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Tree-Ring Perspectives on Fire Regimes and Forest Dynamics in Mixed-Conifer and Spruce-Fir Forests on Mount Graham

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Abstract

Cross sections from fire scarred tree stumps and logs were collected across an elevational gradient on Mount Graham to reconstruct a detailed history of forest fires, and to interpret forest stand dynamics over the past 300 years. The ponderosa pine and mixed-conifer forests of Mount Graham sustained surface fires at least once per decade before disruption of the fire regime around 1900. The reconstructed fire frequencies in the mixed-conifer zone were relatively high compared to frequencies typically found in other Southwestern forests at these elevations. High fire frequencies may have been due to fires easily spreading from many locations on the mountain to the sites that we sampled. A widespread and severe fire apparently occurred in 1685, and age structure from the spruce-fir zone suggests this event was a crown fire at the highest elevations. Both spruce and fir have been co-dominants at the high elevations since 1685, with a large pulse of fir recruitment in the mid-1800s. Ironically, the pre-1900 frequent surface fires in the mixed-conifer zone may have helped protect the spruce-fir forests at the top of the mountain from crown fires by providing a buffer of low fuel accumulation and continuity down slope. After a century of much reduced fire frequency in the mixed-conifer zone, this buffer no longer exists, and now fires can spread more easily from the surface fuels to tree canopies, and from low to high elevations. Restoration of forest structures and reduction of fuel accumulations in the mixed conifer zone is needed. If this work is not carried out soon, and if extreme drought years occur before restoration is accomplished, it is likely that additional extensive crown fires will spread across the elevational gradient and further decrease the area of mature spruce-fir forest on the mountain.

Introduction

Recent wildfires in southern Arizona and other regions of North America have sharply focused our attention on the condition of forests and landscapes. Large, high severity wildfires are occurring in the context of both drought and cumulative changes in forests due to past human land uses. Although the role of humans in changing forest structure and fire regimes in the past century seems relatively clear in mid-elevation ponderosa pine forests (e.g., Allen et al. 2002), it is arguable that fewer changes have occurred in high-elevation spruce-fir forests (e.g., Romme et al. 2003, Schoennagel et al. 2004). Insect and disease outbreaks are also occurring in many western U.S. forests, and likewise, the relative roles of humans and climate in changing these disturbance regimes are subjects of much debate and concern (Logan et al. 2003).

In many ways, Mount Graham is a microcosm of these issues. The forests of Mount Graham have been altered by more than a century of livestock grazing, road building, logging, and active fire suppression (Wilson 1985, Bahre 1991, 1998). In recent years, the addition of astronomical facilities to the mountain has greatly increased the concern about the state of these forest ecosystems (Hoffman and Istock 1995). Concerns were further increased following a large, destructive fire in 1996 and during the current drought and massive outbreak of phytophagous insects on the mountain. The purpose of this paper is to review the fire history of mixed-conifer and age structure of spruce-fir forests, and to use this knowledge to interpret past and current forest and fire regime changes in the Pinaleño Mountains.

Forests and Fuels on Mount Graham

Typical fire regimes and vegetation in the Pinaleño Mountains are associated with the elevational gradients found here (Figures 1 and 2). The topography is generally quite steep, and on the south side of the mountain, where our studies were conducted, there are few major barriers to fire spread (e.g., there are no broad rivers and few unbroken cliff faces or large talus slopes which might impede spreading fires). The consequence of these features are that fires starting in chaparral and woodlands on the steep slopes below about 2,800 m tend to burn upward into the mixed conifer zone at about 2,800 to 3,000 m. The mixed conifer forest covers the relatively level benches and ridges at the mid elevations, and spruce and fir forests occupy the steep slopes and peaks above the benches and ridges (from about 3,000 to 3,300 m).

Summary of Mixed-Conifer Fire History

We began our fire history and age structure investigations on Mount Graham in the early 1990s with support from the University of Arizona and the U.

S. Forest Service. As in many other investigations of fire history in southern Arizona and elsewhere in the western U.S. (see summaries in Swetnam et al. 2001, Swetnam and Baisan 1996, 2003) we utilized tree-ring dated fire scar samples from living and dead trees to reconstruct a multi-century record of fire history (Grissino-Mayer and Fritts 1995, Grissino-Mayer et al. 1996). A total of 90 fire scarred trees from three different sites on the mountain (Figure 1) were obtained, crossdated, and assembled into fire chronology charts (Figure 3). These collections were from relatively small areas (about 50 to 100 hectares each) to the south and west of Webb Peak, and on Webb Peak (Figure 1). The fire scar collection sites were in mixed-conifer forests composed of ponderosa pine, Southwestern white pine, Douglas-fir, and white fir.

The fire-scar chronologies from Mount Graham (Figure 3) illustrate a historical pattern commonly found elsewhere in the Southwest -- a remarkable abundance of surface fires during the period before the 1890s, and a striking decrease in fire frequency during the 20th century. This drop-off in fire occurrence is most likely related to intensive livestock grazing, which began in the 1880s or 1890s, followed by extensive road building and organized fire suppression by government agencies in the early 1900s. The evidence for livestock grazing as the initial cause of decline in the frequency of surface fires in the Southwest was originally noted by Aldo Leopold (1924), and was also commented on by early Forest Service rangers and others who witnessed these changes (Swetnam et al. 2001). The chief effect of intensive livestock grazing appears to have been the removal of grass fuels that were a primary carrier of the frequent surface fires. Another factor was the disruption of continuous ground fuels by livestock driveways and trails.

An interesting feature of the Peters Flat and Camp Point fire scar collection areas was the relatively high fire frequencies in these mixed-conifer sites during the pre-1893 period. The frequency of fires occurring anywhere within each of these sites was at least one fire per decade, and sometimes two or three fires per decade. There were a few longer periods without fire, lasting 13 years or longer. These high fire frequencies were more typical of lower-elevation ponderosa pine-dominated forests studied at numerous locations in the Southwest (Swetnam and Baisan 1996, 2003). Typical fire frequencies in Southwestern mixed-conifer forests above 9,000 feet were about one fire occurring every 15 to 30 years within similar size areas (i.e., about 50 to 100 hectare sites, Swetnam and Baisan 1996). Pre-1900 fire intervals in the Webb Peak site (at around 9,800 feet elevation) were much longer, ranging from about 30 to 60 years. When sampled, this site was essentially mixed-conifer, surrounded by spruce-fir forest

The unusually high fire frequency for the Mount Graham mixed-conifer stands at 9,000 feet elevation may be the result of the topographic setting. Steep slopes drop away to the south and west of these sites (Figure 1), and it was likely that fire occurring at lower elevations within several very large watersheds would spread into these forests. Likewise, fires igniting on the benches and ridges at mid-elevations to the north or east would have spread unhindered because there were no major barriers to fire spread from these directions. The high fire

frequencies in mixed-conifer forests during the pre-1893 period led to some important interpretations regarding the history and dynamics of the spruce-fir forests that existed upslope on the higher peaks (i.e., Webb, Emerald, Hawk, and Mt. Graham). We will return to these interpretations and implications in the summary and conclusions section.

There were a few other interesting changes in fire occurrence in the combined Peters Flat and Camp Point fire chronologies (Figure 2). Specifically, in addition to the sharply decreased fire frequency after the 1890s, other decadal-scale shifts in fire frequency can be discerned between different periods during the 1700s and 1800s (see notations at the top of the fire chronology chart in Figure 2). A relatively higher frequency of fire-scar dates occurred during the 1700s, and a relatively lower frequency during the early to mid-1800s. Moreover, the frequent fires during the 1700s were somewhat less synchronous (i.e., less widespread) between trees than the less frequent fire dates during the early-mid 1800s. A slight increase in fire frequency occurred in the late 1800s.

Similar decadal-scale changes have been detected in several other locations in the Southwest (e.g., the Santa Catalina Mountains, the Mogollon Mountains of southern New Mexico, El Malpais National Monument in west-central New Mexico, and the Jemez Mountains of northern New Mexico) (Grissino-Mayer and Swetnam 2000, Swetnam and Baisan 2003). The shifts in fire frequency are less pronounced in the Mount Graham chronologies than in these other mountains, where the reduced fire frequency during the early 1800s was sometimes marked by an exceptionally long fire-free period lasting 2 or more decades.

Summary of Spruce-Fir Age Structure and Fire History

Spruce-fir forests generally burn only as crown fires and at intervals of centuries (Schoennagle et al. 2004). Surviving fire-scarred trees are exceedingly rare in these forests. Therefore, to determine the fire history and dynamics of spruce-fir forests it is necessary to study tree ages. Numerous trees were felled during the clearing of roadways and telescope construction sites on Mount Graham, and so we took this opportunity to obtain cross-section samples from the stumps near ground level. We crossdated the tree rings and determined the innermost ring dates at the pith on 156 spruce trees and 117 fir trees. These dates were probably within 5 to 10 years of the actual germination dates of the trees. The resulting temporal distribution of innermost ring dates indicates that recruitment of spruce and fir trees was nearly continuous since the late AD1600s, but with several surges in recruitment by spruce or fir (Figure 4).

Several aspects of the spruce-fir age distribution were notable. First, it appears that at least part of the spruce-fir forest on Mount Graham was largely the result of a long-term process of succession following an extensive crown fire in 1685. Both spruce and fir were present early in the succession process. This interpretation derives from the facts that: (1) we identified a widespread 1685 fire event from fire-scar dates within mixed-conifer forests down slope (see Figure 2), (2) none of the innermost tree-ring dates from the spruce or fir extended before

the 1685 fire date, (3) growth rates of surviving Douglas-fir trees at the spruce-fir ecotonal border were severely suppressed, suggesting they may have been damaged (e.g., crown scorch or root killing) by a severe fire, and (4) the average growth rates of spruce and fir trees during the 1690s and early 1700s was rapid, indicating a relatively open stand condition (Figure 3). Stromberg and Patton (1991), who estimated ages for numerous spruce-fir stands on the mountain, also inferred a widespread disturbance just prior to 1700.

In addition to the evidence suggesting a post-1685 fire origin for the sampled spruce-fir stands, the tree-age structure and fire-scar evidence from Webb Peak provides other clues about the dynamics of these forests. Periods of increased and decreased tree recruitment of the two species may reflect responses to the combined effects of climatic variations and fire events (Figure 4). Surface fires were very rare or non-existent in spruce-fir forests on Mount Graham, as indicated from the lack of fire-scarred trees in these stands (personal observations by the authors from extensive searching in these areas). The few fire-scar samples we have from Webb Peak were from a warm, southern exposure supporting a mixed-conifer stand (mainly Douglas-fir and Southwestern white pine), rather than spruce-fir. However, because this stand was nestled within the spruce-fir zone, the fire history from this location reflects the cooler, more mesic environment at this elevation. It was also likely that localized, intense crown-fire events of small to moderate patch size also occurred in the spruce-fir forests during recent centuries. Such localized crown fires were suggested by the presence of small patches of aspen trees within the spruce-fir stands on Mount Graham in various locations. We currently do not have tree-ring dates or size estimates from these aspen patches, but research is underway on these patches in the Pinaleños and elsewhere in the Southwest (Ellis Margolis, Lab. of Tree-Ring Research, personal communication).

The combined evidence of age structure, growth rates, and the few fire-scar dates from the Webb Peak site suggests the following scenario. The 1685 fire burned through mixed-conifer stands at the 9,000-foot level as a very large surface fire, and possibly created openings by torching individual trees and small patches of forest. This fire likely occurred as a widespread crown fire within spruce-fir stands on the higher elevation peaks. After 1685, spruce and fir trees re-established simultaneously in the severely burned areas at the high elevations. Spruce was probably a larger proportion of the initial regeneration than fir. The open nature of the stands during the initial conditions was reflected by the typically large ring widths of trees that established at this time (Figure 4). Occasional fires (e.g., 1719, 1785) may have ignited and spread into parts of the young spruce-fir stands, but by the mid and late 1700s the spruce-fir forest had largely re-established. An increasing proportion of fir trees established during the mid-1800s, with a notable pulse occurring between 1830 and 1860.

We think it is likely that a combination of factors led to the increased fir recruitment during the 19th century, but the exact mechanisms are unclear. Climatic conditions in the Southwest were generally cool during the early to mid 1800s (Briffa et al. 1992, Salzer 2000), and drought conditions prevailed during the 1820s to 1830s (Cook et. al. 1999). Fire regimes shifted from relatively

frequent to less frequent in the mixed-conifer forests down slope. The spruce-fir forests on the high elevation peaks were approaching middle age (i.e., 120-150 years) and some stand thinning probably occurred via individual and group tree mortality (e.g., via lightning, beetle attack, etc.) and wind throw. Perhaps the effects of a sharp and sustained drought between 1817 and 1826 combined with beetle mediated mortality led to stand openings in the upper elevation forests. By the late 19th century and early 20th century the canopies of most spruce-fir stands at the high elevations were relatively closed, with a broad mixture of old growth, middle-aged, and young trees (Figure 4).

Summary and Conclusions

A generalized picture of the variations in fire regimes along elevational gradients on Mount Graham (Figure 2) was one of infrequent surface and crown fires in the lower elevations (i.e., about 7,000 to 8,500 feet), frequent surface fires (5 to 35 year intervals) at middle to high elevations (i.e., about 8,500 to 9,500 feet), and very infrequent crown fires at the highest elevations (i.e., 150 to 300+ year intervals). It is important to note that these arevery general characterizations of fire frequencies and severities, and there was considerable spatial and temporal variability. For example, although fires were frequent in the mixed-conifer zone and generally of low severity, it was also likely that high-severity fire occurred in some variable sized patches within this type. Also, very infrequent, large, and high-severity crown fires were the norm within the spruce-fir zone, but it was possible that occasional surface or ground fires crept into portions of this forest from adjacent mixed-conifer, and high-severity, small-patch size (individual trees or groups) events probably also occurred in this zone.

One of the more interesting implications of the pre-1900, high-frequency surface fire regime of the mixed-conifer forests on Mount Graham was the possibility that this fire regime promoted some degree of long-term stability to the higher elevation spruce-fir forests. Frequent surface fires in the mixed conifer zone probably maintained relatively open stands with low woody fuel accumulations, grassy understories, and elevated tree canopy layers. Fires igniting in the mixed-conifer, or at lower elevations, would have spread through the mixed-conifer zone at relatively low intensities/severities, so that when fires reached the high elevation spruce-fir zone they were unlikely to spread into the canopy and develop into crown fires. A typical observation of surface fire spread from mixed conifer to spruce-fir (under low to moderate wind conditions) is that fire spread slows dramatically in the tightly packed needles of the closed-canopy, spruce-fir. In the shady, cool and moist conditions of spruce-fir, there is generally little herbaceous cover, and surface fires typically become smoldering ground fires that do not spread great distances (personal observations of authors Swetnam and Baisan).

In contrast, a century of greatly reduced fire frequencies since 1893 (Figure 3) has undoubtedly led to increased accumulations of woody fuels and forest densities in the mid-elevation mixed-conifer forests. As a result, fires igniting in this zone, or down slope of this zone, have a high probability of

becoming crown fires before they reach the spruce-fir zone. This kind of transmission of crown fire from the low and mid elevations to the high elevations was the circumstance for the 6,000+ acre Clark Peak Fire of 1996. The fire started near Riggs Lake in pine and mixed conifer and subsequently burned up into the spruce-fir zone (Arizona Daily Star, April 27, 1997 article). This late-April fire might have been a much larger event if it had not occurred so early in the season, when fuel moistures were still relatively high in the spruce-fir zone.

Ultimately, the preservation of extensive spruce-fir ecosystems (including red squirrels) on Mount Graham will depend upon restoring forest structures and surface fire regimes in the mid-elevation mixed-conifer forests. If these structures and fire regimes are not restored at a minimal level, we think that extensive crown fires will continue to occur on Mount Graham until most of the spruce-fir forest is reduced to isolated, small patches, and much younger successional stands with widespread aspen. The mixed-conifer forests are also likely to be increasingly converted to aspen and shrub fields.

The current insect outbreaks on Mount Graham certainly complicate the trajectory of change (see Lynch, this volume). It is likely that beetle outbreaks have occurred before on the mountain, but their frequency and extent is unknown. Conceivably, droughts of the late 1600s contributed to tree death and mortality, including beetle-killed trees, and this may have been a predisposing factor for the 1685 fire.

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Figure 1. Map of tree-ring sample areas in the Pinaleño Mountains, Arizona. Fire scars were sampled in the shaded areas (vertical bars) at Peter's Flat, Camp Point, and Webb Peak. Cross section samples for age structure analysis were obtained from the cleared roadway and telescope construction sites near Emerald Peak and Mt. Graham.

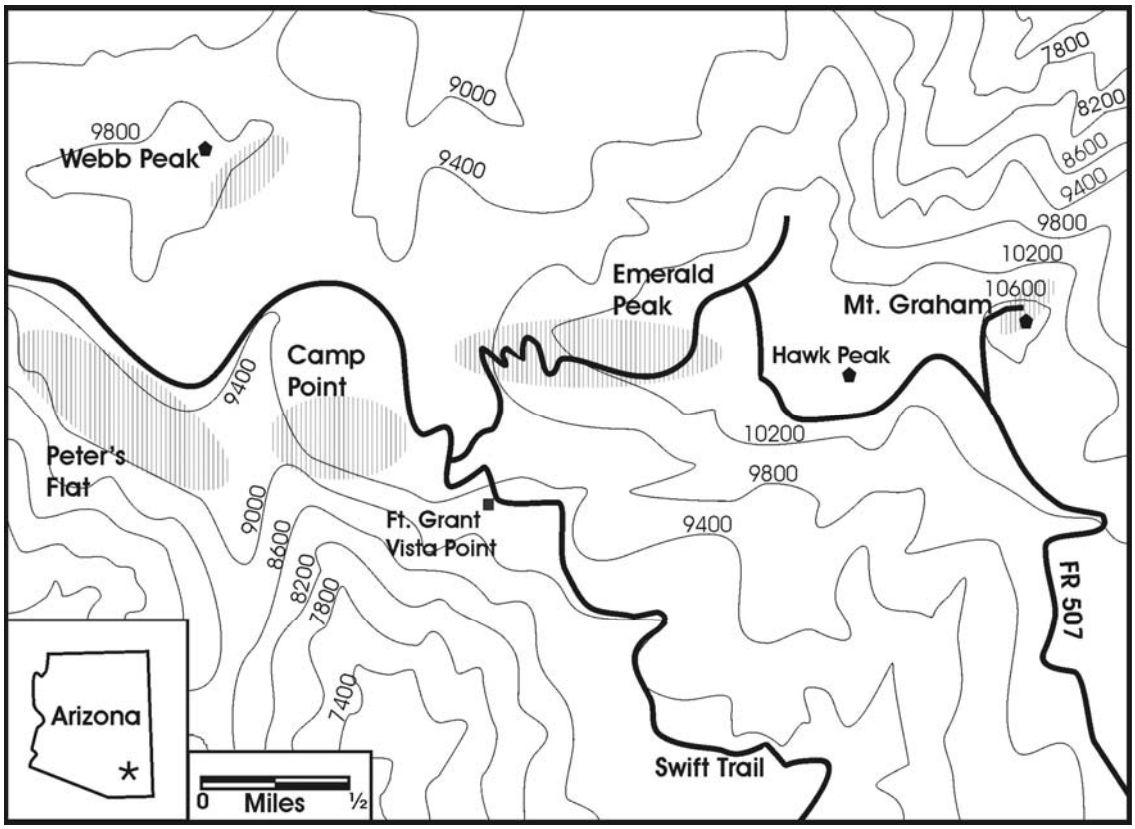
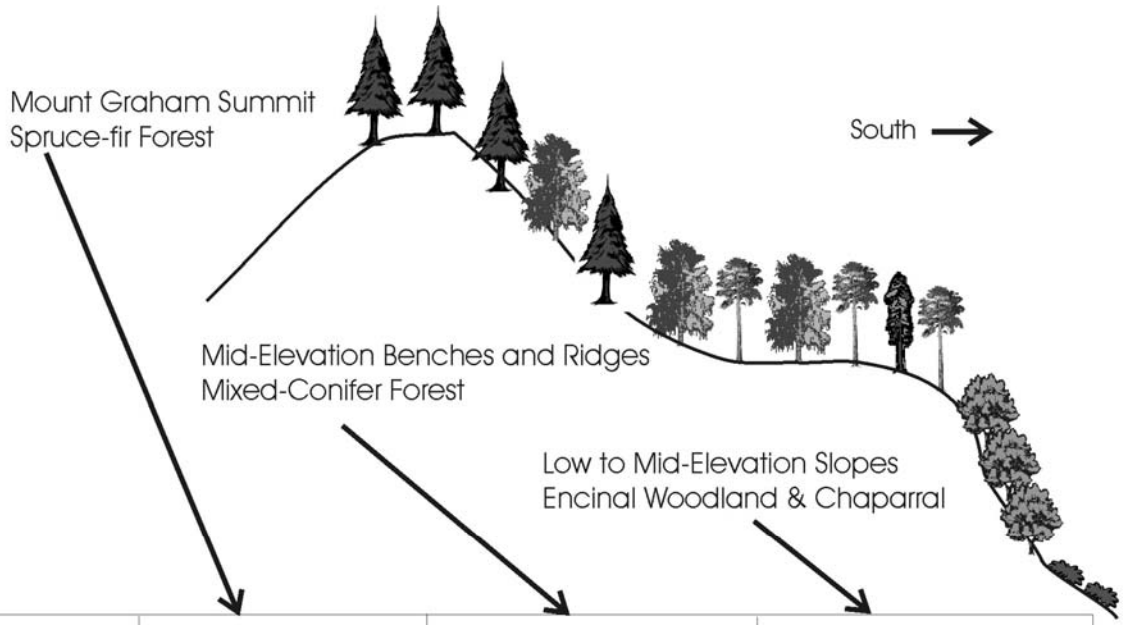


Figure 2. Schematic of elevational gradient on Mount Graham, showing dominant tree species in forest and woodland over stories, and inferred pre-1900 fire regimes (FRI= fire return interval).



Tree Species:	*Picea engelmanni* *Abies lasciocarpa* *Abies concolor* *Populus tremuloides*	*Pinus ponderosa* *Pinus strobiformis* *Pseudotsuga menziesii* *Abies concolor*	*Quercus species* *Juniperus species* *Arctostaphylos species*
Elevation:	9,500-10,600 ft (3,000-3,300 m)	8,000-9,500 ft (2,800-3,000 m)	6,500-8,000 ft (2,000-2,800 m)
Fire Regime:	Infrequent (150y+ FRI), stand-replacing, high intensity & severity	High frequency (5-35y FRI), surface fire & small patch crown fire, low to moderate severity	Moderate frequency (35 to 100y+FRI?), Surface fire & moderate to large patch crown fire, moderate to high severity

Figure 3. Combined fire scar chronology charts from Peter's Flat and Camp Point. Horizontal lines are the time spans covered by the tree-ring record from individual sampled trees, and the vertical tick marks are the fire dates recorded on those trees. The dates listed in the composite at the bottom are the fire events that were probably relatively widespread. (Hint: An effective way to better visualize fire frequency shifts and degree of synchrony of fire dates on the chart is to tilt the page to a low angle relative to your eye – looking toward the top of the page from the bottom.)

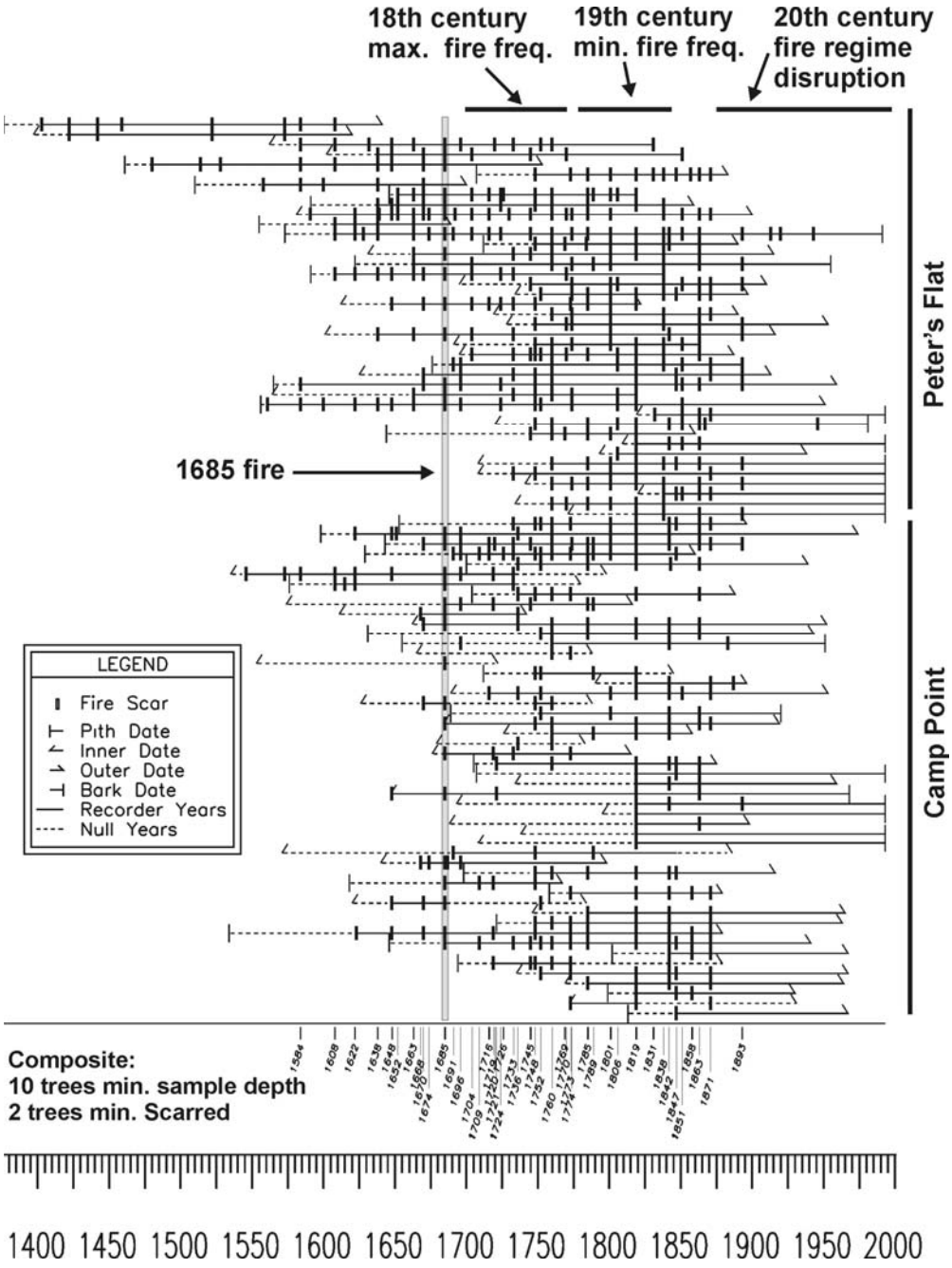


Figure 4. Spruce and fir age structure compared with average initial growth rates. The earliest tree-ring dates from the spruce and fir cross sections are plotted in ten-year groups. The average initial growth is the running average of the first 20 years of ring widths among all of the spruce and fir trees. The fire events indicated were recorded at Webb Peak as well as Peter's Flat and Camp Point fire history sites.