canyon															
	Ponderosa	83	85	63	86	70	46	29	17	14	3	3	1		500
	Douglas fir	67	73	43	15	5		3		1					207
	Juniper	13	16	9	2										40

Ta[illegible]. Total dead woody material sampled along 10x200m belt transects for forest structure in 5cm DBH classes for each site. Actual numbers should not be compared across sites because only 6 transects were sampled on the north-facing and east-facing slopes due to the smaller sampling area in contrast to 12 transects sampled on the west-facing slope and at Long Canyon. Table 1 should be used for comparison with the number of stems/hectare.

				DBH Class (cm)													
Site	Stumps	Logs	Snags	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	Totals
Eldorado Springs																	
East-facing	22	21		3	6	6	8	6	7	5	1		1				43
West-facing	5	13		1	3	2	2	1	2			1		1	1		14
North-facing	13	14	4		5	3	14	2	2		1	1					28
Long Canyon	164	67	3	6	19	38	51	36	33	37	12	3	2	2		3	242

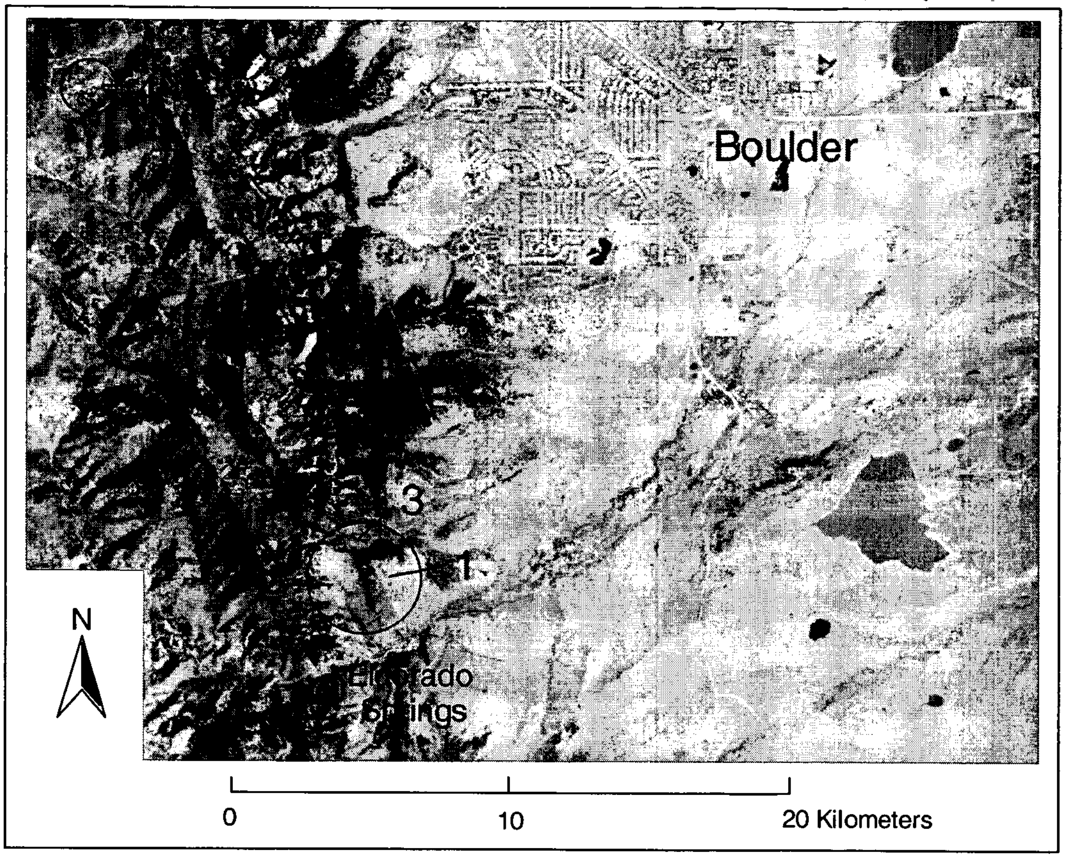
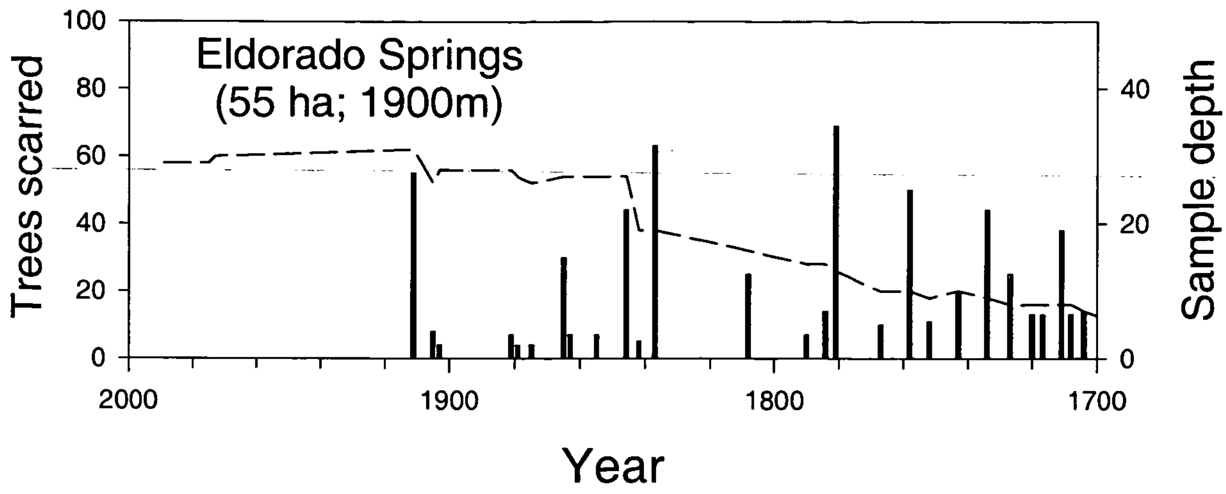


Figure 1. Map of study sites on City of Boulder Open Space and Mountain Parks land. The numbers indicate sample sites. Three sites were sampled near Eldorado Springs: site 1 is the east-facing slope, site 2 is the west-facing slope, and site 3 is the north-facing slope. Site 4 is the Long Canyon site.

A)



B)

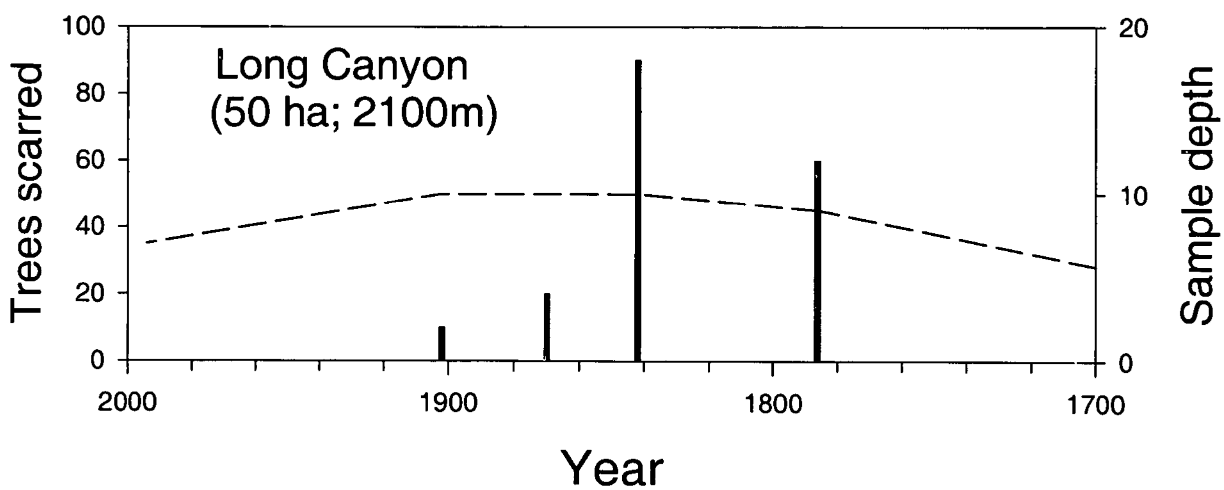


Figure 2. A) Fire history for the Eldorado Springs area across all three slopes (east-facing, west-facing and north-facing sites). Specific details on the fire history are cited in the Veblen et al. 1996 report to the City of Boulder (fire history site 15). B) Fire history for the Long Canyon site (Site 11 in Veblen et al. 1996). The vertical bars indicate the percentage of trees fire-scarred (left axis) during an individual fire year. The dashed line represents the number of recorder trees (right axis) through time. Recorder trees are previously fire-scarred trees that have an exposed scar and will subsequently record fires that occur at the site.

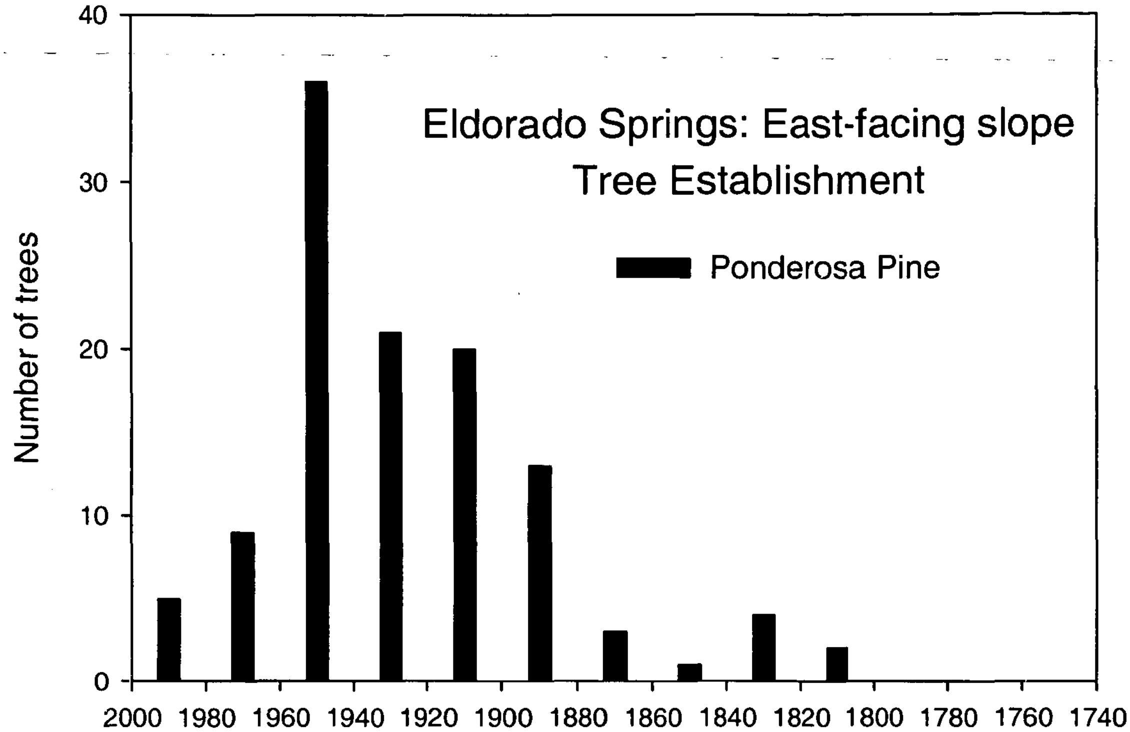


Figure 3. Age structure of live trees (> 4cm DBH) on the east-facing site near Eldorado Springs. The histogram shows the age structure of ponderosa pine trees. Only two Douglas fir trees were sampled for age structure and are not shown (the two Douglas fir establishment dates were 1928 and 1943).

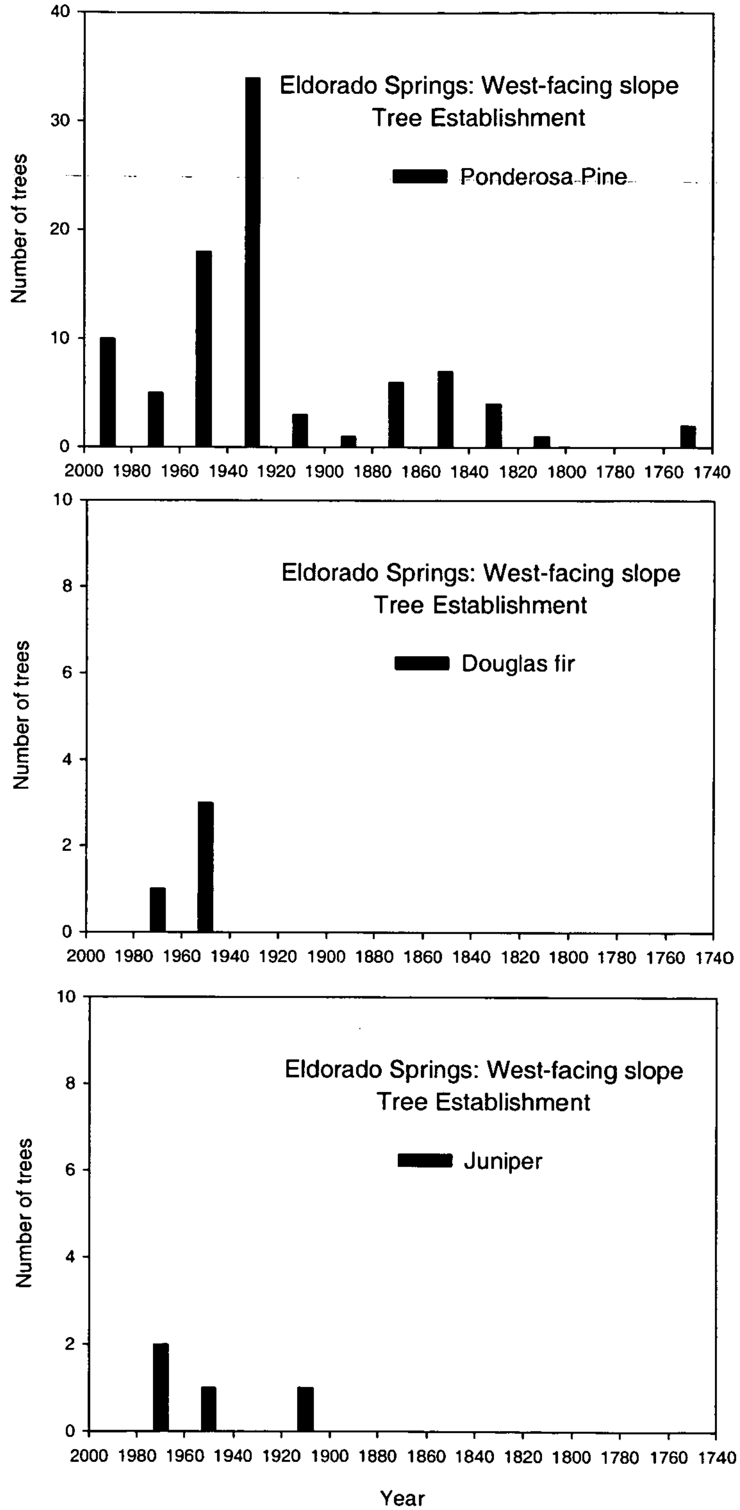


Figure 4. Age structure of live trees (> 4cm DBH) on the west-facing site near Eldorado Springs. A) The histogram shows the age structure of ponderosa pine; B) the age structure of Douglas fir; and C) the age structure of Juniper trees.

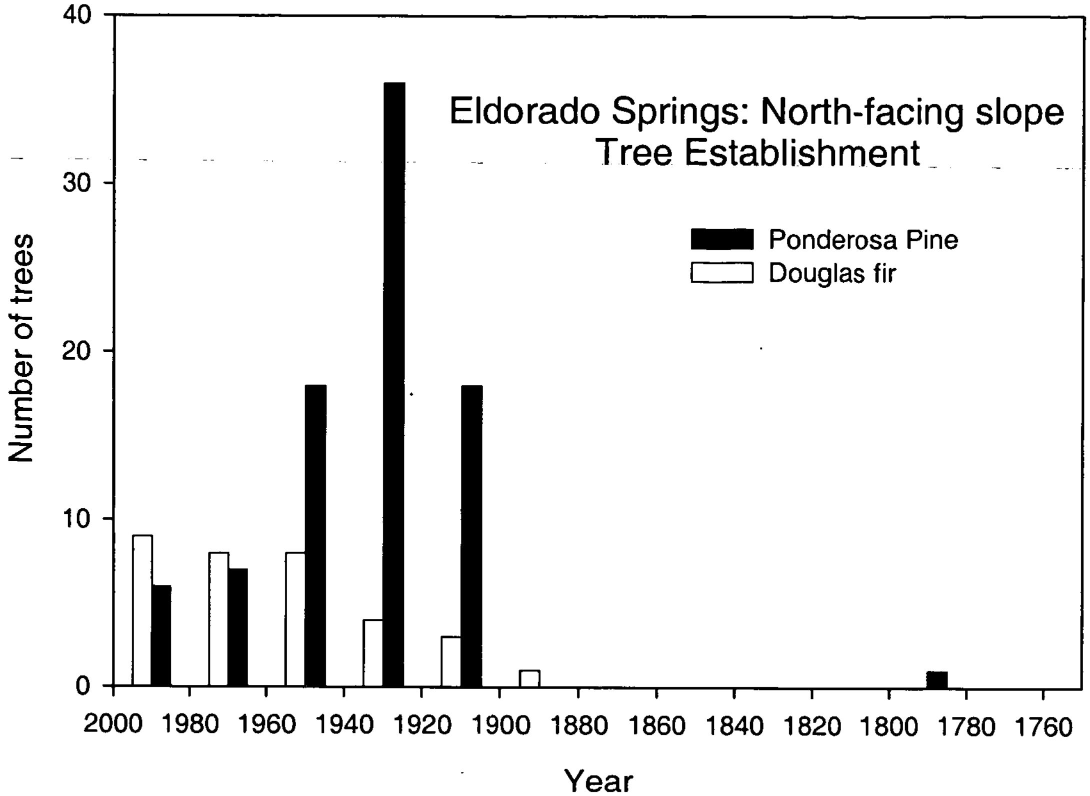


Figure 5. Age structure of live trees (> 4cm DBH) on the north-facing site near Eldorado Springs. The histogram shows the age structure of ponderosa pine and Douglas fir trees.

A)

B)

C)

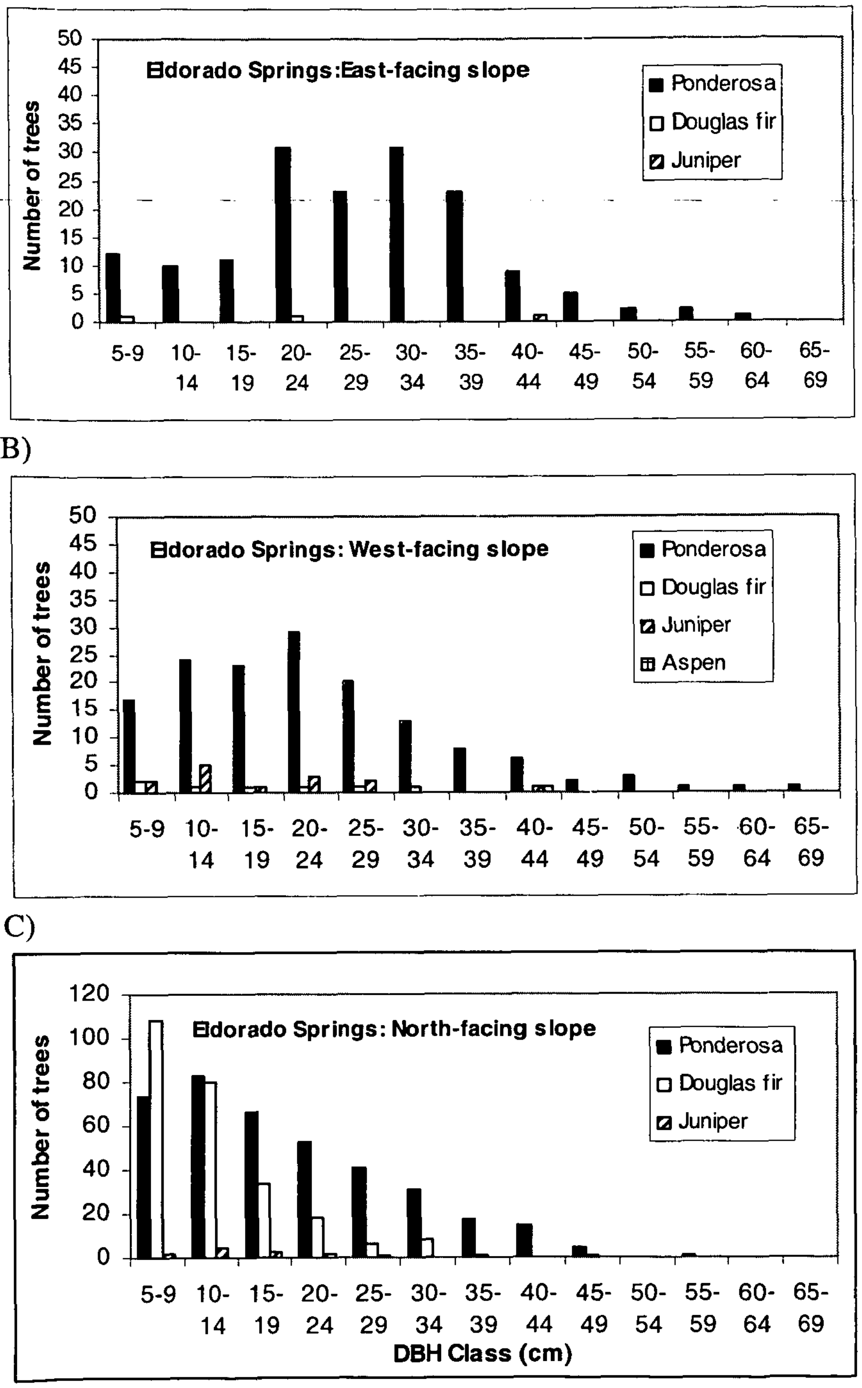


Figure 6. Total live trees (>4cm DBH) sampled for stand structure in each site at Eldorado Springs. The stand structure data is the same information as Table 2. Stand structure of live trees for the A) east-facing slope, B) west-facing slope and C) north-facing slope. The east-facing slope is dominated by trees in the 20-35cm classes. The west-facing and north-facing slopes primarily have smaller diameter trees dominating the stand structure. In contrast to the other two slopes dominated by ponderosa pine, the north-facing slope is dominated by small diameter Douglas fir trees.

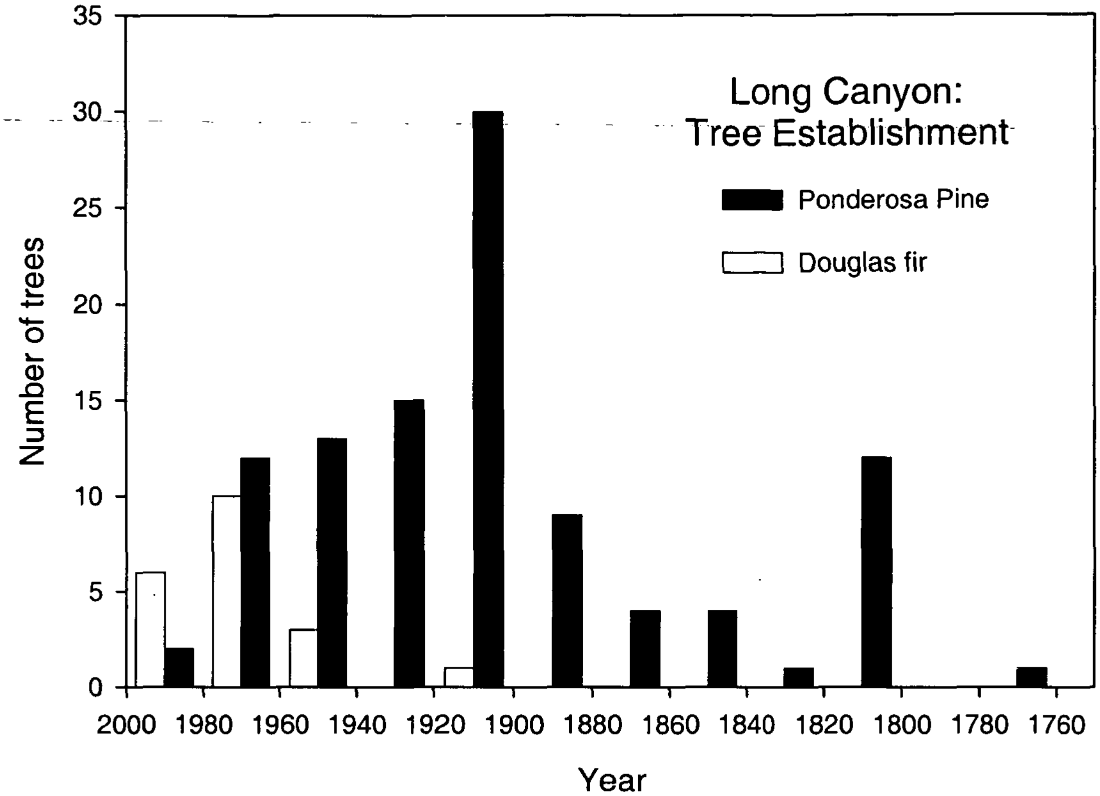


Figure 7. Age structure of live trees (> 4cm DBH) in Long Canyon. The histogram shows the age structure of ponderosa pine and Douglas fir trees. Due to the high number of stumps at the site, the age structure diagram is incomplete and should only be interpreted in context with the stump data from Table 1.

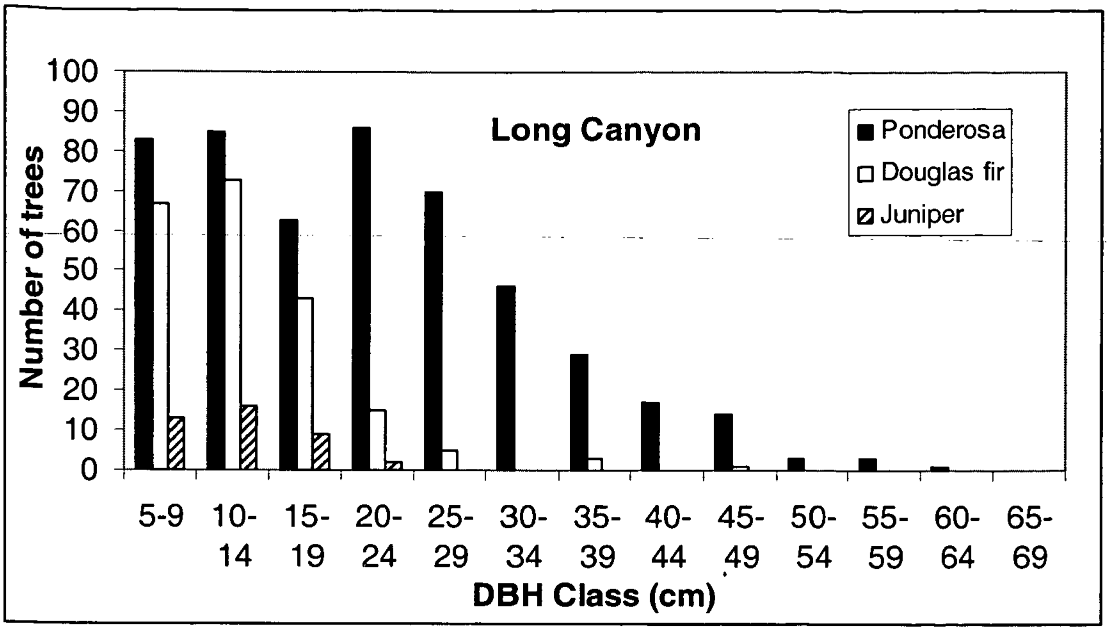


Figure 8. Total live trees (>4cm DBH) sampled for stand structure in Long Canyon. The stand structure data is the same information as Table 2. The site is dominated by smaller diameter ponderosa pine and Douglas fir trees.

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