fire

MDPI

Article

Historical Fire Regimes in Ponderosa Pine and Mixed-Conifer Landscapes of the San Juan Mountains, Colorado, USA, from Multiple Sources

William L. Baker

Program in Ecology/Department of Geography, University of Wyoming, Laramie, WY 82071, USA; bakerwl@uwyo.edu

Received: 28 May 2018; Accepted: 7 July 2018; Published: 9 July 2018

check for updates

Abstract: Reconstructing historical fire regimes is difficult at the landscape scale, but essential to determine whether modern fires are unnaturally severe. I synthesized evidence across 725,000 ha of montane forests in the San Juan Mountains, Colorado, from forest atlases, forest-reserve reports, fire-scar studies, early reports, and newspaper accounts. Atlases mapped moderate- to high-severity fires during 1850–1909 (~60 years), and 86% of atlas area was attributable to 24 fire years. Historical fire rotations from atlases were mostly 225–360 years for high-severity fires and 133–185 years for moderate- to high-severity fires. Historical low-severity fire from tree-ring data at 33 sites revealed a median fire rotation of 31 years in ponderosa pine, 78 years in dry mixed-conifer, and 113 years in moist mixed-conifer forests. Only 15% of montane sites had "frequent-fire" forests with fire rotations <25 years that kept understory fuels at low levels. Moderate- to high-severity fire rotations were long enough to enable old-growth forests, but short enough to foster heterogeneous landscapes with expanses of recovering forests and openings. About 38–39% is still recovering from the 1850–1909 fires. Large, infrequent severe fires historically enhanced resilience to subsequent beetle outbreaks, droughts, and fires, but have burned at lower rates in the last few decades.

Keywords: wildfires; megafires; high-severity fires; frequent fire; historical fires; fire regimes; forest atlases; San Juan Mountains; Colorado; USA

---

1. Introduction

Evidence about historical fire across large landscapes is needed even though climatic change is shifting fire regimes. It is essential to accurately characterize and model historical variability to be able to correctly parse the climatic-change component of recent fire rates and patterns [1]. Historical fire also remains relevant as a guide for restoration. Research on historical ponderosa pine and mixed-conifer landscapes of the montane zone in the San Juan Mountains, Colorado, USA, was based on limited landscape-scale evidence, as this evidence was simply unavailable.

Limited landscape-scale evidence is not unusual for montane forests, but this leaves an incomplete and possibly biased perspective on historical fire regimes. The problem is that tree-ring reconstructions, the main source of evidence about historical fire regimes, are difficult to execute at scales exceeding ~10,000 ha. In the San Juan Mountains, only two fire-history studies have been able to reach scales of 7000–8000 ha [2,3] in a mountain range with >750,000 ha of montane forests. Tree-ring studies in smaller areas can provide invaluable, but potentially biased samples of large landscapes, particularly if focused in old forests to obtain long records of fire [4]. Old forests typically have persisted because they did not have intense wildfires that killed many trees, thus may inherently underestimate fire intensity in larger landscapes [4]. Probabilistic studies that used early aerial photographs, land-survey records, or systematic early records across large landscapes are relatively few. These have shown that, where studied, historical montane landscapes in the western USA were much more diverse in forest structure, than shown by tree-ring studies, because of variable fire regimes that included some severe fires that killed many trees [5–7]. Thus, the key question addressed here, where spatially comprehensive, probabilistic evidence was until now not available, is whether historical fire regimes in the montane zone of the San Juan Mountains were also diverse and included large, severe fires? Evidence presented here shows that large, severe fires did also occur historically in ponderosa pine and mixed-conifer landscapes of this large mountain range.

I used a new source, historical forest atlases, with tree-ring reconstructions and corroboration by early documents, to reconstruct historical fire regimes across a large part of the montane landscapes of the San Juan Mountains, Colorado to add to a previous synthesis [8].

Background on Sources for Reconstructing Montane Historical Fire Regimes in the San Juan Mountains

How can multiple sources be used to reconstruct historical fires and fire severity across large landscapes? First, fires left surviving trees with fire scars that provide potential fire dates and estimates of rates of fire, particularly low-severity fires [4]. Studies typically reported mean/median intervals between fires in a composite list of fire dates found on any tree in a set of trees in a study site. These mean or median "composite fire intervals (CFIs)" [9] are based on counts of fires, a rough measure since fires vary substantially in area. Land managers need estimated area burned, not just counts. The key spatial estimator is the fire rotation, the expected time (in years) for fire to burn across a particular land area once, estimated by adding up areas burned by fires over some period of observation in a study area, then dividing the period by the fraction of the area burned [4,9]. Thus, if 20 fires together burned area equal to half a study area in 10 years, then the fire rotation was an estimated 20 years. From analysis of CFI studies spanning dry forests in the western United States, I found it possible to estimate low-severity fire rotations from CFIs using regression [4].

Second, some fire-scar studies also collected age-structure data, from trees, that allow reconstruction of fire severity, by showing, for example, whether fires had few survivors and were followed by pulses of tree regeneration [10]. Fire severity, effects on tree populations, is often characterized as low severity if $\leq$20% of the basal area of trees was killed, moderate severity if 20–70% was killed, and high severity if $\geq$70% was killed [11]. Stand-origin data, usually obtained by dating the largest trees, can be used to estimate when stands originated after high-severity fires [2].

Third, maps are available showing areas burned by fires in the late-1800s and early 1900s on some National Forests. Soon after creation of National Forests, in and after 1905, staff were tasked with completing maps [12], using surveyed plats, showing topographic contours, natural features (e.g., lakes, streams), and human uses (e.g., towns, railroads, timber claims). These were typically done in black and white at 1" to 1 mile (1:63,360) scale or better on 45.7 $\times$ 53.3 cm (18" $\times$ 21") sheets assembled in a "folio" for each forest [12]. Graves [13] reported that 190 folios and nearly all National Forests had been mapped. Some forests added color maps showing grasslands and shrublands, timber volume, fires, blowdowns, insect mortality, logging, and cultivation, a choice left to each forest [12]; most chose not to add this information. Maps were made in the field by plane table and compass surveys, using chaining to measure distances, often supplemented by prior topographic mapping. Mapping followed standards, including consistent coloring [12,13]. I used color 1908–1909 forest atlases for three forests (Montezuma, San Juan, and Rio Grande) in the southern 2/3 of the San Juan Mountains. The rest of the San Juan Mountains was not apparently mapped in color.

Fourth, prior to the establishment of most National Forests, a "forest-reserve" report was completed by government scientists that described the condition of the forests, including some assessment of fires, as well as human activities (e.g., logging, roads) in the forests. We used forest-reserve reports to assess historical fire and forest conditions in other parts of the Rocky Mountains [14]. I used the Dubois [15] forest-reserve report on the eastern part of the current San Juan National Forest and the southern Rio Grande National Forest and the Dubois [16] forest-reserve report on the Montezuma National Forest, now the western part of the current San Juan National Forest.

Fifth, an early report by Michelsen [17] provided maps of large fires in 1900 in Colorado, along with estimates of area burned by county and descriptions of some of the fires. Finally, miscellaneous early newspaper reports, forest histories, and other early documents corroborate some fires and describe some of their details.

2. Materials and Methods

2.1. Study Area

The study area in the southern San Juan Mountains, Colorado contains six large watersheds over ∼1.7 million ha, about 2/3 of the mountain range (Figure 1a). The study area is limited to this area, because forest atlases with fire information cover only these watersheds. In addition, fire-history data from tree rings are available only for five of these watersheds and only four have >1 site. The San Juan and Montezuma forest atlases are on the moister west side of the continental divide, and the Rio Grande forest atlas is on the drier east side.

Montane forests in the San Juan Mountains have often been classified into: (1) ponderosa pine forests primarily with *Pinus ponderosa* and few other tree species; (2) dry mixed-conifer forests that have abundant ponderosa pine, but also common other trees, including possibly white fir (*Abies concolor*), blue spruce (*Picea pungens*), Douglas-fir (*Pseudotsuga menziesii*), southwestern white pine (*Pinus strobiformis*), or quaking aspen (*Populus tremuloides*); and (3) moist mixed-conifer forests that have some or all the above trees, except ponderosa pine is rare to absent and some subalpine trees (e.g., *Picea engelmannii*) may also occur [8].

To limit the study approximately to historical ponderosa pine and mixed-conifer zones, I made digital maps of the three forest zones (Figure 1a) from current forests and then added some aspen forests, grasslands, and shrublands. I first obtained maps, in the form of ArcGIS geodatabases (ESRI, Inc., Redlands, California), of current vegetation from the San Juan (*n* = 24,576 polygons) and Rio Grande (*n* = 54,536 polygons) National Forests. I began by extracting records from the "LOCAL_TYPE" field in each map that provided classifications of polygons, from remote sensing and field surveys, as ponderosa pine forests (TPP-PP), dry mixed-conifer forests (TMC-WD), and moist mixed-conifer forests (TMC-CM), the focus of this study. Current quaking aspen forests were not assigned in LOCAL_TYPE to the three forest zones. To assign aspen forests to the three forest zones, I extracted records for aspen forests without conifers (TAA), aspen forests with conifers (TAA-SW), and spruce-fir forests (TSF). For the TAA-SW category, I reclassified records as: (a) TMC-WD if the next most abundant tree, given in other fields in the attribute table, was *Pinus ponderosa*, *Juniperus osteosperma*, or *Pinus edulis*; or (b) TMC-CM if the next most abundant tree was *Abies concolor*, *Picea pungens*, or *Pseudotsuga menziesii* and there was little or no *P. ponderosa*. I deleted other records in TAA-SW, which generally represented subalpine spruce-fir forests.

Since associated conifers were not available for the TAA records, but some of these aspen stands likely also occurred in dry mixed-conifer (TMC-WD), moist mixed-conifer (TMC-CM), or spruce-fir (TSF) forest zones, I roughly estimated which zone to assign to each TAA record. To do so, I first exported the attribute data and completed a simple linear discriminant analysis (LDA, [18]) of these three types in Minitab 18 (Minitab, Inc., State College, Pennsylvania), based on their elevation, aspect, and slope, which were in the attribute table. I did not separate the data into model-building and validation subsets, or test predictive accuracy, because this is only a rough approximation from environmental setting. This LDA for the San Juan National Forest, correctly classified 77.9% of 15,516 records in these three categories. I then applied this LDA to all the TAA records (*n* = 2473), then kept records predicted as TMC-WD and TMC-CM and deleted all TSF. This procedure places records that represent seral, semi-persistent, or stable aspen [19], which cannot be discriminated with available compositional data, into its approximate mixed-conifer zone. I followed the same procedure for the Rio Grande National Forest map, where the LDA correctly classified 79.4% of the 16,308 records in these three categories. I again applied the LDA to all the TAA records (*n* = 1970), then kept records predicted as TMC-WD and TMC-CM and deleted all TSF. Both mountain grasslands, with *Festuca arizonica*, *F. thurberi* and other bunchgrasses, and mountain shrublands, with *Quercus gambelii*, *Amelanchier utahensis*, and other shrubs, could also in part have been forests in these zones in the historical period. There is substantial evidence that grasslands and shrublands can be created or renewed by severe forest fires in the Rocky Mountains [9]. I included those <2950 m elevation, in the ponderosa pine and mixed-conifer zones of the San Juan and <3140 m elevation on the Rio Grande. The resulting map is Figure 1a. These zones only delimit the extent of the area within which fires may have occurred that are likely within one of the current and historical montane forest zones.

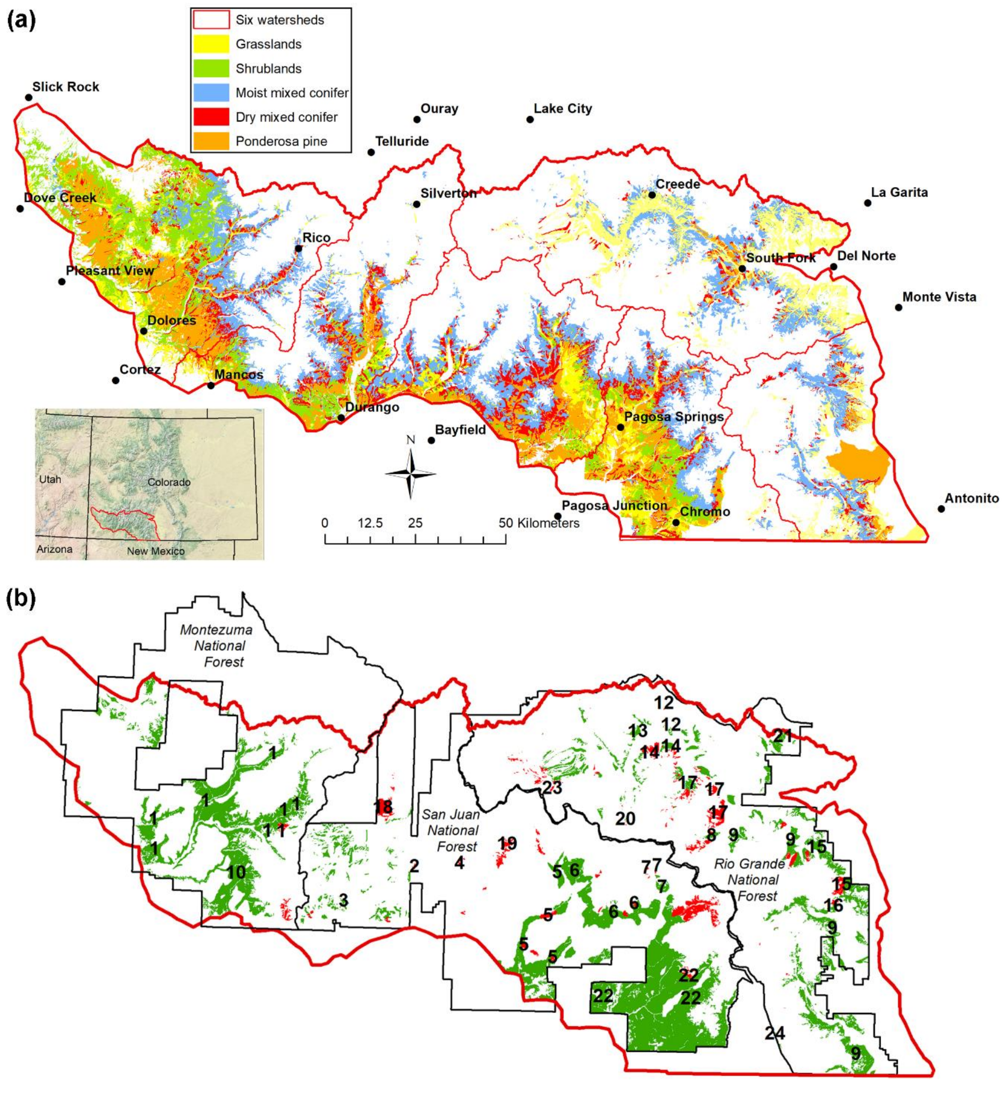

Figure 1. (**a**) The full study area on the current San Juan and Rio Grande National Forests, Colorado, including their ponderosa pine, dry mixed-conifer, and moist mixed-conifer forest zones. The continental divide is between these forests. Watersheds are from left to right the Dolores, Animas and Mancos, Piedra and Florida, San Juan and Navajo, and Alamosa-La Jara-Conejos Rivers. The Rio Grande watershed is at the right and above these others. (**b**) The three atlas boundaries (black lines) and the fires (red) and woodlands (green) shown on the atlases within the area of ponderosa pine and mixed-conifer forests. Fires were likely mostly stand-replacing, and woodlands likely moderate- and high-severity fires, 1850–1909. Fire and woodland numbers are used in tables and text.

The two current national forests in the study area contain ponderosa pine and mixed-conifer zones covering about 725,000 ha, about 3/4 on the current San Juan National Forest (Table 1, Columns

1–3). Moist mixed conifer totaled most area, ponderosa pine intermediate, and dry mixed conifer the least. The San Juan part of the study area had almost all the shrublands and the Rio Grande had disproportionate grassland area. Shrublands and grasslands covered substantial area.

Table 1. Area of forests, shrublands and grasslands in the full study area and the atlas area (Columns 1–4), and the area of fires, woodlands, and total burned area, as well as rates of fire (Columns 5–11). Fire atlases show fire and woodland area from fires in forests over about the preceding 60 years, from 1850 to 1910.

				High Severity					Mod.-High Severity	
Modern Vegetation Types	Full Area (Figure 1a)		Atlas Area (Figure 1b)	Fire Area	1/2 Woodland Area	Total Burn Area	Fraction Burned	Fire Rotation	Fraction Burned [1]	Fire Rotation
	(ha)	(%)	(ha)	(ha)	(ha)	(ha)		(years)		(years)
San Juan National Forest										
Grasslands	73,509	13.6	48,847	277	9586	9863	0.20192	297	0.60008	100
Shrublands	118,302	21.9	73,257	263	14,965	15,228	0.20787	289	0.41215	146
Ponderosa pine	136,494	25.4	113,249	1201	17,785	18,986	0.16756	358	0.32469	185
Dry mixed conifer	75,690	14.0	66,853	2637	12,477	15,114	0.22608	265	0.41271	145
Moist mixed conifer	135,252	25.1	119,692	6714	21,568	28,282	0.23629	254	0.41649	144
Total-San Juan	539,247	100.0	421,898	11,092	76,381	87,473	0.20733	289	0.38836	154
Rio Grande National Forest										
Grasslands	87,908	47.4	60,626	2385	7512	9897	0.16325	368	0.45040	133
Shrublands	907	0.5	414	20	52	72	0.17391	345	0.29952	200
Ponderosa pine	20,188	10.9	7175	125	251	376	0.05240	1145	0.08725	688
Dry mixed conifer	14,313	7.7	13,634	899	2170	3069	0.22510	267	0.38426	156
Moist mixed conifer	62,113	33.5	58,846	4962	10,774	15,736	0.26741	224	0.45050	133
Total-Rio Grande	185,429	100.0	140,695	8391	20,759	29,149	0.20718	289	0.35472	169
Total-both forests	724,676		562,593	19,483	97,140	116,620	0.20729	289	0.37996	158

[1] Fraction burned in this case is the total area of woodlands, rather than half this area, plus fire area, divided by atlas area.

2.2. Moderate- to High-Severity Fires from Forest Atlases and Early Reports

Forest atlases in the National Archives have been scanned and are available from several sources. I downloaded from the Biodiversity Heritage Library [20], the full folio of 17 maps published in 1908 for the Montezuma National Forest. I downloaded 15 available maps of 16 published in 1909 in the folio for the original San Juan National Forest. Map sheet #2 is missing from all archives; it may be missing in originals at the National Archives. I downloaded all 15 maps in the folio published in 1909 for the Rio Grande National Forest, only a part of the current forest; the northern part, the original Cochetopa National Forest, was done only in black and white without fire information. Similarly, atlases are available only in black and white for the Gunnison and Uncompahgre National Forests in the northern San Juans.

I georectified the scanned maps in ArcGIS 10.5 (ESRI, Redlands, California) using online U.S. Geological Survey (1:24,000 scale) topographic maps as the spatial reference, generally placing about 10–20 control points on each map sheet at section or township corners or distinct topographic features (e.g., mountain peaks and stream junctions). After rectification and mosaicking the maps in each forest, I used the ArcGIS measuring tool to measure the distance between the same feature at 30 points on the atlases and the topographic maps, then calculated the root mean square error (RMSE), a common measure of mapping error. RMSE was 572 m for the Montezuma, 630 m for the San Juan, and 555 m for the Rio Grande. In contrast, Kulakowski et al. [21] obtained a 173 m RMSE after georectifying an 1898 smaller-scale map. Thus, the forest atlases used here are not very spatially accurate. I could see that peaks, for example, were at times within 100–200 m, but other times were >1000 m off, suggesting variable accuracy, likely a consequence of variable visibility for plane-table mapping in complex mountain terrain.

Fires and woodlands are the atlas features of interest (Figure 2a). Atlas fires lacked many unburned areas, and mapping categories indicated stages of recovery (Figure 2b), which imply high-severity fire removed most trees. These were likely primarily fires in forests, because fires in grasslands and shrublands recover within a few years [9], so that fires are no longer visible and mappable, whereas forest fires are visible and mappable for several decades after the fire because of standing dead and down wood. As shown later, mapped fires were from more than a few years prior to the 1908–1909 atlases. Atlas fires are also corroborated as stand-replacing fires in forests (very high-severity fires) in two cases. The Rio Grande atlas (Figure 3b) records a stand-replacing fire reconstructed and dated to 1876 by Margolis et al. [22] at Squaw Creek (Figure 3a). An 1898 photograph (Figure 3d) shows the southern part of an atlas fire (Figure 3c), the 1879 Lime Creek burn (Table S1), which appears to have burned as stand-replacing fire over ~1000 ha of ponderosa pine and mixed conifer. Atlas fires were likely mostly stand-replacing fires in forests (sensu [2,22]).

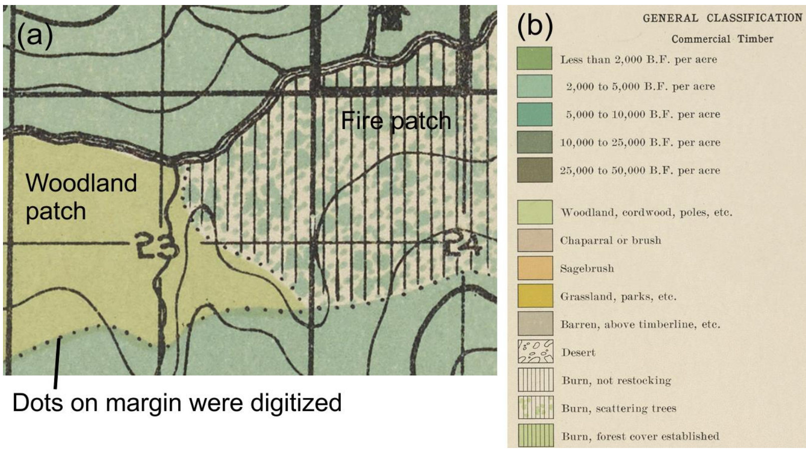

Figure 2. Digitizing the atlas evidence: (**a**) zoomed view of a woodland patch and a fire patch, showing the dots that demarcate the margin of the patches; and (**b**) part of a legend, showing timber volumes and post-fire recovery classes.

Woodlands are explained by Dubois in the Montezuma Forest-Reserve Report: "Woodland signifies all bodies of immature or worthless forest too large to be classed as brush or seedlings growth" [16] (p. 9). These are not woodlands in the modern sense, but instead mostly are burned areas with little timber. Dubois indicated that half of woodland area had very little timber volume: "Allowing an average stand of 3000 feet to the acre on the unburned commercial forest and 500 feet per acre on one-half of the woodland, which is conservative ... " [16] (p. 11). Dubois attributed this half of woodland area with almost no timber volume (only 500 feet/acre) to past severe fires:

> "It is safe to say that 50 per cent of the area classified as woodland has been run over and seriously damaged by fire .... These burns are in all stages, from areas covered with dead standing trees and down timber with no re-growth what so ever on the ground, such as the area at the head of Burnt Timber Creek in the La Plata, to large areas covered by stands of aspen of varying ages with a few scattering groups of conifers in mixture, such as are found on the hills on each side of the main Dolores along which runs the railroad". ([16]; p. 21).

Similarly, in the Cochetopa Forest-Reserve Report on the northern part of the current Rio Grande National Forest, just north of my study area, Hatton ([23]; p. 19) further explained: "Woodlands. Under this head are included lands which for the most part have been burned over and have since come up to lodgepole pine [*Pinus contorta*] or aspen" and "Burned-over forest lands [equivalent to atlas fires in the San Juan and Rio Grande forest-reserve reports] comprise the more recent burns, and differ from woodlands in that there is little or no reproduction to date. In time these areas will probably come under the head of woodlands".

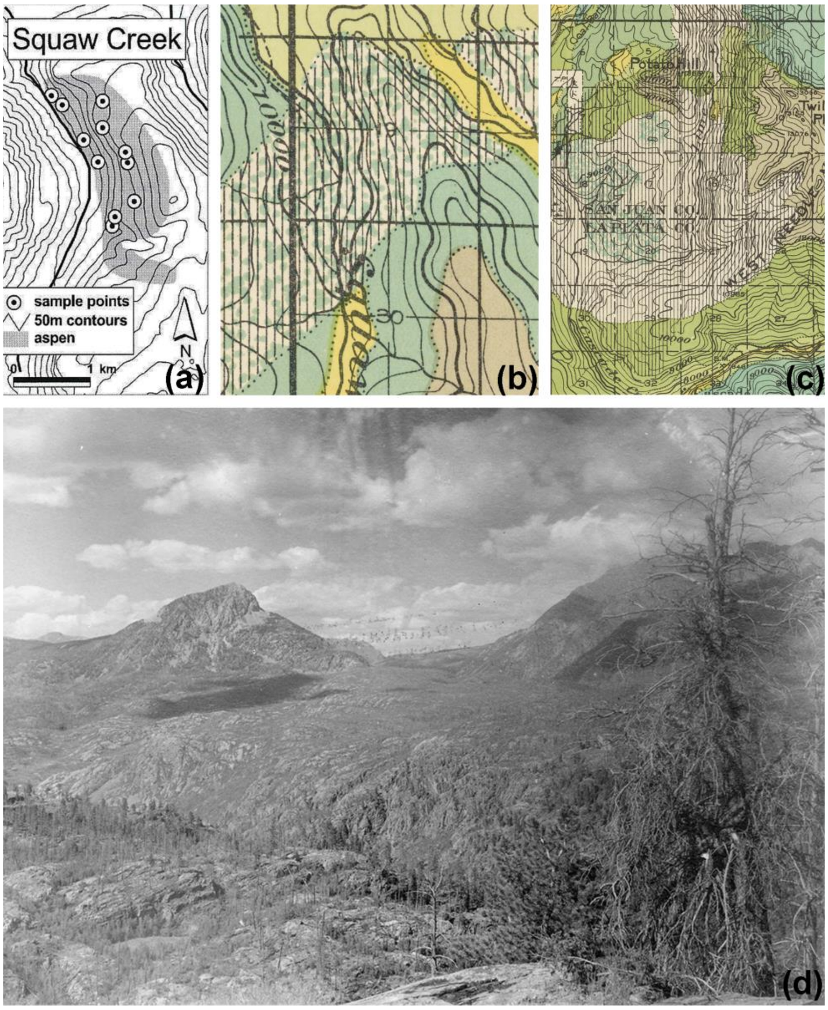

Figure 3. Examples of two mapped atlas fires, showing they were stand-replacing fires (very high severity): (**a**) an 1876 fire dated by Margolis et al. [22] at Squaw Creek on the Rio Grande National Forest, © Canadian Science Publishing or its licensors; (**b**) the Rio Grande Forest Atlas representation of this fire, which appears to have extended over a larger area than the stand-replacing aspen focal area of the Margolis et al. study; (**c**) the 1909 San Juan Forest Atlas representation of the southern part of the 1879 Lime Creek Burn, which burned >1814 ha of ponderosa pine and mixed-conifer forests; and (**d**) about 1000 ha of this area in the southern part of the 1879 Lime Creek Burn, 19 years after the fire, photographed by Charles Whitman Cross, No. 370, original caption: "Potato Hill and slopes of West Needle Mountains from hill west of the mouth of Cascade Creek. Engineer Mountain quadrangle, San Juan County, Colorado. 1898" from the U.S. Geological Survey Denver Library Photographic Collection.

Half of woodlands thus represent high-severity fires that had a few more survivors than in the more stand-replacing atlas fires, or were older stand-replacing high-severity fires that had more post-fire regeneration by the time of mapping. The second half of woodlands more likely burned at moderate severity, given this half also was "immature or worthless forest too large to be classed as brush or seedlings growth" ([16]; p. 9). This second half had >500 feet to the acre of timber volume, but not much more, as the next category was "Less than 2000 B.F. per acre" (Figure 2b). Early reports, reviewed in Section 3.1, corroborate this half was also burned. Hatton's quote above also indicates woodlands, including this second half, were mostly burned. Moderate- rather than low-severity fires are indicated by low timber volume in this second half, as low-severity fires do not keep timber volume so low. Low-severity fires likely spread between some mapped patches.

Some small parts of this second half of woodlands could also represent forests on naturally unproductive sites or from logging. At high elevations, some patchy treeline forests in mapped woodlands may not indicate preceding moderate-severity fires, nor may some very dry low-density woodlands, possible anywhere, but especially on the Rio Grande side. Woodlands were not described as from logging [15,16]. Moreover, "cuttings" are a separate category in atlas legends and are mapped elsewhere, but not adjacent to, or within woodland areas. Some woodlands could possibly have resulted from railroad logging in the Pagosa Springs area (Figure 4a), the main area on the San Juan side described in 1903 as having logging [15]. Some railroad logging had also begun east of Dolores (Figure 4b) in 1907–1914 [24]. Tracks were laid during 1899–1900 from Pagosa Junction to Pagosa Springs and from Edith to southeast of Pagosa Springs (Figure 4a) during 1902–1904 [18]. Logging began quickly, with sawmills at Edith, Chromo, Pagosa Junction, and Dyke, and was done or well underway by the time of the atlases. It is unclear how far from the tracks logging occurred. The government restricted cutting to the immediate vicinity of the right-of-way, but timber companies assumed they could cut any timber reachable by spurs or by horse or oxen [25]. Routes avoided woodlands in several areas (Figure 4a), clearly targeting larger timber, and later railroad logging north of Dolores (1924 to 1948) avoided most woodlands (Figure 4b), corroborating they had little timber to log. In the area north and east of Dolores, timber claims were mapped only among larger timber later railroad logged, not within woodlands. Claims scattered within woodland areas near Pagosa Springs were mostly homestead claims, with few timber claims. Logging on the Rio Grande side primarily selected Douglas-fir for ties on the South Fork of the Rio Grande [15], likely not reducing timber volume to low levels. Thus, this second half of woodlands was likely mostly from moderate-severity fires, occasionally from environmental limitations, but seldom from logging.

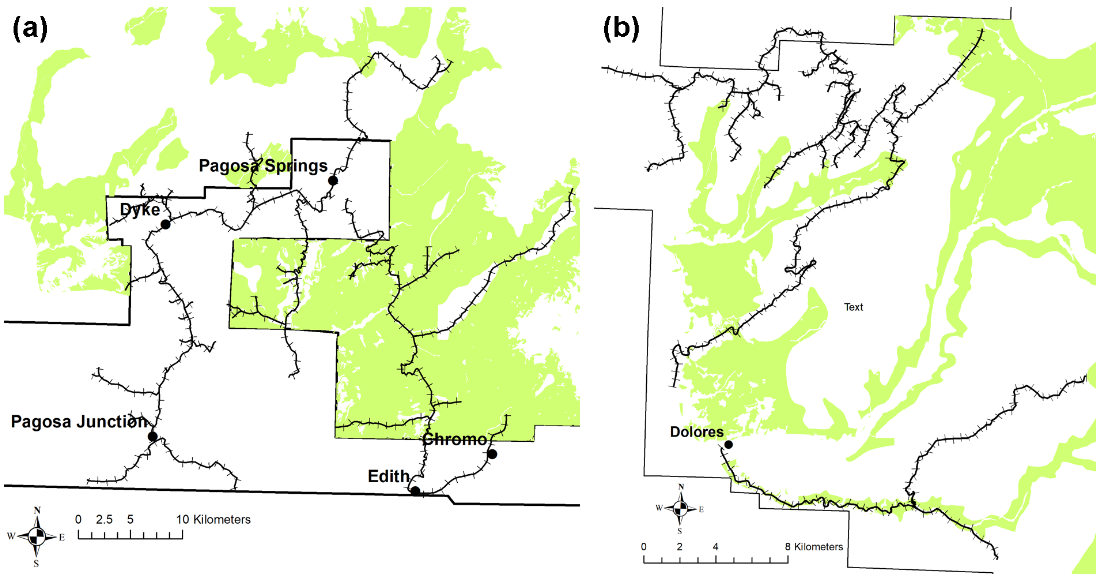

Figure 4. Logging railroads through ponderosa pine and mixed-conifer landscapes in: (**a**) the area near and south of Pagosa Springs; and (**b**) the area north and east of Dolores. Woodlands are shown in green. Railroad locations were digitized from maps in Ormes [24] and Chappell [25], and from online U.S. Geological Survey topographic maps that may show old railroad grades.

Using the georectified forest-atlas mosaics as the backdrop, I zoomed in on screen and hand digitized the boundaries of each atlas fire or woodland polygon, following dots used to demarcate feature boundaries (Figure 2a). Fires are identified in map legends by vertical cross-hatched lines (Figure 2b) and woodlands by light green shading (Figure 2a). The resulting digitized fires and woodlands are available (Data S1). The georectified forest-atlas mosaics are also available (Data S2).

In analyzing the forest-atlas data, I restricted analysis of fires and woodlands to the area of ponderosa and mixed-conifer forests, inside the six watersheds in the San Juan Mountains, that was also within area covered by the atlases (Figure 1b). On the San Juan side, the full area of ponderosa pine and mixed-conifer forests was 539,247 ha, but the atlases covered 421,898 ha (78%). On the Rio Grande side, the full area of ponderosa pine and mixed-conifer forests was 185,429 ha, but the atlas covered 140,695 ha (76%). Total atlas area in the ponderosa and mixed-conifer zones was 562,593 ha (78%) of the 724,593 ha in the full area of ponderosa and mixed conifer (Table 1, Columns 1–4). I used ArcGIS to analyze atlas areas and atlas fires and woodlands (Figure 1b) within the ponderosa pine, dry mixed-conifer, and moist mixed-conifer zones (Figure 1a) of the study area.

I used tree-ring studies and early records to corroborate atlas fires and the extent to which woodlands represented fires and particular fire years. The 1700–1909 period, most likely the later part of it, likely includes the historical period in which I hypothesized that atlas fires and woodlands were most likely to successfully detect fires, since evidence of fire disappears over time. A key question is: to what extent and how far back were dated or recorded moderate- to high-severity fires in this period actually recorded as fires or woodlands in the atlases? I analyzed this by counting fires, known from tree-ring studies and early records (Table S1), that were correctly or incorrectly detected by atlas fires or woodlands. Since atlases are at 1:63,360 scale, and have substantial locational error, larger fires were likely mapped best, locations may have been displaced, and there were likely some omissions. To address fire size, I categorized each fire at tree-ring sites by its size. It is also likely the most recent (first) moderate- to high-severity fires would be mapped best, because evidence would be most visible and freshest, and little of it had been burned over by subsequent fires. To address this, I numbered fires at each site in inverse order by year, and calculated the percentage of fires, by severity if available, correctly identified. Seven tree-ring studies analyzed age structure [10,26–31], which can be used to reconstruct fire severity [10], and three others dated stand-origins to identify high-severity fires [2,3,22]. I used these ten studies to identify years and locations of historical moderate- to high-severity fires. I mapped study sites to enable overlays.

Since atlas fires and woodlands were generally corroborated (see results), I analyzed attributes of the resulting sets of atlas fires and woodlands, in the area of ponderosa pine and mixed-conifer zones, inside atlas areas. I first calculated total area of fire burned at high severity, based on the report of Dubois [16], that about half the area of woodlands represented severe, high-severity fires and evidence that atlas fires represented mostly stand-replacing fires, also high-severity fires. I then assumed that all atlas woodland area plus all fire area equals area burned at moderate- to high-severity combined. I calculated fire rotations as 60 years/fraction of the total area burned within the ponderosa pine and mixed-conifer area and by forest zone. Use of 60 years is explained in Section 3.1. I graphed a size distribution for severe parts of better-dated fires. The evidence and these methods allow only an approximation. Dubois' estimate is based on detailed field examinations, but is only a rough summary. Results may overestimate by including some areas that were woodlands because of environmental limitations, not fires. However, results may underestimate by omitting smaller fires (see results), and some area mapped as fires and woodlands may have burned more than once.

To provide some independent corroboration for the approximations, I separately estimated fire rotations for both high- and moderate- to high-severity fires at 19 smaller tree-ring sampling sites where moderate- to high-severity fires were reconstructed as present or absent from 1700–1909. I used only smaller sites, excluding Tepley and Veblen's sites [10] where fires were mapped, and the Romme et al. [2] and Aoki [3] sites, because the purpose was to use presence/absence at points, not areas, and only from scar-based tree-ring reconstructions, not stand-origin dating, to independently estimate fire rotations. Since a landscape sample of points estimates the population mean fire interval (PMFI), and PMFI is equivalent to the fire rotation [9], this provides an independent, potentially corroborating estimate, although these point estimates are not a probabilistic sample.

2.3. Low-Severity Fire Rotations and Fire Years from Tree-Ring Studies

Nine fire-scar studies provided data about fire frequency, particularly for low-severity fires, in these forests [10,26–33]. Data are only available for the southern and western part of the San Juan Mountains, except one site at Hot Creek on the eastern slope of the San Juan Mountains (Figure 5a). I used regression equations in Baker [4] to estimate fire rotation from reported mean/median CFI estimates in the nine studies (Table 2). These are simple linear regression equations without an intercept, that can be applied to reported CFI estimates by multiplying the CFI estimate by the regression coefficient, given in [4] (Table 2). Equations are preliminary for nine moist mixed-conifer sites, which were not in the calibration, but these likely are still reasonable estimates. I extracted data on mean or median CFI for all fires, for $\geq$10% scarred, and for $\geq$25% scarred, which represent increasing fire sizes, from all the sites used in each fire-history study, placed these in a spreadsheet and did the multiplication in Minitab. Reported CFIs are for all fire severities combined, not just for low-severity fires, which would have longer rotations if moderate- to high-severity fires were excluded [4]. I converted fire rotations to annual probabilities, then subtracted moderate- to high-severity fire rotations from all-severity fire rotations to derive low-severity fire rotations [4]. Input data are in Table 2. I placed study sites in the three forest zones using author determinations. I mapped approximate locations of each study site in ArcGIS, using author descriptions and maps. These data are available in a digital shapefile (Data S3).

Fire rotation data were not normally distributed. I completed a Kruskal–Wallis nonparametric test of the null hypothesis that median low-severity fire rotations differed among the three forest zones, at $\alpha = 0.05$. In Minitab, I produced summary statistics (e.g., median) across all 33 study sites and separately within each of the three forest types, then a scatterplot to help understand potential influences of elevation, aspect, and forest zone on fire rotations. This led to regression analysis to determine whether elevation, aspect, or forest zone could predict rotations.

Table 2. Fire-history data for composite fire intervals (CFIs) and their corresponding estimated fire rotation (FR) in ponderosa pine (Ponderosa), dry mixed-conifer (Dry MC), and moist mixed-conifer (Moist MC) zones.

Author(s)	Site	Forest Zone	Best Source	Value	Regr. Coeff.	All-Severity FR (yrs) [a]	Low-Severity FR (yrs) [b]
Bigio et al. [31]	Haflin Creek North	Dry MC	CFI-All	30.0	2.440	73.2	147.8
Bigio et al. [31]	Haflin Creek South	Ponderosa	CFI-25%	26.0	1.715	44.6	58.8
Bigio et al. [31]	Marina East	Dry MC	CFI-25%	29.0	1.715	49.7	75.6
Bigio et al. [31]	Marina West	Dry MC	CFI-25%	19.0	1.715	32.6	42.1
Bigio et al. [31]	Steven's Creek North	Dry MC	CFI-All	46.0	2.440	112.2	496.0
Bigio et al. [31]	Steven's Creek South	Ponderosa	CFI-25%	24.0	1.715	41.2	53.0
Brown et al. [32]	Hot Creek	Ponderosa	CFI-All	9.5 [c]	2.450	23.3	24.1
Brown and Wu [27]	Archuleta Mesa	Ponderosa	CFI-All	14.1	2.440	34.4	42.3
Fule et al. [28]; Korb et al. [29]	Lower Middle Mountain	Dry MC	CFI-25%	32.3	1.715	55.4	89.7
Grissino-Mayer et al. [33]	Benson Creek	Ponderosa	CFI-All	8.0	2.440	19.5	21.8
Grissino-Mayer et al. [33]	Burnette Canyon	Dry MC	CFI-All	30.0	2.440	73.2	147.8
Grissino-Mayer et al. [33]	Five Pine Canyon	Ponderosa	CFI-All	7.0	2.440	17.1	18.8
Grissino-Mayer et al. [33]	Hermosa Creek	Dry MC	CFI-All	11.0	2.440	26.8	32.9
Grissino-Mayer et al. [33]	Monument	Dry MC	CFI-All	21.0	2.440	51.2	79.1
Grissino-Mayer et al. [33]	Plateau Creek	Ponderosa	CFI-All	6.0	2.440	14.6	15.9
Grissino-Mayer et al. [33]	Smoothing Iron	Ponderosa	CFI-All	13.0	2.440	31.7	38.3
Grissino-Mayer et al. [33]	Taylor Creek	Dry MC	CFI-All	19.0	2.440	46.4	68.2
Grissino-Mayer et al. [33]	Turkey Springs	Ponderosa	CFI-All	11.0	2.440	26.8	31.3
Korb et al. [29]	Grassy Mountain	Dry MC	CFI-25%	10.0	1.715	17.2	19.5
Tepley and Veblen [10]	Aspen	Moist MC	CFI-All [d]	18.0	2.440	43.9	63.2
Tepley and Veblen [10]	Dry MC	Dry MC	CFI-All [d]	20.8	2.440	50.8	78.2
Tepley and Veblen [10]	Moist mixed conifer	Moist MC	CFI-All [d]	32.3	2.440	78.8	174.0
Wu [26]	Bear Park 1	Dry MC	CFI-25%	14.7	1.715	25.2	30.5
Wu [26]	Bear Park 2	Moist MC	CFI-25%	17.7	1.715	30.4	38.5
Wu [26]	Bear Park 3	Moist MC	CFI-25%	21.7	1.715	37.2	50.2
Wu [26]	Corral Mountain 1	Moist MC	CFI-25%	41.5	1.715	71.2	140.8
Wu [26]	Corral Mountain 2	Dry MC	CFI-25%	41.5	1.715	71.2	139.9
Wu [26]	Corral Mountain 3	Moist MC	CFI-25%	36.9	1.715	63.3	113.0
Wu [26]	Corral Mountain 4	Moist MC	CFI-25%	41.5	1.715	71.2	140.8
Wu [26]	Jackson Mountain 1, 2	Moist MC	CFI-25%	62.7	1.715	107.5	424.1
Wu [26]	Jackson Mountain 3	Moist MC	CFI-25%	20.9	1.715	35.8	47.6
Wu [26]; Korb et al. [29]	Jackson Mountain 4	Dry MC	CFI-25%	29.8	1.715	51.1	78.9
Wu [26]; Korb et al. [29]	Jackson Mountain 5	Dry MC	CFI-25%	23.5	1.715	40.3	55.8

[a] All-severity fire rotations are derived by multiplying the regression coefficient ([4] (Table 2)) times the "Value" which is the CFI estimate from the "Best source". The best source is the source that produces the best regression equation, based on R^2_{adj} in Baker [4] (Table 2). [b] The low-severity fire rotation is estimated by partitioning the moderate- to high-severity fire rotations out of the all-severity fire rotations (see text for details). [c] The only estimate reported was median CFI-All, which is used here. [d] This study assigned fire scars within up to 300 m to transects. Since a radius of 300 m corresponds with 9 ha, this substantially overcompensates for the number of trees estimated to be needed to detect a fire if one occurred [4], and this produces then what is effectively an all-tree composite fire interval at the transect scale. The study also targeted trees with open catfaces and used recorders, as traditionally used in composite-fire-interval studies. However, since this study used ancillary information from the transect area itself, including scars found on increment cores (<1/3 of scars) and tree-regeneration pulses likely linked to fires, it is likely that the fire information is not overcompensated in cases where evidence is primarily from the transect area itself. Thus, it may be appropriate to view the fire rotation estimates as upper estimates, with the true values lower by a variable and unknown amount.

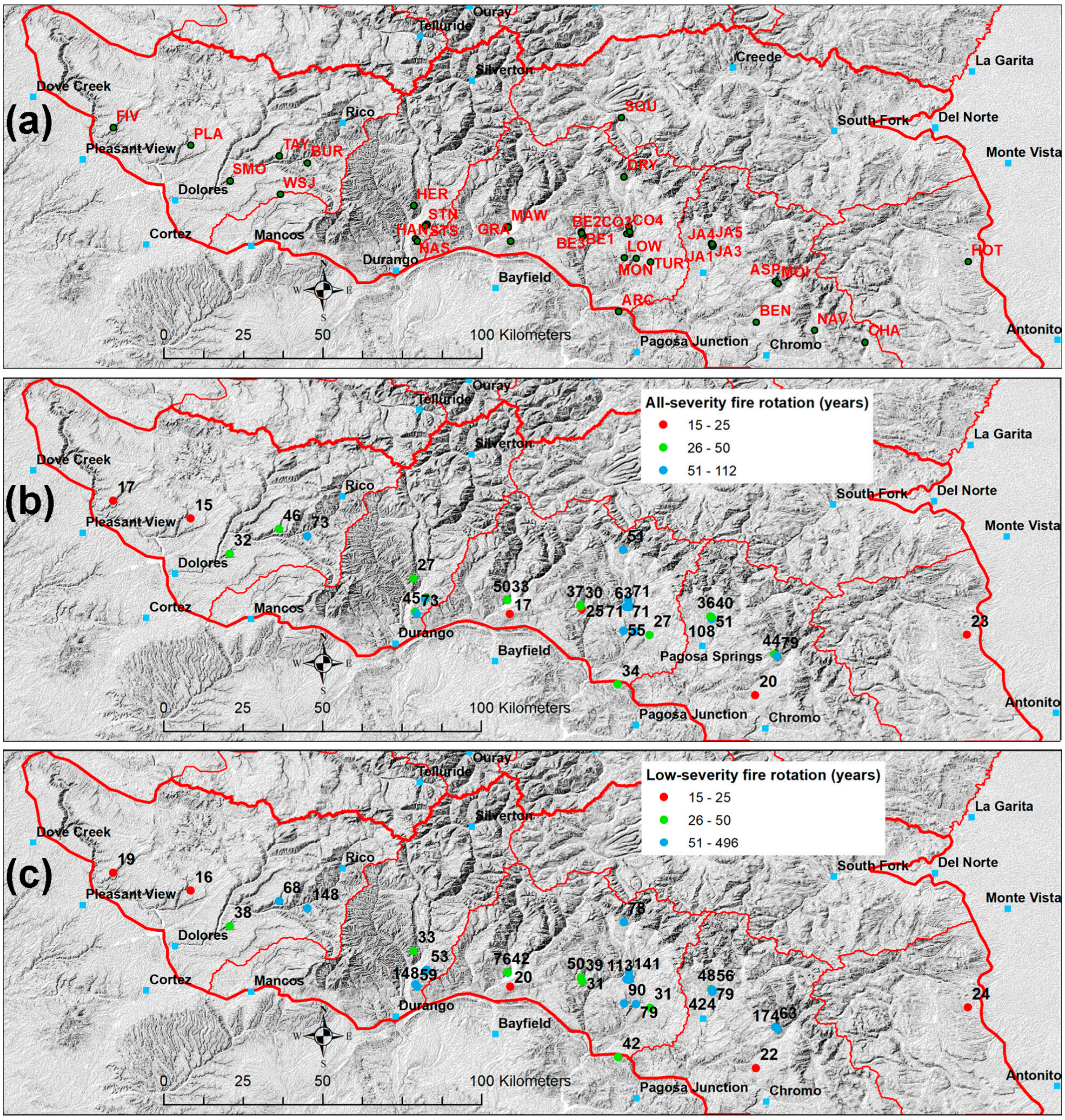

Figure 5. The 33 study sites listed in Table 2 and the three stand-origin sites (WSJ = western San Juans [2]; SQU = Squaw Creek [22]; CHA = Chama [22]): (**a**) site names are generally abbreviated by their first two or three letters; (**b**) the estimated historical all-severity fire rotation (years) at each site; and (**c**) the estimated historical low-severity fire rotation (years) at each site. The red lines are boundaries for the six watersheds, which are from left to right the Dolores, Animas and Mancos, Piedra and Florida, San Juan and Navajo, and Alamosa-La Jara-Conejos Rivers. The Rio Grande watershed is at the right and above these others.

2.4. Fire Information from Forest-Reserve Reports, the Michelsen Report and Other Early Sources

The Forest-Reserve reports [15,16] provided descriptions of the forests, including their understories, and descriptions of fires and woodlands. I used these to cross-check and corroborate other sources. Henry Michelsen of the Colorado Forestry Association published an account of fires in 1900, which he reported burned >200,000 ha in Colorado, including estimates of area burned by county and a map showing general areas burned [17]. I specifically sought early newspaper accounts of the 1900 fires by searching the Colorado Historic Newspapers Collection [34], which allows multiple papers to be searched, using publication-date ranges and other constraints. I searched other early historical records, including forest histories, for any information about historical fires.

3. Results

3.1. Moderate- to High-Severity Fires from Tree-Rings, Early Records, and Forest Atlases

Nine tree-ring studies found 28 years with moderate- to high-severity fires during 1700–1909 (Table 3). Reconstructing fire size was not a goal and most sites were small: nine <500 ha, four 1100–1600 ha, and two 7000–8000 ha [2,3]. Maps of fire years were reconstructed at two 1330–1340 ha sites [10]. These studies show that severe fires occurred, but not their spatial extent.

Table 3. Moderate- to high-severity fires during 1700–1909 identified by tree-ring studies that reconstructed historical fire severity. There were fires before 1700, but this period is most relevant to whether atlas fires and woodlands detect these fires in historical forests.

Fire-History Evidence						Atlas Evidence		
Fire Year	**Fire No.** [1]	**Site**	**Author(s)**	**Fire Severity**	**Fire Size** [2]	**Fires**	**Wood-Lands**	**C/I** [3]
Sites with age-structure or stand-origin evidence of moderate- to high-severity fires								
1902	1	WIL	Tepley and Veblen [10]	Moderate [4]	M	No	No	I
1899	1	SQU	Tepley and Veblen [10]	High	M	No	Yes	C
				Moderate	L	Yes	Yes	C
1896/1891	2	WIL	Tepley and Veblen [10]	High	S	No	No	I
				Moderate	M	No	No	I
1880–1860	1	WSW	Romme et al. [2] [5]	High	L	No	Yes	C
1879	1	WES [6]	Aoki [3] (p. 16, 19, 21) [6]	High	L	No	Yes	C
1879	1	MAR2	Bigio [30]; Bigio et al. [31]	High, mixed	M	No	No	I
1879	3	WIL	Tepley and Veblen [10]	High	M	No	Yes	C
				Moderate	L	No	Yes	C
1879/1878	2	SQU	Tepley and Veblen [10]	High	L	Yes	Yes	C
				Moderate	L	Yes	Yes	C
1879	1	BPK1	Wu [26] (p. 101)	High	S	No	No	I
1876	1	SQW	Margolis et al. [22]	High	M	Yes	No	C
1873	1	JAK1	Wu [26] (p. 101)	High	S	No	No	I
1873	1	JAK4	Wu [26] (p. 101)	High	S	No	No	I
1870	1	SC4	Bigio [30]; Bigio et al. [31]	High, mixed	S	No	No	I
1861	1	All	Brown and Wu [27]	Moderate [7]	M	No	Yes	C
1861	1	All	Fulé et al. [28]	Moderate [8]	M	No	No	I
1861	4	WIL	Tepley and Veblen [10]	High	M	No	Yes	C
				Moderate	M	No	Yes	C
1861/1860	3	SQU	Tepley and Veblen [10]	High	M	Yes	Yes	C
				Moderate	M	Yes	Yes	C
1851	2	MAR2	Bigio [30]; Bigio et al. [31]	High, mixed	M	No	No	I
1851	1	CHA	Margolis et al. [22]	High [9]	L	No	Yes [9]	C
1851	5	WIL	Tepley and Veblen [10]	Moderate	S	No	No	I
1851	1	CRL1	Wu [26] (p. 132)	High	M	No	No	I
1851	1	CRL2	Wu [26] (p. 101)	High	M	No	Yes	C
1847	4	SQU	Tepley and Veblen [10]	High	S	Yes	Yes	C
				Moderate	M	Yes	Yes	C
1838	1	HC3	Bigio [30]; Bigio et al. [31]	Low, mixed	M	No	No	I
1836	6	WIL	Tepley and Veblen [10]	High	M	No	No	I
				Moderate	L	No	Yes	C
1834	5	SQU	Tepley and Veblen [10]	Moderate	S	No	Yes	C
1824	2	All	Fulé et al. [28]	Moderate [8]	M	No	No	I

Table 3. *Cont.*

Fire-History Evidence						Atlas Evidence		
Fire Year	**Fire No.** [1]	**Site**	**Author(s)**	**Fire Severity**	**Fire Size** [2]	**Fires**	**Wood-Lands**	**C/I** [3]
1822/1820	7	WIL	Tepley and Veblen [10]	Moderate	L	No	No	I
1819	6	SQU	Tepley and Veblen [10]	High	S	No	Yes	C
				Moderate	L	Yes	Yes	C
1818	2	All	Brown and Wu [27]	Moderate [7]	M	No	Yes	I
1818	1	HC4–6	Bigio [30]; Bigio et al. [31]	High, mixed	M	No	No	I
1806/1797	8	WIL	Tepley and Veblen [10]	Moderate	M	No	Yes	C
1806	7	SQU	Tepley and Veblen [10]	Moderate	S	Yes	Yes	C
1795	1	JAK3	Wu [26] (pp. 100, 134)	High	M	No	No	I
1786	2	JAK3	Wu [26] (pp. 100, 134)	High	M	No	No	I
1786	9	WIL	Tepley and Veblen [10]	High	L	No	No	I
				Moderate	M	Yes	Yes	C
1786	8	SQU	Tepley and Veblen [10]	High	M	Yes	Yes	C
				Moderate	L	Yes	Yes	C
1778	1	SC2	Bigio [30]; Bigio et al. [31]	Mixed	S	No	No	I
1778	2	SC5–6	Bigio [30]; Bigio et al. [31]	Low, mixed	S	No	No	I
1774	9	SQU	Tepley and Veblen [10]	Moderate	S	No	Yes	C
1773	10	WIL	Tepley and Veblen [10]	Moderate	M	No	No	I
1748	11	WIL	Tepley and Veblen [10]	High	M	No	Yes	C
				Moderate	M	No	Yes	C
1748	1	BPK2	Wu [26] (pp. 100, 132)	High	M	No	No	I
1748	2	CRL1	Wu [26] (pp. 100, 132)	High	M	No	No	I
1748	1	JAK2	Wu [26] (pp. 100, 132)	High	M	No	No	I
1748	1	JAK5	Wu [26] (pp. 100, 132)	High	M	No	No	I
1724	12	WIL	Tepley and Veblen [10]	Moderate	M	No	Yes	C
1707	13	WIL	Tepley and Veblen [10]	Moderate	S	No	No	I
Sites with age-structure evidence of no high-severity fires in the 1800s, only low- to moderate-severity fires								
-		HC1–2	Bigio [30]; Bigio et al. [31]	Low-4 [10]	S	No	No	C
-		MAR1	Bigio [30]; Bigio et al. [31]	Low-5 [10]	S	No	No	C
-		SC1,3	Bigio [30]; Bigio et al. [31]	Low-4 [10]	S	No	No	C
-		GRA	Korb et al. [29]	Low-11 [10]	S	No	No	C

[1] Fire No. is the sequential number of the fires within a single site, starting with the latest and going backwards in time. [2] Fire size is abbreviated as follows: S = small, means a different age class or the sampling area boundary was found within <500 m of most of the patch area; M = medium, means within 500–2000 m; L = large, means within >2000 m. [3] Whether the forest-atlas evidence from fires or woodlands correctly (C) or incorrectly (I) identified the occurrence of the fire, accepting that fire-atlas evidence could be spatially displaced by 500–1000 m at times. [4] The Tepley and Veblen [10] study did not provide a direct equivalence between their percentile ranges for fire severity and traditional fire-severity categories. I chose to consider their ">90th percentile" category as high severity and their "50th to 90th percentile" categories as moderate severity. This is an arbitrary, but likely conservative, criterion. [5] Romme et al. dated stand origins successfully at 57 sites across several townships and found 16 of them originated in the 1860s and 1870s. [6] Aoki [3] had sites on the west (WES) side of the Navajo River, at Beaver Creek, Elephant Head, and Dolomite Lake, that are overlapped by the San Juan Forest Atlas. The five sites on the east side of the Navajo River are not covered in an atlas. [7] The 1818 and 1861 fires documented in this study were not linked by the authors to the pulses of tree regeneration evident in the age structure [27] (Figure 2); this is my interpretation. Since the largest pulse, including "other trees" was after 1861, I interpret that this large pulse is likely the only structure detected by woodlands at this site. [8] The 1824 and 1861 fires documented in this study were not linked by the authors to the post-fire pulses of tree regeneration evident in the age structures [28] (Figure 5); this is my interpretation. [9] For the Chama site, Margolis does not show the location, which I estimated based on elevation and location near the Chama River. The Atlas does not extend to this site, but a large patch of woodland appears to have extended to the site. Since Aoki [3] detected an 1851 fire to the west of this site, the 1851 fire was likely large in this area. [10] This is the number of low-severity fires in the 1800s.

Atlas fires and woodlands detected fires found at these tree-ring sites (Table 3), but only back to about 1850. I found that, among first fires, some were correctly detected by fires or woodlands back to 1851, but none was correctly detected prior to 1851. Of first fires during 1851–1909, four of four large fires (100%) were correctly detected, but only four of eight medium fires (50%) were correctly detected, and none of four small fires (0%) was correctly detected. Among first and second fires, the trends were similar: none was correctly detected prior to 1851, and only the largest fires were all correctly detected after 1851. Sites that had only low-severity fires in the 1800s were all correctly detected (Table 3). Atlas fires and woodlands may thus generally detect large fires over the period since about 1850 or over about 60 years prior to the atlases, but about half the medium and most small fires were likely not mapped, thus total burned area would be underestimated somewhat and fire-size distributions would underestimate smaller fires. Atlas fires and woodlands can be seen in shapefiles (Data S1).

It was possible to identify 24 moderate- to high-severity fires in atlas fires and woodlands, and the years they burned, between about 1850 and 1909, or at least narrow the range of possible years (Table S1, Figure 1b, and Table 4). Larger fires often had parts that burned in separate fire years or dating could only be narrowed to a set of possible years. The 24 fires covered 86% of total area of atlas woodlands and fires within the ponderosa and mixed-conifer zones. The remaining 14% was undocumented in early reports, tree-ring dates or other sources I found. Entries for reported fires (Table S1) corresponded with atlas woodlands and fires in 41 of 57 cases (72%); the other 28% were either small or medium-sized fires the atlases do not detect well (Table 3) or were vague or likely incorrect. Most reported moderate- to high-severity fires during 1850–1909 were recorded in atlas fires and woodlands (Table S1). More recent fires were better corroborated. The 1900 fires had newspaper accounts and a report [17]. Two large fires, fire 1 on the Dolores River, and fire 22 south of Pagosa Springs (Table 4), need more dating or records. Two atlas fires, in 1876 and 1879, are shown to be reasonably mapped relative to independent sources (Figure 3). Fire locations were usually reported relative to drainages or other physiographic features and mapped locations were quite similar in most cases (details in Table S1). Fire sizes were seldom reported or estimated, but one atlas fire (Fire 4) and two large fires from both atlas fires and woodlands (Fires 6 and 9) had mapped sizes and locations that were quite similar to reported fire sizes and locations. Another from both atlas fires and woodlands (Fire 19) appeared quite similar but a map is missing that completes the fire area. Together, these corroborations support the interpretation that atlas fires were very high severity (stand-replacing) and atlas woodlands were mostly also burned severely.

Accounts of fires in Michelsen [17] and newspapers offered vivid early evidence of severe fires in 1900, as compiled in Table S1. For example, Michelsen reported large 1900 fires on the Rio Grande side, particularly Fire 9: "The length of the path burned over was about forty-five miles" and one (Fire 6) north of Pagosa Springs on the San Juan side in which "some forty square miles (10,364 ha) of Yellow Pine forest were burnt over" [17] (p. 59).

High-severity fire rotations from atlas fires and woodlands overall were 289 years on both sides of the study area, and were mostly in the range of about 225–360 years in all three forest zones on both sides of the study area, except 1145 years in ponderosa pine on the Rio Grande side (Table 1). High-severity fire rotations were generally shortest in moist mixed-conifer forests and longest in ponderosa pine forests. Combined moderate- to high-severity fire rotations were 154 and 158 years overall on the two sides of the study area, mostly 133–185 years in forest zones, except 688 years in ponderosa pine on the Rio Grande (Table 1, Columns 5–11). Note that these are approximations in part because only 60 years of data, a fraction of a full rotation, are available from the atlases.

Fire rotations from tree-ring reconstructions (Table 3) were 235 years for high-severity fire and 166 years for moderate- and high-severity fire from 1700–1909, in the same ballpark as the atlas' 289 year high-severity and 154–158 year moderate- and high-severity fire rotations. Point estimates for 1850–1909 were 114 years for high-severity and 95 years for moderate- to high-severity fire. These unexpectedly short rotations may be because the sample size is small (n = 12 fires) in this period relative to the 1700–1909 period (n = 24 fires). In addition, tree-ring sites are not a probabilistic sample. Corroboration with the longer tree-ring period but not 1850–1909 leaves this comparison uncertain.

Table 4. The 24 moderate- to high-severity historical fires identified between about 1850 and 1909 on the San Juan (SJ) and Rio Grande (RG) National Forests using atlas woodlands (Wood.) and fires, early historical reports, and tree-ring studies (details in Table S1). Fires are ordered by years, and possible years include all the years that may have affected parts of the woodland or fire polygons. MC = mixed conifer. Total area is for ponderosa pine and mixed-conifer forests and associated grasslands and shrublands.

Fire No.	SJ or RG	Where	Poss. Years	Total Area (ha)	Ponderosa		Dry MC		Moist MC		Grasslands		Shrublands	
					Wood (ha)	Fire (ha)	Wood (ha)	Fire (ha)	Wood (ha)	Fire (ha)	Wood (ha)	Fire (ha)	Wood (ha)	Fire (ha)
1	SJ	Dolores River	Unknown 1900, 1878	32,828	4787	0	5070	89	13,023	247	3727	15	5870	0
2	SJ	N of Durango	1900	66	0	0	0	0	0	64	0	0	0	2
3	SJ	N of Durango	1900	211	15	0	21	0	175	0	0	0	0	0
4	SJ	Vallecito River	1900	95	0	0	0	15	0	80	0	0	0	0
5	SJ	Piedra River	1900, 1898 1879, 1861	13,872	6148	311	4127	334	973	406	510	29	1012	22
6	SJ	N of Pagosa Springs	1900, 1898	13,088	1432	4	2665	80	5271	180	1952	10	1481	13
7	SJ	San Juan River	1900	845	99	0	92	0	493	121	40	0	0	0
8	RG	S Fork Rio Grande	1900	1145	91	0	55	41	145	298	116	399	0	0
9	RG	Alamosa-Conejos	1900, 1875, 1873	21,585	159	0	2441	149	12,879	812	5030	89	26	0
10	SJ	NE of Mancos	1898, 1892 1884–1850	18,167	2633	0	3374	0	6907	0	1776	0	3477	0
11	RG	Platoro	1898, 1875	23	0	0	0	0	0	0	0	23	0	0
12	RG	E of Creede	1893	136	0	0	14	0	40	6	76	0	0	0
13	RG	W of Creede	1893	2375	0	0	0	0	1612	0	601	0	162	0
14	RG	S of Creede	1893	2635	0	11	19	5	752	908	598	342	0	0
15	RG	S of Del Norte	1893, 1892	6892	105	17	574	243	3343	583	1908	110	9	0
16	RG	Cat Creek	1887	234	0	0	0	14	0	209	0	11	0	0
17	RG	Wagon Wheel Gap	1900, 1881	4252	21	98	83	234	561	1967	496	772	0	20
18	SJ	Lime Creek	1879	1814	0	323	0	674	0	744	0	1	0	72
19	SJ	Upper Pine River	1879, 1860	1132	0	89	0	209	0	827	0	6	0	1
20	RG	SW of Creede	1879	373	0	0	66	5	4	0	282	16	0	0
21	RG	La Garita Creek	1872	507	0	0	10	0	400	0	97	0	0	0
22	SJ	S of Pagosa Spr.	1899 1879–1878 1861–1860	62,135	18,006	0	8011	16	11,118	441	9783	0	14,759	1
23	RG	Squaw Creek	1876	169	0	0	0	117	0	0	0	52	0	0
24	RG	Chama River	1851	89	0	0	26	0	0	0	63	0	0	0
Total area burned in the 24 atlas fires and woodlands				184,668	33,496	853	26,648	2225	57,696	7893	27,055	1875	26,796	131
Total area burned in all atlas fires and woodlands				213,763	36,072	1326	29,294	3536	64,684	11,676	34,196	2662	30,034	283

Size distributions were limited by the 7 of 24 fires that could not be assigned to a single year (Table 4) and by woodland patches that could be from more than one fire. The moderate-to high-severity parts of the 17 fires appeared to have an inverse-J shaped size distribution, with more small than large areas; two severe fire areas exceeded 13,000 ha (Figure 6). Fire and woodland Patches were larger and had more consistent patterns of orientation on the San Juan than the Rio Grande side (Figure 1b). Most striking were very large woodland patches, along the Dolores River from Dolores to Rico and south and west of Pagosa Springs (Figure 1b). Fires often (Fires 1, 5, and 22), but not always (Fires 6 and 10), had a southwest to northeast orientation on the San Juan side, but fires on the Rio Grande side appeared less consistently oriented.

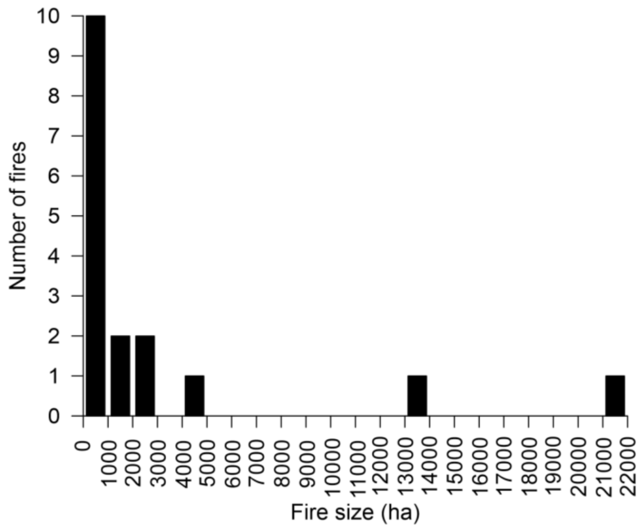

Figure 6. Size distributions for moderate- to high-severity parts of 17 fires dated mostly to a single year.

3.2. *Low-Severity Fire Rotations from Tree-Ring Studies*

The 33 scar-based low-severity study sites were well distributed spatially, although unevenly, across the five large watersheds that cover the southern San Juan Mountains (Figure 5) and the three forest zones. There were 9 sites in ponderosa, 15 in dry mixed-conifer, and 9 in moist mixed-conifer forests (Tables 2 and 5), also a little uneven. Overall, across the 33 sites, the mean historical all-severity fire rotation in ponderosa pine and mixed-conifer forests was about 48 years, with a median of 44 years (Table 5). The distribution of fire rotations was skewed toward values less than the mean, so the median of 44 years is a better measure of central tendency. The mean historical low-severity fire rotation overall was almost twice as long, at 93.3 years, likely because of two exceptionally long estimates of 424.1 and 496.0 years. The median historical low-severity fire rotation of 58.8 years is again a better measure of central tendency. I focus here on low-severity fire rotations, rather than reviewing the all-severity data.

The southern San Juan Mountains had a surprisingly large overall range of historical low-severity fire rotations, from 16 to 174 years, except two longer rotations (Table 5). Four watersheds each had close to this full range (Figure 5c), suggesting a tendency toward similar variability across the mountain range. Based on quartiles, 1/4 of sites had low-severity fire rotations shorter than about 36 years and 1/4 longer than about 126 years (Table 5). Median low-severity fire rotations also differed significantly among forest zones (Kruskal–Wallis H = 11.13, $p = 0.004$). Among the nine ponderosa-pine sites, the historical median low-severity fire rotation was 31 years (Table 5). Variability was lower than in the other two forest zones, ranging only from about 16–59 years for low-severity fire rotations (Table 5). Based on quartiles, 1/4 of rotations were shorter than about 20 years and 1/4 were longer than about 48 years. Among the 15 dry mixed-conifer sites, the historical median low-severity fire rotation was 78 years (Table 5). Variability was highest among the three forest zones, ranging from about 20–496 for low-severity fire rotations (Table 5). Based on quartiles, 1/4 of rotations were shorter than 42 years and 1/4 longer than 140 years. Among the nine moist mixed-conifer sites, the historical median low-severity fire rotation was 113 years (Table 5). Variability was intermediate, with low-severity fire rotations ranging from about 39–424 years (Table 5). Based on quartiles, 1/4 of rotations were shorter than about 49 years and 1/4 longer than about 157 years (Table 5).

Table 5. Statistics of the distributions of historical all-severity and low-severity fire rotations overall and for the three forest zones. Table entries are all in years, except *n*, which is a count.

Type of Fire Rotation/Statistic	Overall	Ponderosa Pine	Dry Mixed Conifer	Moist Mixed Conifer [1]
All-Severity Fire Rotations				
n	33	9	15	9
Mean	47.5	28.1	51.8	59.9
Standard deviation	24.4	10.6	23.9	25.3
Minimum	14.6	14.6	17.2	30.4
1st quartile	28.6	18.3	32.6	36.5
Median	43.9	26.8	50.7	63.3
3rd quartile	67.2	37.8	71.2	75.0
Maximum	112.2	44.6	112.2	107.5
95% confidence interval for mean	38.9–56.2	20.0–36.3	38.5–65.0	40.5–79.4
95% confidence interval for median	33.5–51.2	17.6–39.6	35.5–65.3	36.2–77.1
Low-Severity Fire Rotations				
n	33	9	15	9
Mean	93.3	33.8	105.5	132.5
Standard deviation	104.8	15.3	115.5	119.8
Minimum	15.9	15.9	19.5	38.5
1st quartile	35.6	20.3	42.1	48.9
Median	58.8	31.3	78.2	113.0
3rd quartile	126.4	47.7	139.9	157.4
Maximum	496.0	58.8	496.0	424.1
95% confidence interval for mean	56.1–130.4	22.0–45.6	41.5–169.4	40.4–224.6
95% confidence interval for median	42.2–79.0	19.5–50.6	47.2–121.1	48.2–166.5

[1] Equations and results are preliminary, as these forests were not in the regression calibration.

There were modest, significant trends for fire rotations to increase exponentially from lowest to highest elevations (Figure 7). Two sites ([26] (Jackson Mt. 1, 2); [31] (Steven's Creek N)), outliers with exceptionally long rotations, were omitted from regressions. Data on aspect were available for only 30 of 33 sites and were reported at times in general terms (e.g., southerly-facing), so analysis is rough. Aspect improved regressions very little. Zone improved low-severity equations (R^2_{adj} = 0.438) over equations in Figure 7b (R^2_{adj} = 0.350) for all three forest zones: historical ponderosa pine rotations = $e^{-2.040+0.002192*\text{elevation}}$, dry mixed-conifer rotations = $e^{-1.47+0.002192*\text{elevation}}$ and moist mixed-conifer rotations = $e^{-1.46+0.002192*\text{elevation}}$.

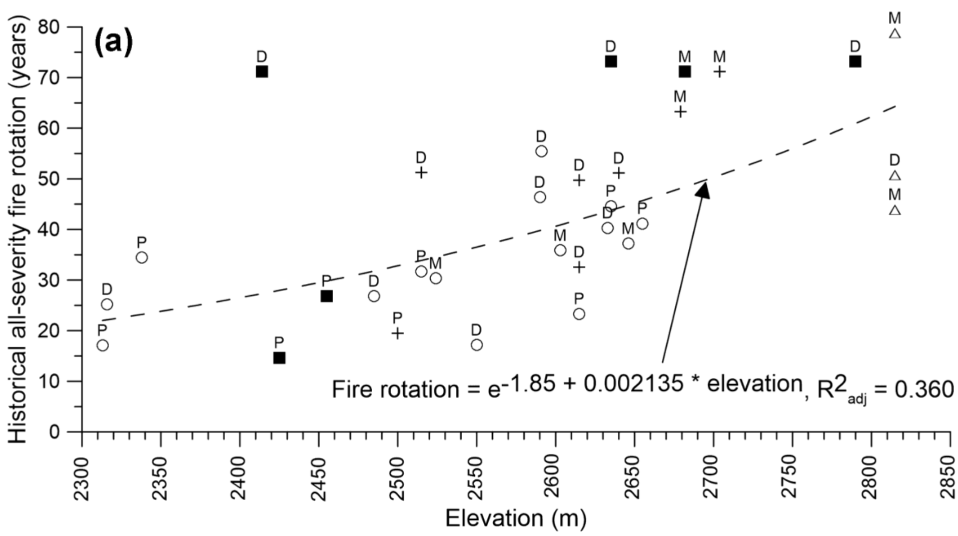

Figure 7. *Cont.*

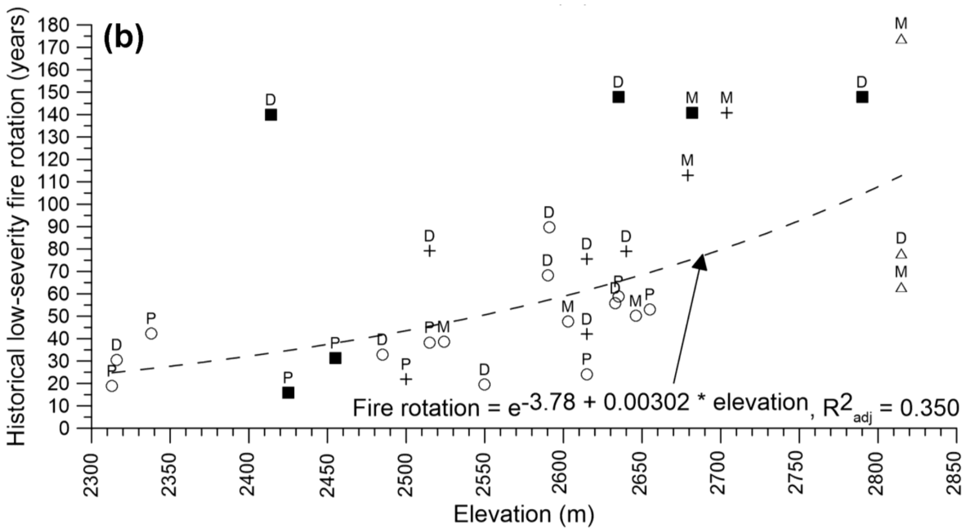

Figure 7. Historical fire rotations versus elevation, aspect, and forest zone, and the equation for estimating fire rotations from elevation: (**a**) historical all-severity fire rotations; and (**b**) historical low-severity fire rotations. For aspect, open circles = southerly-facing sites; dark squares = northerly-facing sites; pluses = easterly- and westerly-facing sites; and triangles = unknown aspects. For forest zones, P = ponderosa pine; D = dry mixed conifer; and M = moist mixed conifer. Moist mixed-conifer forest estimates are preliminary.

4. Discussion

4.1. Low-Severity Fire Rotations and Population Mean Fire Intervals from Tree-Ring Data

Ponderosa pine and mixed-conifer forests in the southern San Juan Mountains historically were not generally frequent-fire forests with historical fire rotations <25 years [4]. Only 5 of 33 sites (about 15%), four in ponderosa pine and one in dry mixed-conifer forests, had historical low-severity fire rotations <25 years (Table 2). This is similar to the overall pattern in the western USA, where only about 14% of 342 sites, mostly in the southwest, had frequent fire with historical fire rotations <25 years [4]. Frequent-fire forests were concentrated in Arizona and New Mexico, which had 96% and 56% frequent-fire forests, respectively [4]. Understory fuels typically recover after low-severity fires to pre-fire levels within about 7–25 years, thus would have been kept generally at or below fully recovered levels in frequent-fire forests [4]. In contrast, 28 of 33 or about 85% of historical low-severity fire rotations in montane forests in the southern San Juan Mountains were multi-decadal. In ponderosa pine forests with 31-year median historical low-severity fire rotations, understory shrubby fuels would often have been fully recovered historically between fires. In mixed-conifer forests with 78–113 year median historical low-severity fire rotations (Table 5), understory fuels would have nearly always been fully recovered for almost a century before the next fire. Trees would have been able to regenerate and reach sufficient size to resist mortality in the next fire, enabling the diverse tree composition found historically in mature mixed-conifer forests [10]. The predominant understory shrub, Gambel oak (*Quercus gambelii*), would have commonly been able to resprout after fire [9], and remain at maturity for many decades before the next fire. Most other common shrubs in these forests also resprout [9], so that dense shrubby understories were historically probable. However, Gambel oak is also vulnerable to frost [35].

Early scientific observations corroborate that historical fire rotations, and perhaps long periods without heavy frost, allowed dense shrubby understories to predominate in these forests, but with variable tree regeneration. Dubois [15], in the San Juan Forest-Reserve Report, described regeneration in ponderosa pine and dry mixed conifer: “Reproduction of bull pine is poor. In many places groups of seedlings are coming in, but in the large blanks made by cutting, restocking is slow” (p. 7). Bull pine is younger ponderosa pine. Dubois also said: "The underbrush is very heavy, chiefly oak brush, choke-cherry, scarlet thorn, and wild rose" [15] (p. 7). The Montezuma Forest-Reserve Report [16] also described tree regeneration: "In the virgin forest and in the poor open stand on thin soil there is practically no reproduction" [16] (p. 9), and a dense shrubby understory: "The underbrush of oak, service berry, wild rose, thornbush, and buffalo berry is very heavy".

The southern San Juan Mountains had a high diversity of historical low-severity fire rotations in montane forests over short distances (Figure 5c) and, partly related to forest zone and topography. Shorter fire rotations predominated in ponderosa pine forests at lower elevations and on southerly-facing aspects, while longer rotations predominated in mixed-conifer forests at higher elevations and on northerly-facing aspects (Figures 5c and 7b). Other unstudied factors, including topographic position (e.g., canyon vs. ridge) could also help explain variability.

These low-severity fire-rotation estimates have some limitations. First, they are from CFIs, which have error from using small plots, and error is associated with equations used to estimate fire rotations [4]. Second, CFI studies were not probabilistic samples of landscapes; old forests were typically targeted, since the goal was to obtain long fire records [4]. Younger forests predominant today likely burned at longer fire rotations than the estimates reported here [4]. Of course, tree-ring records cannot distinguish ignition sources, but ignitions by Indians were likely relative low [36].

4.2. Moderate to High-Severity Fires from Forest Atlases and Other Sources

Mapped atlas fires and woodlands were shown to be generally reliable in reconstructing larger severe fires across this study area. Here, 24 moderate- to high-severity fires, which covered 86% of total atlas fire and woodland area, were corroborated by multiple sources (Table 4, Table S1, and Figure 3). Corroboration for landscape-scale fire history will always be incomplete, as corroborating sources are imprecise and typically cover only parts of large fires. Tree-ring dating could be used to fill in some missing information and resolve some ambiguity in fire dates, but the land area is too large to cover very fully. Atlases provide an imperfect, but unique and important source of information, particularly when corroborated as well as possible with multiple other sources.

Estimated historical high-severity fire rotations were mostly 225–250 years in moist mixed-conifer, 265 years in dry mixed-conifer, and >350 years in ponderosa pine forests (Table 1). Ponderosa pine and dry mixed-conifer estimates, if pooled, would be roughly congruent with pooled estimates of 271 years in the Colorado Front Range [37] and 281–354 years in the western Sierra [38], but longer than the 217-year rotation on Black Mesa, northern Arizona [37], and the 175-year rotation on the Uncompahgre Plateau, which is just north of the San Juan Mountains [39].

The atlases document that about 19,000 ha of ponderosa pine forest burned at high severity in the 1850–1909 period in the San Juan National Forest, which led to the high-severity fire rotation estimate of 358 years (Table 1). About 1/3 of ponderosa-pine forest area in the San Juan National Forest had evidence of either moderate- or high-severity fire in the 1850–1909 period, a rotation of about 185 years. High-severity fires also burned historically in dry mixed-conifer forests, where ponderosa pine was dominant; about 18,000 ha of high-severity fire was documented by the atlases during 1850–1909 (Table 1). Evidence of high-severity fire has been found in nearly all other ponderosa pine and dry mixed-conifer landscapes where probabilistic landscape-level historical evidence has been studied [6,40,41]. Large high-severity fires in ponderosa pine and dry mixed-conifer forests had not been documented by tree-ring studies in the San Juan Mountains, likely because tree-ring fire studies often cannot reach sufficiently large landscape scales. Tree-ring studies were valuable, but often not probabilistic samples of landscapes, focusing in older forests with long records of fire. Tree-ring studies found some of the large, severe fires, but could not determine they were very large.

Fires appeared to have reached much larger sizes and appeared more uniformly oriented on the San Juan than Rio Grande side (Figure 1b). Larger fires on the San Juan side may have occurred in part because it has much more abundant, dense understory shrubs that promote higher-severity fires. However, much of the area of large patches (Fires 1, 5, and 22 in Figure 1b) also had a southwest-to-northeast orientation typical of fires that expanded under the influence of strong winds, possibly associated with passing cold fronts or other windstorms [3]. This effect, if it partly explains the pattern, also likely was enhanced by the common southerly- or southwesterly-facing river valleys on the San Juan side, which are lacking on the Rio Grande side (Figure 1b). However, other large fires on the San Juan side (Fires 6 and 10) have different orientation or expanded more broadly (Fire 22) across large landscapes with modest topography. Fires on the Rio Grande side appeared to lack a consistent orientation, and instead appeared constrained by a smaller area of montane forests and more diverse orientations of river valleys (Figure 1b). Some fires burned from valley bottoms in the montane zone up to treeline (e.g., Fire 1 and 18, and the atlas fire on the East Fork of the San Juan River southeast of Fire 7 in Figure 1b), although only the montane forest parts are shown.

How large did historical fires become? Moderate- to high-severity parts of fires appear mostly <5000 ha (Figure 6), but with two or more >13,000 ha in ponderosa pine and mixed conifer, similar to the 14,873 ha of moderate- to high-severity fire in the 2002 Missionary Ridge fire, based on MTBS data [42]. However, potential total area burned in a fire, not just in the montane, at moderate to high severity could historically have reached 38,805 ha (Fire 5), 54,631 ha (Fire 1), 55,975 ha (Fire 9), or even 73,925 ha (Fire 22), approaching the 75,000–90,000 ha estimated to have burned in 1879 on the Uncompahgre Plateau, just north of the San Juan Mountains [39]. If an added 1/3 to 1/2 burned at low severity, as in modern fires, total fire areas could have reached 50,000–100,000 ha, about 2–4 times the 27,903 ha of the 2002 Missionary Ridge fire. However, these very large historical fires need more research, as some could be from smaller adjoining fires in separate years. In any case, these represent very large contiguous areas, likely all burned in a 60-year period, that are still undergoing natural recovery, evident today as large patches of aspen [2,22], middle-aged forests, and openings.

A historically complex landscape with heterogeneous stages of recovery is expected, given high-severity fire rotations of 225–360 years, and moderate- to high-severity fire rotations of about 133–185 years (Table 1), and is documented by the atlases. These rotations were long enough to allow old-growth forests to develop, but short enough so that large fractions of landscapes had younger, recovering forests. About 17% of the ponderosa-pine zone and 21% of all three zones was likely <60 years old, after high-severity fires, at the time of the 1908–1909 atlases, and about 38–39% of these landscapes was burned at moderate to high severity between 1850 and 1909 (Table 1), and is still recovering from these fires. This is a substantial amount of severe fire, but is corroborated by a 1905 observation of limited large ponderosa pine timber on the San Juan relative to other areas (Table S2).

Atlas evidence of moderate- to high-severity fires has several limitations. Large spatial errors affect atlas utility in spatial overlays with modern data. Overlays with parts of the ponderosa and mixed-conifer zones could include some fire area not in the zone, and some parts of the zone could be mis-assigned. A significant constraint is that the resolution or minimum mapping unit is not specified; some grassland and shrubland patches down to about 15–20 ha were mapped, but smaller fires likely were often missed. Atlas evidence of severe fires extends back only to about 1850, and the period 1850–1909 in other parts of the southern Rockies had evidence of extensive burning due to a climatically favorable period for fire and added ignitions by settlers [9]. Ignitions by Indians likely did occur, but were relatively minor [36]. Mapping dates of 1908–1909 are late relative to expanding land uses after the early 1880s and an increased possibility that fires were human-set and forests had been logged and grazed. I presented evidence that railroad logging likely did not produce most woodlands, but logging could have contributed in some areas, and some fires were caused by railroads and logging in this period [9]. Fire severities were not explained in the atlases and, for woodlands, the best estimate from Dubois [16] is that half of woodland area was severely burned. However, woodlands could include some areas of patchy treeline forests, riparian areas, and naturally dry, low-density forests, these latter particularly on the Rio Grande side. Woodlands likely did not generally originate from other disturbances (e.g., beetle outbreaks and droughts) since they had sharp boundaries and contiguous area unlikely to be from other disturbances, and woodlands were explicitly described as from fires. The year of some fires is not known, and corroboration of others is limited, particularly with earlier fires. Further research could add more spatial-accuracy analysis, field dating of fires, and analysis of woodlands. Despite limitations, forest atlases currently represent the best available source of landscape-scale historical fire evidence for this land area.

4.3. Managing Low-, Moderate-, and High-Severity Fires in Montane Landscapes of the San Juan Mountains

Change in ponderosa pine and mixed-conifer landscapes since Euro-American settlement was previously attributed to suppression of frequent fires, with added impact from logging and livestock grazing, leading to increased tree density and basal area, and tree recruitment in grasslands and shrublands. Restoration thus focused on reducing tree density and basal area and reintroducing frequent fires. However, now it is known that ponderosa pine and mixed-conifer landscapes in the San Juan Mountains had frequent fires only on the lowest and driest 15% of the area, as found elsewhere in Colorado [43]. Most (85%) of the southern San Juan montane zone historically had multi-decadal low-severity fire rotations (Table 2), as elsewhere in Colorado [4]. These longer historical low-severity fire rotations enabled dense shrubby understories to persist in a mature state for decades between fires. This likely partly explains, along with southerly-facing valleys and modest topography, the extensive moderate- to high-severity fires now known in this study area (Figure 1b), as also on the adjoining Uncompahgre Plateau just north of the San Juan Mountains [39].

Together this new evidence shows that ponderosa pine, dry mixed-conifer, and moist mixed-conifer landscapes in the San Juan Mountains were all shaped by both low-severity fires, that helped maintain low-density mature and old-growth forests, and by infrequent moderate- to high-severity fires that fostered large expanses of younger, more heterogeneous forests, as well as grasslands and shrublands, in various states of survival and recovery. The resulting landscape heterogeneity of old forests, younger forests, and openings conferred bet-hedging resistance and resilience to unpredictable subsequent disturbances by fires, insects, and droughts, especially important as we enter a period of climate change with expected natural disturbances and tree mortality [41,44]. Bet-hedging at the landscape scale means that the landscape is not uniformly resistant or resilient to any one type of disturbance, but instead provides resistance and resilience to a diversity of disturbances in different parts of the landscape [41,44].

High-severity fires were often thought to have increased since EuroAmerican settlement, but new landscape-scale evidence here refutes this. Fire rotations for high-severity fires, between 1984 and 2012, in analysis polygons that contain the San Juan Mountains, were 1816 years in ponderosa pine and 926 years in dry mixed-conifer forests [40]. Analysis is not available for rates since 1984 in moist mixed-conifer forests. Since estimated historical high-severity fire rotations in ponderosa pine forests were 358 years on the San Juan and 1145 years on the Rio Grande, and in dry mixed-conifer forests were 265 years on the San Juan and 267 years on the Rio Grande (Table 1), high-severity fires have burned since 1984 at well below historical rates. Thinning and reduction of understory shrubs or other fuels to reduce severe fires, in ponderosa pine and dry mixed-conifer forests, is thus fire suppression, which has known adverse effects on biological diversity and ecosystem functioning [9].

If the goal is ecological restoration, it is essential to protect areas primarily undergoing natural postfire recovery, and focus intentional restoration in areas recovering from logging, grazing, and fire suppression. Thinning and logging trees recovering from severe fires is not ecological restoration; it is natural in these areas for tree density and basal area to increase during recovery. Areas today inside atlas fire and woodland areas are still recovering from the moderate- to high-severity fires of 1850–1909. This is 38–39% of San Juan and Rio Grande ponderosa pine and mixed-conifer forest area (Table 1). Digital atlas fires and woodlands provide mapped locations where facilitating natural recovery can be emphasized during restoration (Data S1). Natural recovery favored shade-tolerant trees (*Abies concolor*, *Pseudotsuga menziesii*, and *Picea pungens*), in the middle- to later-stages of succession in mixed-conifer forests [26]; these trees were even dominant in older dry mixed-conifer forests [10]. Where mixed-conifer forests are recovering, restored fires and other disturbances can readjust the abundance of shade-tolerant trees, and in the meantime recovering forests provide a key component of bet-hedging resilience at the stand scale [41,44]. For example, recovering forests, which already have small trees, are increasingly valuable because post-fire tree regeneration has been lower with warmer and drier conditions since 2000 [45].

For other areas, the simplest approach to separation of confounded recovery, logging, and fire-suppression effects, to determine restoration needs, is by dating and field observation. Since fire suppression was ineffective until after World War II [9], small trees <65 years old more likely represent fire suppression or recovery from logging, whereas older trees most likely represent natural recovery after low- to moderate-severity fires, except near early-1900s logging railroads (Figure 4). Other logged areas can often be identified in the field by persistent stumps [8]. In these later logged areas, small trees <65 years old could represent recovery after logging itself, livestock grazing, or fire suppression, which have effects that are difficult to separate. Using natural recovery and managed fire to restore these forests can be just as effective, or more so, than are thinning or other mechanical treatments [46], and do not require particular prescriptions. If mechanical treatment is undertaken anyway in these areas, I suggest now retaining all older trees and sufficient trees <65 years old, of as many species as possible, so that after-treatment stand-structure is numerically dominated by small trees of maximum available species diversity and variable density. These provide bet-hedging against impending future beetle outbreaks, droughts, and fires [41,44].

If the fire management goal is to restore heterogeneous San Juan montane landscapes shaped by historical variability in low-, moderate-, and high-severity fires, managed fires for resource benefit, not prescribed fires, can enable the higher-severity fires needed for effective restoration [47]. Fire rotations are the best available rate estimators to use in burning programs because they are area-based estimates of the historical rate of burning [4]. Biological diversity and ecosystem services will certainly be best maintained by mimicking the large variability in historical fire among forest zones and across topography (Table 5, Figures 1b and 5). In addition, most of the total burned area historically came from the few percent of fires that were large [9]. During the intervals between large fires, there can be ample time and variable settings that allow diverse species to recover. This can be mimicked by concentrating burned area into fewer years, rather than burning similarly each year.

It is not easy to restore and live with dangerous, but ecologically important large, severe fires or even with low-severity fires [48]. New landscape-scale evidence shows that montane landscapes are among the most inherently dangerous places to try to live with fire in the San Juan Mountains.

Supplementary Materials: The following are available online at http://www.mdpi.com/2571-6255/1/2/23/s1, Table S1: Moderate- to high-severity fires during 1850–1909 in the ponderosa pine and mixed-conifer forests of the southern San Juan Mountains from multiple sources, Table S2: General descriptions of fires and forest structure in Colorado and the San Juan Mountains, Data S1: Digital maps (shapefiles) of atlas fires and woodlands, Data S3: Digital fire-history data. Data S2: Georectified forest-atlas mosaics, are available from the Open Science Framework online at: https://osf.io/jk6ce/ (doi:10.17605/OSF.IO/JK6CE).

Funding: This research received no external funding.

Acknowledgments: The author appreciates assistance from the San Juan and Rio Grande National Forests with their GIS data, and the U.S. Geological Survey Denver Library Photographic Collection. Comments from peer reviewers significantly improved the manuscript and are appreciated.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Wehner, M.F.; Arnold, J.R.; Knutson, T.; Kunkel, K.E.; LeGrande, A.N. Droughts, floods, and hydrology. In *Climate Science Special Report: Fourth National Climate Assessment*; Wuebbles, D.J., Fahey, D.W., Hibbard, K.A., Dokken, D.J., Stewart, B.C., Maycock, T.K., Eds.; U.S. Global Change Research Program: Washington, DC, USA, 2017; Volume 1, pp. 231–256.
2. Romme, W.H.; Floyd-Hanna, L.; Hanna, D.D.; Bartlett, E. Aspen's ecological role in the West. In *Sustaining Aspen in Western Landscapes: Symposium Proceedings*; Shepperd, W.D., Binkley, D., Bartos, D.L., Stohlgren, T.J., Eskew, L.G., Eds.; USDA Forest Service Proceedings RMRS-P-18; Rocky Mountain Research Station: Fort Collins, CO, USA, 2001; pp. 243–259.

3. Aoki, C.F. Fire History and Serotiny in the Rocky Mountains of Colorado. Master's Thesis, Colorado State University, Fort Collins, CO, USA, 2010.
4. Baker, W.L. Restoring and managing low-severity fire in dry-forest landscapes of the western USA. *PLoS ONE* **2017**, *12*, e0172288. [CrossRef] [PubMed]
5. Hessburg, P.F.; Salter, R.B.; James, K.M. Re-examining fire severity relations in pre-management era mixed-conifer forests: Inferences from landscape patterns of forest structure. *Landsc. Ecol.* **2007**, *22*, 5–24. [CrossRef]
6. Odion, D.C.; Hanson, C.T.; Arsenault, A.; Baker, W.L.; DellaSala, D.A.; Hutto, R.L.; Klenner, W.; Moritz, M.A.; Sherriff, R.L.; Veblen, T.T.; et al. Examining historical and current mixed-severity fire regimes in ponderosa pine and mixed-conifer forests of western North America. *PLoS ONE* **2014**, *9*, e87852. [CrossRef] [PubMed]
7. Baker, W.L.; Williams, M.A. Land surveys show regional variability of historical fire regimes and dry forest structure of the western United States. *Ecol. Appl.* **2018**, *28*, 284–290. [CrossRef] [PubMed]
8. Romme, W.H.; Floyd, M.L.; Hanna, D. *Historical Range of Variability and Current Landscape Condition Analysis: South Central Highlands Section, Southwestern Colorado & Northwestern New Mexico*; Colorado Forest Restoration Institute, Colorado State University: Fort Collins, CO, USA, 2009. Available online: https://cfri.colostate.edu/publications/ (accessed on 7 July 2018).
9. Baker, W.L. *Fire Ecology in Rocky Mountain landscapes*; Island Press: Washington, DC, USA, 2009.
10. Tepley, A.J.; Veblen, T.T. Spatiotemporal fire dynamics in mixed-conifer and aspen forests in the San Juan Mountains of southwestern Colorado, USA. *Ecol. Monogr.* **2015**, *85*, 583–603. [CrossRef]
11. Agee, J.K. *Fire ecology of Pacific Northwest Forests*; Island Press: Washington, DC, USA, 1993.
12. Pinchot, G. *Preparation of the Forest Atlas*; United States Department of Agriculture, Forest Service: Washington, DC, USA, 1907.
13. Graves, H.S. *Instructions for Making Forest Surveys and Maps*; U.S. Government Printing Office: Washington, DC, USA, 1912.
14. Baker, W.L.; Veblen, T.T.; Sherriff, R.L. Fire, fuels and restoration of ponderosa pine-Douglas-fir forests in the Rocky Mountains, USA. *J. Biogeogr.* **2007**, *34*, 251–269. [CrossRef]
15. Dubois, C. *Report on the Proposed San Juan Forest Reserve, Colorado*; Unpublished Report on file at the San Juan National Forest, Supervisor's Office; San Juan National Forest: Durango, CO, USA, 1903.
16. Dubois, C. *The Proposed Montezuma Forest Reserve, Colorado*; Original document is in the National Archives and Records Administration; U.S. Department of Agriculture, Bureau of Forestry: Broomfield, CO, USA, 1904; A Typed Facsimile Version. Available online: https://www.fs.usda.gov/detail/gmug/landmanagement/resourcemanagement/?cid=stelprdb5378367 (accessed on 7 July 2018).
17. Michelsen, H. Colorado forest fires in nineteen hundred. *Forester* **1901**, *7*, 56–61.
18. Snedecor, G.W.; Cochran, W.G. *Statistical Methods*, 6th ed.; Iowa State University Press: Ames, IA, USA, 1967.
19. Shinneman, D.J.; Baker, W.L.; Rogers, P.C.; Kulakowski, D. Fire regimes of quaking aspen in the Mountain West. *For. Ecol. Manag.* **2013**, *299*, 22–34. [CrossRef]
20. Biodiversity Heritage Library. Available online: https://www.biodiversitylibrary.org (accessed on 26 May 2018).
21. Kulakowski, D.; Veblen, T.T.; Drinkwater, S. The persistence of quaking aspen (*Populus tremuloides*) in the Grand Mesa area, Colorado. *Ecol. Appl.* **2004**, *14*, 1603–1614. [CrossRef]
22. Margolis, E.Q.; Swetnam, T.W.; Allen, C.D. A stand-replacing fire history in upper montane forests of the southern Rocky Mountains. *Can. J. For. Res.* **2007**, *37*, 2227–2241. [CrossRef]
23. Hatton, J.H. *The Proposed Cochetopa Forest Reserve: Examination, Report and Recommendations*; Bureau of Forestry, U.S. Department of Agriculture, National Archives and Records Administration: Broomfield, CO, USA, 1904.
24. Ormes, R.M. *Tracking Ghost Railroads in Colorado*; Century One Press: Colorado Springs, CO, USA, 1975.
25. Chappell, G.S. *Logging along the Denver & Rio Grande: Narrow Gauge Logging Railroads of Southwestern Colorado and Northern New Mexico*; Colorado Railroad Museum: Golden, CO, USA, 1971.
26. Wu, R. Fire History and Forest Structure in the Mixed Conifer Forests of Southwest Colorado. Master's Thesis, Colorado State University, Fort Collins, CO, USA, 1999.

27. Brown, P.M.; Wu, R. Climate and disturbance forcing of episodic tree recruitment in a southwestern ponderosa pine landscape. *Ecology* **2005**, *86*, 3030–3038. [CrossRef]
28. Fulé, P.Z.; Korb, J.E.; Wu, R. Changes in forest structure of a mixed conifer forest, southwestern Colorado, USA. *For. Ecol. Manag.* **2009**, *258*, 1200–1210. [CrossRef]
29. Korb, J.E.; Fulé, P.Z.; Wu, R. Variability of warm/dry mixed conifer forests in southwestern Colorado, USA: Implications for ecological restoration. *For. Ecol. Manag.* **2013**, *304*, 182–191. [CrossRef]
30. Bigio, E.R. Late Holocene Fire and Climate History of the Western San Juan Mountains, Colorado: Results from Alluvial Stratigraphy and Tree-Ring Methods. Ph.D. Thesis, University of Arizona, Tucson, AZ, USA, 2013.
31. Bigio, E.R.; Swetnam, T.W.; Baisan, C.H. Local-scale and regional climate controls on historical fire regimes in the San Juan Mountains, Colorado. *For. Ecol. Manag.* **2016**, *360*, 311–322. [CrossRef]
32. Brown, P.M.; Ryan, M.G.; Andrews, T.G. Historical surface fire frequency in ponderosa pine stands in Research Natural Areas, central Rocky Mountains and Black Hills, USA. *Nat. Areas J.* **2000**, *20*, 133–139.
33. Grissino-Mayer, H.D.; Romme, W.H.; Floyd, M.L.; Hanna, D.D. Climatic and human influences on fire regimes of the southern San Juan Mountains, CO, USA. *Ecology* **2004**, *85*, 1708–1724. [CrossRef]
34. Colorado Historic Newpapers Collection. Available online: https://www.coloradohistoricnewspapers.org (accessed on 26 May 2018).
35. Kaufmann, M.R.; Huisjen, D.W.; Kitchen, S.; Babler, M.; Abella, S.R.; Gardiner, T.S.; McAvoy, D.; Howie, J.; Page, D.H., Jr. *Gambel Oak Ecology and Management in the Southern Rockies: The Status of Our Knowledge*; Southern Rockies Fire Science Network Publication 2016-1; Colorado State University: Fort Collins, CO, USA, 2016.
36. Baker, W.L. Indians and fire in the Rocky Mountains: The wilderness hypothesis renewed. In *Fire, Native Peoples, and the Natural Landscape*; Vale, T.R., Ed.; Island Press: Washington, DC, USA, 2002; pp. 41–76.
37. Williams, M.A.; Baker, W.L. Spatially extensive reconstructions show variable-severity fire and heterogeneous structure in historical western United States dry forests. *Glob. Ecol. Biogeogr.* **2012**, *21*, 1042–1052. [CrossRef]
38. Baker, W.L. Historical forest structure and fire in Sierran mixed-conifer forests reconstructed from General Land Office survey data. *Ecosphere* **2014**, *5*, 79. [CrossRef]
39. Baker, W.L. *The Landscapes They Are A-Changin'–Severe 19th-Century Fires, Spatial Complexity, and Natural Recovery in Historical Landscapes on the Uncompahgre Plateau*; Colorado Forest Restoration Institute, Colorado State University: Fort Collins, CO, USA, 2017. Available online: https://cfri.colostate.edu/publications/ (accessed on 7 July 2018).
40. Baker, W.L. Are high-severity fires burning at much higher rates recently than historically in dry-forest landscapes of the western USA? *PLoS ONE* **2015**, *10*, e0136147.
41. Baker, W.L. Transitioning western U.S. dry forests to limited committed warming with bet-hedging and natural disturbances. *Ecosphere* **2018**, *9*, e02288. [CrossRef]
42. Monitoring Trends in Burn Severity. Available online: https://www.mtbs.gov (accessed on 26 May 2018).
43. Sherriff, R.L.; Platt, R.V.; Veblen, T.T.; Schoennagel, T.L.; Gartner, M.H. Historical, observed, and modeled wildfire severity in montane forests of the Colorado Front Range. *PLoS ONE* **2014**, *9*, e106971. [CrossRef] [PubMed]
44. Baker, W.L.; Williams, M.A. Bet-hedging dry-forest resilience to climate-change threats in the western USA based on historical forest structure. *Front. Ecol. Evol.* **2015**, *2*, 88. [CrossRef]
45. Stevens-Rumann, C.S.; Kemp, K.B.; Higuera, P.E.; Harvey, B.J.; Rother, M.T.; Donato, D.C.; Morgan, P.; Veblen, T.T. Evidence for declining forest resilience to wildfires under climate change. *Ecol. Lett.* **2018**, *21*, 243–252. [CrossRef] [PubMed]
46. Zachmann, L.J.; Shaw, D.W.H.; Dickson, B.G. Prescribed fire and natural recovery produce similar long-term patterns of change in forest structure in the Lake Tahoe basin, California. *For. Ecol. Manag.* **2018**, *409*, 276–287. [CrossRef]

47. Van Wagtendonk, J.W.; Lutz, J.A. Fire regime attributes of wildland fires in Yosemite National Park, USA. *Fire Ecol.* **2007**, *3*, 34–52. [CrossRef]
48. Schoennagel, T.; Balch, J.K.; Brenkert-Smith, H.; Dennison, P.E.; Harvey, B.J.; Krawchuk, M.A.; Mietkiewicz, N.; Morgan, P.; Moritz, M.A.; Rasker, R.; et al. Adapt to more wildfire in western North American forests as climate changes. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 4582–4590. [CrossRef] [PubMed]

Table S1. Moderate- to high-severity fires from 1850-1909 in the ponderosa pine and mixed-conifer forests of the southern San Juan Mountains from multiple sources. Fires can include many patches of atlas woodlands and/or fires.

Year and Side/Sources	**Type of source**	**GIS map**	**Quote and discussion**
1900-San Juan side			
[34] (The Daily Journal, Telluride 7-28-1900) [16] (p. 21) [20] (Forest Atlas-Montezuma NF 1908 p. 13)	Early report Early report Early maps	 Fire1 Woodland and Fire	"The hazy appearance of the atmosphere yesterday and again today is due to terrific fires raging in the timber south and east of Rico, where a heavy growth covers the mountains. Fires started yesterday afternoon at the head of Remine creek in Deep creek basin, but it is thought this fire has been put out. Over the hill south of town smoke was discovered this afternoon...The month just closing has been the dryest July in the memory of the oldest inhabitants, and the danger from forest fires increases daily. It is said that over a million dollars worth of timber has been consumed near Bear creek on the Dolores below Rico, where on Thursday there was only two or three small fires that could have been easily controlled..." "It is safe to say that 50 per cent of the area classified as woodland has been run over and seriously damaged by fire...These burns are in all stages, from areas covered with dead standing trees and down timber with no re-growth what so ever on the ground, such as the area at the head of Burnt Timber Creek in the La Plata, to large areas covered by stands of aspen of varying ages with a few scattering groups of conifers in mixture, such as are found on the hills on each side of the main Dolores along which runs the railroad." The area described by Dubois on the Dolores matches the 54,631 ha woodland and fire patches from Rico to Dolores, which contain 32,828 ha of the ponderosa and mixed-conifer zones. The fire year is unknown, but likely includes 1900 and 1878. The Telluride paper quote likely represents at least part of a 1900 fire.
[34] (The Durango Democrat 7-20-1900) [20] (Forest Atlas-San Juan NF 1909 p. 7)	Early report Early maps	 Fire2 Fire only	"North East of Durango in the section east of Baker's bridge is raging the most destructive fire our people have ever known of. The distance from Durango is some fifteen miles, but the flames can almost be detected at mid-day and the volume of smoke is dense and expansive, lays like a huge bank of clouds in the north east. It is in the heavy spruce forests that abound in that section and the loss of such an enormous expanse of red and white spruce is one of millions to the mining industry and railroads. All such visitations can be traced directly to campers who are purposely negligent and the only regret is that they cannot share the heat as a partial reward for cussedness." T36N-T38N R7W shows a large area, possibly of woodland, but the shading switches suddenly at the western township boundary of T37N R7W, so I left this out of the digital map of fires based on woodlands, because of its ambiguity. This patch was about 13,000 ha (32,000 acres) within which was mapped a fire covering 2,296 ha, which could also have been the fire. Only 66 ha of this fire was in the ponderosa and mixed-conifer zones. This fire was reported to have been in 1900.

[34] (The Durango Democrat 7-22-1900) [20] (Forest Atlas-San Juan NF 1909 p. 6)	Early report Early maps	 Fire3 Woodland only	"The forest fire up the Animas began near the old Lambert ranch about three miles north of the Steinegar-Thompson ranches, and is sweeping the forests in a northwest direction on north side of range between Junction and Hermosa creeks. It is a destructive blaze and will destroy thousands of pine and spruce trees. Capt. Dudley says it is the worst La Plata has experienced in point of destruction and is now raging in the heavy spruce forests near Oro Fino." T36N R9W-R10W shows the Oro Fino Mine NW of Monument Hill and a narrow stretch of woodland and grassland extending down to the Tripp Gulch area on the west side of the Animas Valley, where there are also old cuttings mapped, that could have been fires, but no actual fires are mapped. The woodland patch itself was 265 ha, with 211 ha in the ponderosa and mixed-conifer zones, and it burned in 1900.
[49] (p. 23) [50] (p. 117, 124) [20] (Forest Atlas-San Juan NF 1909 p. 8)	Early report Early report Early maps	 Fire4 Fire only	"...a sheepherder supposedly set a fire that burned over 500 acres in the Vallecito area." "The Vallecito Country had five hundred acres burned over in 1900, from a fire supposed to have been incendiary and set by one of the sheep herders of that time. Over one thousand dollars worth of damage was the result." T37N-T38N R6W shows a 205 ha fire near Vallecito Creek, but only 95 ha was in the ponderosa pine and mixed-conifer zones, and the fire burned in 1900.
[34] (The Pagosa Springs News 8-17-1900) [49] (p. 23) [50] (p. 117) [20] (Forest Atlas-San Juan NF 1909 p. 9, 13)	Early report Early report Early report Early maps	 Fire5 Woodland and Fire	"In the western part of the county [Archuleta County] several forest fires are reported, which is burning some of the finest timber in this section." "One fire started near the Piedra River, it was believed by lightning, traveled up Sand Creek and Weminuche Creek" This likely is reporting the same fire(s) as the previous reference. "1900 proved to be another bad fire year. The summer was hot and dry when a fire started down the Piedra River and travelled up Sand Creek and Weminuche Creek. This fire was uncontrolled for over three weeks and is believed to have been started by lightning" The entire length of the Piedra River, from where Highway 160 crosses it at the lower end upstream to the Hinsdale-Archuleta County line is part of a large woodland patch and four smaller fires. There is also a woodland patch on Weminuche Creek, but no woodland patch or fire on Little Sand Creek. Much of this may have burned in 1900, but part of this may have burned in 1898, 1879, or 1861. Total burned area is 38,805 ha, with 13,872 ha in the ponderosa and mixed-conifer zones.

[17] (p. 59) [49] (p. 23) [50] (p. 117, 124) [34] (The Pagosa Springs News 8-17-1900) [34] (The Pagosa Springs News 8-31-1900) [20] (Forest Atlas-San Juan NF 1909 p. 11, 13)	Early report Early report Early report Early report Early maps	 Fire6 Woodland and Fire	"August 30th, the woods fringing the entire northern boundary of Archuleta County were found to be ignited. A large fire was burning near the head of Four Mile Creek, the smoke resembling a huge cloud as it passed over Pagosa Springs. Some forty square miles [10,400 ha, 25,600 ac] of Yellow Pine forest were burnt over. It was asserted that sheep herders who fired the grass in order to improve the pasture for next year are responsible in this case." The table on p. 60 also lists 40 square miles burned in Archuleta County and the map on p. 57 shows the burn area along the northern boundary. This mapped (p. 57) Michelsen fire patch, which I roughly digitized to have been 151,647 ha, extended into southwestern Rio Grande and southern Hinsdale and Mineral Counties. Hinsdale was reported in the table on p. 60 to have had 6 square miles [1,555 ha, 3,840 ac] burned, Mineral to have had 10 square miles [2,591 ha; 6,400 ac] burned. Thus, the area within Archuleta, Hinsdale, and Mineral Counties would have totaled 56 square miles [14,510 ha, 35,840 ac.]. Rio Grande county burned area is discussed later in this table. "Another fire raged between Middle Fork and the East Piedra Rivers" This is likely also this fire, which burned part of the area between the Middle Fork and East Piedra Rivers. "During the same summer [1900] another fire burned over the country between Middle Fork and the East Piedra Rivers. This fire burned for ten days with only four men to fight it." "Several forest fires are raging in the vicinity of Pagosa Springs. Last Sunday a large fire was doing a great deal of damage near Mrs. Cade's ranch, and another area near the top of the range northeast of town, both of which could easily be seen in Pagosa." "If the forest fire above Mrs. Cade's ranch burns much longer there won't be any timber left in that part of the country. It has been burning the last two months." "A big forest fire is reported in Laughlin Park." Mrs. Cade's ranch east of Pagosa Peak in S35 T37N R2W is within a woodland patch with two associated fires. This 14,145 ha total area, with 13,088 ha in the ponderosa and mixed-conifer zones, matches the 14,510 ha fire reported by Michelsen and matches the locations described in the above sources. This patch goes down to within 0.7 km of Laughlin Park. Most of this burned in 1900, but part could have burned in 1898.
[49] (p. 23) [50] (p. 117) [20] (Forest Atlas-San Juan NF 1909 p. 11, 13)	Early report Early report Early maps	 Fire7 Woodland and Fire	"...Several large fires burned over the Pagosa area, particularly one started by campers (from either their camp fire or from smoking) around Borne Lake, Beaver Creek, and a portion of West Fork." "Sometime during the period 1899-1905, the exact year being unknown, several large fires burned in the transitional and spruce types in the Pagosa Country. Apparently no efforts were made to extinguish these fires and many of them burned nearly all summer. Some of them threatened to get down into the lower altitudes. Henry Born father of the James Born now residing near Pagosa Springs, fought fire off-an-on all one summer to save the timber around the Borns Lake. This fire burned out Beaver Creek and part of West Fork and was believed to have been started by campers either from their camp fires or from smoking." Borne Lake may be Borns Lake, and Beaver Creek is just upstream from it on the West Fork of the San Juan. This area has a woodland patch with fires on the two sides of the West Fork. The total is 2,324 ha burned, 845 ha in the ponderosa and mixed-conifer zone, likely all in 1900.

1900-Rio Grande side	**Type of source**	**GIS map**	**Quote and discussion**
[51] (p. 2, 7) [17] (p. 59) [20] (Forest Atlas-Rio Grande NF 1909 p. 8)	Early report Early report Early maps	 Michelsen Fire8 Woodland only	"Tie Hill...Extensive area of Decker, Goodrich, and Lake Fork Creeks" SW of South Fork on the Rio Grande. "Started from Bengards Mill on the South Fork just below Park Creek." "August 16, two fires originated on the South Fork of the Rio Grande, one east and the other west of the river, within three miles of each other. The one on the west side burned up the mountain and stopped after reaching timber line..." The west side of the South Fork of the Rio Grande is covered by a fire patch and a woodland patch. Total burned area is 2,439 ha, with 1,145 ha in the ponderosa and mixed-conifer zones. Some of the area in a fire patch for Fire17 in 1881, on Goodrich Creek, likely burned in this 1900 fire.
[17] (p. 59) [15] (p. 9) [34] (The San Juan Prospector, Del Norte, Colorado 9-1-1900) [20] (Forest Atlas-Rio Grande NF 1909 p. 8, 9)	Early report Early report Early report Early maps	Michelsen Fire9 Woodland and Fire	"August 16, two fires originated on the South Fork of the Rio Grande...that on the east side burned a swath from five to twenty miles wide, taking everything in its way driving several hundred thousands of cattle and sheep into the valley, and destroying mine buildings, machinery and shaft houses in the whole region at the headwaters of the Alamosa and Conejos rivers. The length of the path burned over was about forty-five miles. All of this devastation can be traced to sheep herders who, either carelessly or maliciously, left their logs burning on breaking camp." The table on p. 60 lists 205 square miles (53,117 ha, 131,200 ac) burned in Rio Grande County, but data appear missing for Conejos County. The map on p. 57 shows a large fire down the west side of both counties. "The effect of denudation [by fire] is shown by the Conejos River...For the past six years [1897-1903] fires have occurred repeatedly in the timber on its headwaters." "The great devastation of timber continues in the country south and west of Del Norte and it is the general belief that the fires are being started intentionally. The State authorities evidently do not think enough of this part of Colorado to make an effort to apprehend the men who are guilty of such work. In the meantime, the loss entailed upon the people of this section is very great. Never within our recollection has the destruction of timber been as great as this season, a destruction that will be felt in a higher price for lumber, a scarcity of mining timber and fuel, and an earlier melting of the snow upon which the farmer relies for water for his crops." The fire start may have been in T39N R3E S21-S22 (p. 9), in a woodland. It is possible to connect up (there are some large gaps, though, where fire either spotted or burned at low severity) along a set of patches to the southeast from the South Fork of the Rio Grande across the headwaters of the Alamosa and Conejos Rivers, which would stretch 77 km (48 miles), if so, going from p. 9 to p. 12-13 to p. 14-15. The resulting set of fire patches would total 55,975 ha, with 21,585 ha in the ponderosa and mixed-conifer zones. Some of this area burned in 1900 may have burned earlier, in 1875 or 1873.
1899-San Juan side			
[10] [20] (Forest Atlas-San Juan NF 1909 p. 15).	Tree-rings Early maps	 Fire22 Woodland and Fire	Squaretop study area This area contains a fire patch that encloses much of Tepley and Veblen's study area, which also partly overlaps a very large woodland patch. Tepley and Veblen (2015) showed that the fire patch and nearby woodland patch burned in 1899, 1879/1878, and 1861/1860. Their maps show which parts of the atlas fire and adjoining woodland patch burned in these years, but not the whole woodland patch. The total fire area is 73,925 ha, with 62,135 ha in the ponderosa and mixed-conifer zones.

1898-San Juan side	Source	GIS map	Quote and discussion
[49] (p. 23) [50] (p. 116) [20] (Forest Atlas–San Juan NF 1909 p. 12)	Early report Early report Early maps	Fire5 Woodland and Fire	"In 1898, a fire, started from an unknown source, near Bayfield burned approximately 5,000 acres..." "Near Bayfield there was an area of approximately five thousand acres which had been burned over years before. This area burned over for the second time in 1898, the fire starting from an unknown cause. It burned during the month of August for fourteen days. There is a large woodland patch of 35,143 ha that is in part only about 3 km east of Bayfield; it is likely that part of this large patch burned in 1898, rather than 1900.
[49] (p. 23) [50] (p. 116-117, 124) [20] (Forest Atlas–San Juan NF 1909 p. 9-10)	Early report Early report Early maps	Fire6 Woodland and Fire	"...another fire started by a hunter's camp fire burned along the west side of middle Fork Creek and up Oak Brush Hill in the Piedra area" "...a forest fire started by a hunter's camp fire burned uncontrolled along the west side of Middle Fork Creek and up Oak Brush Hill in the Piedra country. It burned until extinguished by heavy rains." This is part of a large patch of 14,145 ha, reported to have burned in 1900, that terminates on its western end right in this area; it is likely that part of this area burned in 1898, not 1900.
[49] (p. 23) [50] (p. 124) [20] (Forest Atlas–Montezuma NF 1908 p. 17)	Early report Early report Early maps	Fire10 Woodland only	"That same year also witnessed a fire that began on Horse Creek when Pat Murphy built a smudge fire to keep flies away from his horses and burned east to Gold Run Creek and north to the Hogback, northeast of Mancos" "Also in 1898 a fire started on Horse Creek and burned East to Gold Run Creek and north to the Hogback which is northeast of Mancos. Messrs. William Young and Herbert Shackley fought this fire to save Mr. Young's cabin and fencing. This fire was started by Pat Murphy who built a "smudge fire" to keep flies away from his horses." This is a large woodland patch of 28,381 ha, that at its southeastern extent, runs across this specific area; it seems likely that about 1,000 ha (2,500 ac) of this large patch burned in 1898, and another 2,000 ha in 1892, but the Romme et al. study suggests fires in or before 1879, in the period from about 1880-1850, in a larger area near this.
1898-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 12)	Early report Early maps	Fire11 Fire only	"Klondike Mountain Adams Fork, and Globe Creek" in upper Conejos and Alamosa River drainages T36N R4E has a 1,464 ha fire, with only 23 ha in the ponderosa and mixed-conifer zones. This 1898 fire area may be in the same area as reported by Spero to have burned in 1875.
1896/1891-San Juan side			
[10] [20] (Forest Atlas-San Juan NF 1909 p. 9)	Tree-rings Early maps	No fire detected	Williams Creek study area The small high-severity fire area and medium moderate-severity fire area were not detected here by atlas fires or woodlands, as the area is mapped as forest with 2,000-5,000 b.f. It is possible that fire in the moderate-severity area reduced timber volume somewhat, leaving this level of b.f., but not enough to produce a woodland.

1895-San Juan side			
[50] (p. 116, 123) [20] (Forest Atlas–San Juan NF 1909 p. 4, 8)	Early report Early map	 No fire detected	"In 1895 campers were the cause of a thousand acre fire in the Vallecito country. Five million board feet of timber was destroyed with a value of over five thousand dollars. Most of the early fires, including this one, were allowed to burn until rain put them out." No fires or woodlands are mapped in the Vallecito drainage except a 1900 fire patch. This same description was attributed to 1879 by Romme and Bunting [49] (p. 23).
1893-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 3)	Early report Early maps	 Fire12 Fire only	"Dry Gulch...Entire Gulch," and "Farmers Creek...Upper part of watershed" just east of Creede "Mammoth Mountain South and east exposures" N of Creede. Likely the same fire. This burned area is 2,059 ha in total, with 136 ha in the ponderosa and mixed-conifer zones.
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 2)	Early report Early maps	 Fire13 Woodland only	"Willow Creeks East and West Willow, Shallow, Sunnyside Creeks, Dry Gulch and the vicinity of the town of Bachelor" north and west of Creede. Quotes from Nolie Mumey: "The town of Bachelor was threatened by fire on June 23, 1893 when the forest fire which had been burning moved toward town. The people of Jimtown rushed up to Bachelor and helped save the town. The forest fire burned up to the edge of Bachelor devastating East Willow and West Willow Creeks. Shallow Creek and Sunnyside Creek were also burned in the same fire." T42N R1W-R2W–this area has a woodland and two fire patches over 6,841 ha with 2,375 ha of the ponderosa and mixed-conifer zones. Other parts of this area are shown as a grassland of 2,500 ha + (6,000 ac +), which could also be part of the fire area, as there are sharp boundaries with forests. This area burned in 1893.
[51] (p. 2, 4, 6) [20] (Forest Atlas-Rio Grande NF 1909 p. 2, 7, 8)	Early report Early maps	 Fire14 Woodland and Fire	"Douglas Mountain Lime, McCall, Credit & Deep Creeks. Also the N and NE exposure of Snowshoe Mountain" large circular mountain south of Creede. On p. 4 from LaFont (1922)–"During the summer of 1893 the town [Spar City] was threatened by forest fires. A large forest fire was burning south of Spar City and another to the north. The one to the north burned till the snow fell and its area extended from the Point of Rocks over the Deep Creek Hills, and Snowshoe Mountain...This fire swept Lime Creek and continued in a N/NE direction until snow fell." This 1893 fire area has nine patches of fire and six patches of woodland over 8,488 ha, with 2,635 ha of the ponderosa and mixed-conifer zones.
[51] (p. 2, 3, 7) [20] (Forest Atlas-Rio Grande NF 1909 p. 13)	Early report Early maps	 Fire15 Woodland and Fire	"Rock Creek" NE of Alamosa River drainage.."In June 1893 in a single day fire swept the entire watershed of North Rock Creek" This area has a total burn area of 10,493 ha, with 6,892 ha of the ponderosa and mixed-conifer zones. It is likely part of this total area burned in 1893 and part in 1892 (see below).

1892-San Juan side			
[50] (p. 123) [20] (Forest Atlas–Montezuma NF 1900 p. 17)	Early report Early maps	 Fire10 Woodland only	“In 1892 the Townsend Basin fire started along the East Mancos Creek and burned to timber line. Cause of fire unknown.” T36N R12W About 2,000 ha burned in 1892, with about 770 ha of ponderosa pine and mixed-conifer forest, within a large woodland patch of 28,381 ha, that likely also burned in 1898 and 1880-1850.
1892-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 2)	Early report Early maps	 Fire15 Woodland and Fire	“South Rock Creek” Likely part of the Fire15 area, which may also have burned in 1893.
1887-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[49] (p. 23) [20] (Forest Atlas–San Juan NF 1909 p. 4, 8)	Early report Early maps	 No fire detected	“...campers ignited a 1,000 acre fire in the Vallecito country that destroyed 5 million board feet of timber, valued at over $5,000" No fires or woodlands are mapped in the Vallecito drainage except a 1900 fire patch
1887-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 13)	Early report Early maps	 Fire16 Fire only	“Cat Creek Entire upper reaches of Cat Creek” in Alamosa drainage. A single fire patch of 316 ha, with 234 ha in the ponderosa and mixed-conifer zones. Could have burned some of the adjoining woodland patch which I assigned to a 1900 fire.
1884-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[49] (p. 23) [50] (p. 123) [20] (Forest Atlas–San Juan NF 1909 p. 4, 8)	Early report Early report Early maps	 Fire 10 Woodland & cutting	“The next large fire occurred in 1884. Reportedly set by Indians, the fire burned most of the summer.” Lacking locational information, it is impossible to validate this fire, but it seems likely it is the same as in York: “In the year 1884 a large fire burned over sections 25, 26, 35 and 36, T. 37 N, R. 14 W, and burned all summer. The Indians are credited as having set it. The area which was covered by this fire now has a stand of Ponderosa Pine.” This fire area is partly identified in the atlas by the large woodland patch of 28,381 ha., but is likely also represented on the atlas by an “old cutting,” suggesting it was logged after the fire. Based on the locational description it likely covered about 1,035 ha in four sections, all in ponderosa pine and dry mixed conifer with associated grasslands and shrublands.

1881-Rio Grande side	Source	GIS map	Quote and discussion
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 8)	Early report Early maps	 Fire17 Woodland and Fire	"Elk Creek, Raspberry, Trout Soda, Leopard, Roaring Fork and Goose Creeks" This 1881 fire area has 14,912 ha of total burn area, with 4,252 ha of ponderosa and mixed conifer. Some of this area, on Goodrich Creek, likely burned in fire9 in 1900.
1880-1850-San Juan side			
[2] [20] (Forest Atlas-San Juan NF 1909 p. 13, 16, 17)	Tree-rings Early maps	 Fire10 Woodland only	The Romme et al. study area included all of T37N R12W, the northeastern corner of T37N R13W, the southernmost portion of T38N R12W, and the southeastern corner of T38N R13W (William Romme, Pers. Comm., 1-5-2016). Only 18 of the 57 dated stands in this area (32%) had "last fires" in the 1850s-1870s, which are potentially detectable with atlas fires and woodlands. The study area is half or more occupied by part of a woodland patch of 28,381 ha, with 18,167 ha in the ponderosa pine and mixed-conifer zones. About 1,000 ha of this patch to the south may have burned in 1898. The Romme et al. study suggests fires in or before 1879. A substantial part of the study area had older forests.
1879-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[49] (p. 23) [52] (p. 258-263) [50] (p. 116, 123) [20] (Forest Atlas-San Juan NF 1909 p. 3)	Early report Early report Early report Early maps	 Fire18 Fire only	"The century's most significant fire, however, occurred in June, 1879. The subsequently labeled, Lime Creek Burn, fired over 26,000 acres. More significantly, the fire burned not only trees and litter, but the soil itself." Nossaman has an extensive report on the origins of this fire, the direction it burned, a map of the fire, and details of its impacts, too lengthy to quote here. "...in some way a great conflagration was started. Although many old-timers claimed the Indians started the fire, the true cause of the fire has never been definitely ascertained. This horrible fire burned over twenty-six thousand acres of timberland is even to this spoken of as the "Lime Creek Burn." Although over a half a century has passed this ruined forest still bears witness to the deadly effect of fire. The fire burned the needles, leaves, timber, the very soil itself. Each windy day a few more of the scarred snags would fall until now they are on the ground forming a part of the vast waste. Another coating of soil is gradually covering the mass and although timber is still missing, some grazing is available now." This 1879 burn has a single large fire patch of 8,155 ha, with 1,814 ha in the ponderosa and mixed-conifer zones. The full boundary of this fire is truncated on the western margin of the fire apparently by private land, so this is not the entire extent of the fire. This is the Lime Creek burn, as it is still called today.
[49] (p. 23) [50] (p. 116, 123) [20] (Forest Atlas-San Juan NF 1909 p. 3)	Early report Early report Early maps	 Fire19 Woodland and Fire	"That same year [1879] fire swept through the Cave Basin area, along the Piedra Divide, and in the upper Pine River country." "In the same year as the disastrous Lime Creek burn a fire raged unchecked throughout most of the summer in the Cave Basin country. Also along the Piedra Divide and along the upper Pine River country fires burned. The large area burned over in Cave Basin even now shows but a stand of brush and aspen were one where once stood good timber." This area contains a total fire area of 10,672 ha, with 1,132 ha in the ponderosa and mixed-conifer zones. The upper Pine River area burned extensively, but the Cave Basin creek area itself is not shown to have burned, but perhaps burned at low severity. This 1879 fire also could have been in 1860.

[49] (p. 23) [20] (Forest Atlas–San Juan NF 1909 p. 4, 8)	Early report Early map	 No fire detected	“Campers started a 1,000 acre blaze in the Vallecito area that destroyed 5 million board feet of timber.” No fires or woodlands are mapped in the Vallecito drainage except a 1900 fire patch
[3] [20] (Forest Atlas-San Juan NF 1909 p. 16).	Tree-rings Early maps	 Fire22 Woodland and Fire	Navajo River study area-western part The western part of Aoki’s study area overlaps the eastern edge of a large woodland patch of 72,848 ha, which contains 61,768 ha of ponderosa and mixed conifer. At their Squaretop site further north, Tepley and Veblen (2015) showed that parts of this woodland patch burned in 1899, 1879/1878, and 1861/1860. Aoki found evidence of much high-severity fire in 1879 on the eastern side of the Navajo River, but not on this western side, which may have burned in earlier fires. Aoki did find 1861 and 1851 fire dates.
[30-31] [20] (Forest Atlas-San Juan NF 1909 p. 8)	Tree-rings Early maps	 No fire detected	MAR2 study area. The atlas does not show either fires or woodlands at this location. Failure to detect this fire may be because it was only medium in size.
[10] [20] (Forest Atlas-San Juan NF 1909 p. 9)	Tree-rings Early maps	 Fire5 Woodland only	Williams Creek study area The fire area in part intersects a woodland patch, that is in part in the ponderosa and mixed-conifer zones, which may, in part, have also burned in 1900 or in 1861.
[26] [20] (Forest Atlas-San Juan NF 1909 p. 9)	Tree-rings Early maps	 No fire detected	BPK1 study site A woodland patch was located on the Piedra River about 2 km southeast of the site, but no fire or woodland was mapped in the study site itself. Failure to detect this high-severity fire patch may be because it was small.
1879/1878-San Juan side			
[10] [20] (Forest Atlas-San Juan NF 1909 p. 15).	Tree-rings Early maps	 Fire22 Woodland and Fire	Squaretop study area This area contains a fire patch that encloses much of Tepley and Veblen’s study area, which also partly overlaps a very large woodland patch. Tepley and Veblen (2015) showed that the fire patch and nearby woodland patch burned in 1899, 1879/1878, and 1861/1860. Their maps show which parts of the atlas fire and adjoining woodland patch burned in these years. The total fire area is 73,925 ha, with 62,135 ha in the ponderosa and mixed-conifer zones.
1879-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 3)	Early report Early maps	 No fire detected	“Dry Gulch...Rather small in lower watershed” just east of Creede T42N R2E S31 shows an “Old cutting” of about 120 ha that could have been the fire and was subsequently logged.

[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 7)	Early report Early maps	 Fire20 Woodland and Fire	"Middle Mountain, Red and Middle Mountains, and portions of Trout Creek" N of Piedra Peak SW of Creede Total burn area is 1,941 ha with 373 ha in the ponderosa and mixed-conifer zones.
[51] (p. 2, 7) [20] (Forest Atlas-Rio Grande NF 1909 p. 12)	Early report Early maps	 No fire detected or Fire9	"Osier Burn," 12,000 ha (30,000 ac) on NM border. "This fire was the most extensive and intensive that occurred locally in the 19th century. Its boundaries were Grouse Creek on the west, the Rio Conejos on the north, the limits of timber on the east, and points far south of the state line on the south. All evidence points to the conclusion that it was started on the railroad. Intensity is still evident: very few snags standing or down were left. Aspen did not come in."..."Most of the burn was in Engelmann spruce-white fir mixture. There were some ponderosa pine, bristlecone pine, and Douglas fir at the lower elevations on the Los Pinos and Conejos Rivers. The fire was believed to have been started by railroad crews." T32N R6E, no fire shown, but a large grassland that might approach the 12,000 ha scale could be it? A substantial patch of woodland to the east possibly part of this fire but instead or also fire9 in 1900. One small patch to the south on the Los Pinos River. Most of this fire likely above the ponderosa and mixed-conifer zones.
1878-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[49] (p. 23) [50] (p. 123) [20] (Forest Atlas-Montezuma NF 1909 p. 13)	Early report Early report Early maps	 Fire1 Woodland and Fire	"An Indian party was supposedly responsible for setting a fire that consumed a large body of spruce timber on Bear Creek, a tributary of the Dolores River, during the fall of 1878" "In the fall of 1878 an Indian party supposedally [sic] set fire to a large body of spruce on bear creek, a trubutary of the Dolores River. The fire did considerable damage to the timber of the region. At present the area is covered with a dense stand of aspen." Bear Creek adjoins a large woodland patch that extends from Rico to Dolores, which contains 32,828 ha of the ponderosa and mixed-conifer zones. Part of this patch may have also burned in 1900.
[49] (p. 22-23) [50] (p. 115, 123) [20] (Forest Atlas-San Juan NF 1909 p. 3)	Early report Early report Early maps	 No fire detected	"In 1878, a fire for more than forty days burned over 18,000 acres between Rockwood and Silverton. Such fires in the San Juans no doubt resulted from whites. Certainly the indictment of two men by a Silverton grand jury in October, 1877, for setting public land forests on fire indicate as much." "A fire which burned for forty days and covered over eighteen thousand acres burned in the year 1878 between Rockwood and Silverton, over four hundred and fifty millions of board feet of timber were destroyed with an estimated loss in timber of nine hundred thousand dollars. The area burned over was partly in San Juan and partly within La Plata County. M.A. Hubbard, later resident of Aztec, New Mexico, witnessed the fire and supplied the information included here" No fire or woodland patch of this size is visible on the San Juan [12] (Forest Atlas, but this description seems to fit the Lime Creek Burn of 1879, suggesting a possibly unreliable date in this historical report.

1876-Rio Grande side	Source	GIS map	Quote and discussion
[51] (p. 6) [22] [20] (Forest Atlas-Rio Grande NF 1909 p. 6)	Early report Tree-rings Early maps	 Fire23 Fire only	"Lieutenant C.C. Morrison said in 1876 that 'we crossed the Sangre de Cristo Pass June 15, 1876. From the summit the San Juan range was seen enveloped in smoke of burning forests..." SQW study area This area contains two fire patches, likely parts of the same fire, that span Little Squaw Creek and Squaw Creek. Total burn area is 1,066 ha, with 169 ha in the ponderosa and mixed-conifer zones.
1875-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 2, 7) [20] (Forest Atlas-Rio Grande NF 1909 p. 12)	Early report Early maps	 Fire9-part Woodland and Fire	"Hayden Expedition topographer Franklin Rhoda stated that great volumes of smoke were coming from the head of the Alamosa River reaching Fort Garland 70 miles away. One week later he reported that in a rough canyon on the Alamosa a great fire was raging in the spruce. This fire accounts for most of the extensive burns within the canon between Stunner and the Worrel Ranch especially around Jasper." A woodland patch of 26,842 ha covers this area and a large area to the south, with 7,950 ha of ponderosa and mixed conifer. This patch was attributed to the 1900 fire, Fire9, which may have burned over this same area.
1874-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[49] (p. 22) [52] (p. 257) [20] (Forest Atlas-San Juan NF 1909 p. 3, 6, 7)	Early report Early report Early maps	 No fire detected	"In 1874, a 18,000 acre burn consumed over 450 million board feet of timber between Rockwood and Silverton." "The second was in 1874, when a fire in the Animas Canyon straddling what is now the San Juan-La Plata county line burned more than 18,000 acres over a period of 40 days. This fire has been traced from ground signs, and M.A. Hubbard claims to have been an eye-witness to this incident, which was apparently from natural causes." No fire or woodland patch of this size is visible on the San Juan [12] (Forest Atlas on p. 3, 6, or 7, but p. 2 is missing from the folio and could possibly have evidence. Also, parts of this area were not mapped as they were in private claims, particularly just north of Rockwood.
1873-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[26] [20] (Forest Atlas-San Juan NF 1909 p. 10)	Tree-rings Early maps	 No fire detected	JAK1, JAK4 A woodland patch was located about 1 km northeast of the site, but no fire or woodland was mapped in the study sites. Failure to detect this high-severity fire patch may be because it was small.

1873-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 2) [20] (Forest Atlas-Rio Grande NF 1909 p. 12)	Early report Early maps	Fire9-part Woodland and Fire	Jasper/Burnt Creeks, 1,619 ha (4,000 ac) in Alamosa drainage Part of a large woodland patch of 26,842 ha may have burned in 1873 in the Jasper/Burnt Creek area, and possibly burned again in 1875 or 1900.
1872-Rio Grande side	**Source**	**GIS map**	**Quote and discussion**
[51] (p. 3, 6) [20] (Forest Atlas-Rio Grande NF 1909 p. 4)	Early report Early maps	Fire21 Woodland only	"La Garita Creek" W of La Garita. "A sheepherder stated that he had to leave the Mesa Peak country with his sheep because of the dense smoke from forest fires burning in the La Garita country." This area has burned area totaling 2,653 ha, with one patch of woodland containing 508 ha in the ponderosa and mixed-conifer zones.
1870-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[30-31] [20] (Forest Atlas-San Juan NF 1909 p. 8)	Tree-rings Early maps	No fire detected	SC4 The atlas does not show either fires or woodlands at this location. Failure to detect this fire may be because it was small.
1861-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[10] [20] (Forest Atlas-San Juan NF 1909 p. 9)	Tree-rings Early maps	Fire5 Woodland only	Williams Creek study area The fire area in part intersects a woodland patch of 1,461 ha, with 1,379 ha of the ponderosa and mixed-conifer zones, which may, in part, have also burned in 1900, 1898, or 1879.
[27] [20] (Forest Atlas-San Juan NF 1909 p. 13)	Tree-rings Early maps	Fire5 Woodland only	Archuleta Mesa study area This study area is within a very large woodland patch of 35,143 ha, with 10,405 ha of ponderosa and mixed conifer, that extends up the Piedra River and west almost to Bayfield. It would be surprising if this large patch originated from a single fire year. Parts of the patch burned in 1900, 1898, 1879 as well as this date of 1861.
[29] [20] (Forest Atlas-San Juan NF 1909 p. 13)	Tree-rings Early maps	No fire detected	Lower Middle Mountain study area No fire or woodland patch was mapped in this area. The closest woodland patch is about 1.5 km southeast. The failure of the atlas to record this fire could be because it was medium in size and moderate in severity.

1861/1860-San Juan side			
[10] [20] (Forest Atlas-San Juan NF 1909 p. 15).	Tree-rings Early maps	 Fire22 Woodland and Fire	Squaretop study area This area contains a fire patch that encloses much of Tepley and Veblen's study area, which also partly overlaps a very large woodland patch. Tepley and Veblen (2015) showed that the fire patch and nearby woodland patch burned in 1899, 1879/1878, and 1861/1860. Their maps show which parts of the atlas fire and adjoining woodland patch burned in these years. The total fire area is 73,925 ha, with 62,135 ha in the ponderosa and mixed-conifer zones.
1860-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[49] (p. 22) [50] (p. 115, 122) [20] (Forest Atlas-San Juan NF 1909 p. 3)	Early report Early report Early maps	 Fire19 Woodland and Fire	"In 1860, a fire attributed to northern Utes burned about 20,000 acres and an estimated 25 million board feet of timber in Hinsdale and La Plata counties at the head of the Pine and Vallecito Rivers above Durango. Supposedly the Northern Utes had set the fire in order to prevent pursuing Southern Utes, with whom they were at war, from overtaking them." "In the year 1860 a very disastrous fire burned over about twenty-thousand acres in Hinsdale and La Plata Counties at the head of Pine and Vallecito Rivers above Durango. The fire burned up a large amount of timber, estimated to be twenty-five million board feet with a value of over fifty thousand dollars. It is believed the Northern Utes set this fire to stop pursuit by the Southern Utes with whom they were at war at the time. This information was supplied by Chief Buckskin Charlie. This area contains a total fire area of 10,672 ha, with 1,132 ha in the ponderosa and mixed-conifer zones. This area may have burned in 1879 or in 1860. This fire is all in the current Hinsdale county, not in the current La Plata county.
1851-San Juan side	**Source**	**GIS map**	**Quote and discussion**
[30-31] [20] (Forest Atlas-San Juan NF 1909 p. 8)	Tree-rings Early maps	 No fire detected	MAR2 study area. The atlas does not show either fires or woodlands at this location. Failure to detect this fire may be because it was only medium in size.
[22] [20] (Forest Atlas-Rio Grande NF 1909 p. 14)	Tree-rings Early maps	 Fire24 Woodland only	The Chama River, CHA, study area in mixed conifer Margolis does not show a detailed location for this site, which I estimated based on elevation and a location near the Chama River. The atlas does not quite extend to this estimated site, but a large woodland patch on the atlas border appears to have extended to the site. The woodland patch is 1,308 ha, with 89 ha in ponderosa and mixed conifer, but was likely larger due to truncation by the mapping.
[10] [20] (Forest Atlas-San Juan NF 1909 p. 9)	Tree-rings Early maps	 No fire detected	Williams Creek study area This 1851 high-severity fire at the Williams Creek study area was not detected by atlas fires or woodlands, likely because it is a small fire area.

[26] [20] (Forest Atlas-San Juan NF 1909 p. 9)	Tree-rings Early maps	No fire detected	CRL1 study area This study site is only 0.5 km from a woodland patch of 1,061 ha, that contains the companion CRL2 study site. Possibly the failure to detect this fire at this site reflects the known mapping error in the atlases.
[26] [20] (Forest Atlas-San Juan NF 1909 p. 9)	Tree-rings Early maps	Fire5 Woodland only	CRL2 study area This study site is within a woodland patch of 1,061 ha, with 988 ha of ponderosa and mixed conifer, that is part of a larger fire patch extending along the full length of the Piedra River. Wu (1999) dated the stand origin at this site to high-severity fire in 1851.

References are in the main text, except [49]-[54]:

49. Romme, W.H.; Bunting, R. *A History of the San Juan National Forest*; Unpublished report; San Juan National Forest, Supervisor's Office: Durango, CO, USA, 2001.
50. York, R. *Forest History*, *Volume 1*, *1905–1971*; Unpublished report; San Juan and Montezuma National Forests, Supervisor's Office: Durango, CO, USA, 1984.
51. Spero, V. *Fire History of the Rio Grande National Forest*; Unpublished report; Rio Grande National Forest, Supervisor's Office: Monte Vista, CO, USA, 1991.
52. Nossaman, A. *Many More Mountains. Volume 2: Ruts into Silverton*; Sundance Books: Denver, CO, USA, 1993.
53. Hough, F.B. *Report on Forestry*; US Department of Agriculture, Forest Service, US Government Printing Office: Washington, DC, USA, 1882.
54. Anonymous. Yellow pine in the Southwest. The Bureau of Forestry has been studying this important tree in Colorado, Arizona, and New Mexico. *For. Irrig.* **1905**, *11*, 120–124.

Table S2. General descriptions of fires and forest structure in Colorado and the San Juan Mountains

[53] (p. 196)	Large fires from 1876-1882 in Colorado	"...fully one-third of all the timber accessible among the mountains in [Colorado] has been burned over and killed by fire within the last six years"
[15] (p. 21)	Large, severe fires in the San Juan Forest Reserve	"Of the total forest area within the reserve boundaries 12-1/4 percent has been burned over, and 5 percent within ten years. All the Rio Grande side of the range from Hot Springs east, with the exception of bodies of spruce on the heads of creeks, has been burnt, much of it repeatedly. The result is a stand of aspen of varying ages, containing scattering small bodies of conifers, the ground throughout being covered with down timber and thick underbrush. Recent burns, especially above the aspen line, present a scene of complete desolation. Nothing is left but bare burnt poles. Even the top soil is burnt off in many cases, leaving only dust and rock. Such burns are very slow in restocking. After eight or ten years the poles will have fallen, piling up four feet high and making travel next to impossible. Here and there will be bushy, scrubby spruce seedlings, and everywhere on the ground a dense mat of grass which greatly retards reproduction."
[54] (p. 121)	San Juan ponderosa pine timber was uneven and less abundant than in the Zuni Mountains in New Mexico	"In the Southwest this species [ponderosa pine] is found scattered over the slopes of the Rocky Mountains at altitudes between 6,000 and 9,000 feet. There are three regions, however, where it extends over large areas in practically pure stands. The first of these is in extreme southwestern Colorado and northwestern New Mexico. Here a belt of western yellow pine forest, twenty-five miles wide, runs northwest and southeast for one hundred miles. There are six important mills operating in this territory, supported mainly by Denver trade and capital...The second region is in west central New Mexico, in the Zuni Mountains. This timber area is smaller than the former–only fifty miles in length by eighteen miles wide. The stand of pine is more uniform than that of the Colorado forest, however, and over a large part of the area it is of better development. The Colorado timber is estimated to yield from 3,000 to 4,000 board feet per acre; the Zuni timber will average from 4,000 to 6,000 board feet per acre. Stands of from 10,000-25,000 feet per acre occur quite frequently in the Zuni Mountains, but are rare in Colorado."

[50] (p. 122)	San Juan National Forest	"On the whole, the area now comprising the San Juan National Forest has suffered less from fires than is the case in many other sections of the west. Even so, there have been some disastrous fires in this territory and in some cases, years after the fire, the areas are entirely barren of timber"
[50] (p. 122)	San Juan National Forest	"Throughout the early days, before the white man reached the Western slopes numerous fires burned unchecked over large areas and their origin was contributed to Indians for purposes of securing game or improving grass lands. This theory is reported to be false by people who have lived with and know the Indians. They have never heard of Indians hunting in that manner. Most of those fires were probably caused by lightning. Fall is the dryest time of the year and because that was the time the Indians were hunting they were blamed. The fires burned over large areas owing to the fact that forage at that time was heavier and nobody bothered to put them out. Most of the early fires were allowed to burn until rain put them out. It is also believed that the largest of the fires came after the white man arrived. The old settlers contribute these fires to Indians, but more likely those settlers had the same habits and were as careless as the same type of people today."

References are in the main text, except [50], [53], [54]:

50. York, R. *Forest History*, *Volume 1*, *1905–1971*; Unpublished report; San Juan and Montezuma National Forests, Supervisor's Office: Durango, CO, USA, 1984.
53. Hough, F.B. *Report on Forestry*; US Department of Agriculture, Forest Service, US Government Printing Office: Washington, DC, USA, 1882.
54. Anonymous. Yellow pine in the Southwest. The Bureau of Forestry has been studying this important tree in Colorado, Arizona, and New Mexico. *For. Irrig.* **1905**, *11*, 120–124.