STAND-REPLACING FIRE HISTORY AND ASPEN ECOLOGY IN THE UPPER RIO GRANDE BASIN

by

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ABSTRACT

Dendroecological techniques were applied to reconstruct stand-replacing fire history in mixed conifer and spruce-fir forests in northern New Mexico and southern Colorado. Stand-replacing fire dates with annual accuracy and precision were determined using four lines of evidence for each of twelve sites within a 75,000 square kilometer area. The four lines of evidence were: (1) aspen inner-ring dates, (2) conifer death dates, (3) tree-ring width changes, or other morphological indicators of injury, and (4) fire scars. The annual precision of dating allowed the identification of significant synchrony of stand-replacing fires among the 12 sites and regional surface fire events previously reconstructed from the large network of fire scar collections in the Southwest. Nearly all of these synchronous stand-replacing and surface fire years coincided with extreme droughts. This suggests that stand-replacing fire activity occurred primarily when drought conditions allowed fires to ignite and spread within these high elevation forests and/or for the spread of surface fires between lower and upper elevations. Fifty percent of reconstructed stand-replacing fires pre-dated large-scale Euro-American settlement in this region. This may suggest that land use practices (such as logging and mining) were not as important in promoting stand-replacing fires in these study sites, as compared with other areas in Colorado.

CHAPTER ONE

INTRODUCTION TO THE THESIS

Disturbance and Fire

The importance of understanding the role and effects of natural disturbances is a paradigm of current ecological research (Pickett and White 1985; Turner 1987). Large, infrequent disturbance events are of particular interest (Turner et al. 1997), because of their ecological significance, threats to human life and property, and high visibility in the media (e.g., 1988 Yellowstone fires, 2000 Cerro Grande fire, and the 2003 southern California fires). The extent and frequency of high severity crown fires are key determinants of subsequent successional processes and vegetation composition in subalpine and boreal forest types (Turner et al. 1994; Turner and Romme 1994; Bessie and Johnson 1995). Beyond the local ecological effects of large crown fire events, the potential influence of these disturbances on regional and global carbon cycles further broadens the implications and importance of understanding these events (Houghton et al. 2000; Page et al. 2002; Breshears and Allen 2002)

A common approach to studying disturbance regimes is to use historical ecological data to gain an understanding of the natural range of variability of the process, which can be an important input to land management (Swetnam et al. 1999). Numerous stand-replacing fire history studies have been conducted in the northern and central latitudes of North America (Heinselman 1973; Van Wagner 1978; Romme 1982; Johnson and Gutsell 1994; Kipfmueller and Baker 2000), where forest types with crown fires regimes are dominant on the landscape. In the arid Southwestern United States, surface fire regimes have been extensively studied (Baisan and Swetnam 1990; Swetnam and Baisan 1996; Moore et al. 1999; Veblen et al. 2000; Brown et al. 2001; Allen 2002; Swetnam and Baisan 2003), yet few studies have addressed stand-replacing, crown fire events in the region (*see* Touchan et al. 1996; Romme et al. 1996; Abolt 1997).

Research on stand-replacing fires is important not only because of the effects on vegetation, but also because of hydrologic effects. Post-fire watershed responses to recent crown fires in the Southwestern U.S. have resulted in runoff and erosion events two orders of magnitude greater than pre-fire conditions (Johansen et al. 2001; Veenhuis 2002). Crown fires remove overstory vegetation and ground cover that dramatically affects watersheds and water resources by altering the important processes of evapotranspiration, interception, surface flow, and subsurface flow (Knight et al. 1985). Alteration of these processes results in sediment and water yield increases on most watersheds following fires (Potts et al. 1985). An increase in water yield may seem to be beneficial in an arid region, yet the increase is often in the form of flood events coupled with increased potential of mass movements. For example, the stand-replacing La Mesa Fire of 1977 in Bandelier National Monument, NM was followed by back to back 50-year magnitude flood events in 1977 and 1978 (McCord 1996; Veenhuis 2002). The potential hydrologic impacts of stand-replacing fires pose serious problems for water resources in a region currently faced with a limited water supply that is increasingly vulnerable to climatic variation (Liverman and Merideth 2002).

Fire-Climate Relationships

Recent occurrence of high severity fires, larger than any in the documentary records of the Southwestern U.S. (e.g., 2002 Rodeo-Chedeski Fire), are cause for immediate concern. Twentieth century fire suppression has resulted in increased fuel loading in many areas. Combined with drought events, these changes have led to an increase in crown fire occurrence in recent decades (Swetnam 1990; Covington and Moore 1994; Dahms and Geils 1997). In addition to fire suppression effects, the increased vegetation stress and mortality caused by anticipated climate changes are expected to lead to increasing impacts from disturbances such as intense crown fires (Overpeck et al. 1990). Considering that region-wide fire occurrence is linked to inter-annual and decadal climatic fluctuations (Swetnam and Betancourt 1998; Grissino-Mayer and Swetnam 2000) regional warming trends would probably lead to an increase in regionally synchronous and severe fire events in the future (Torn and Fried 1992; Price and Rind 1994).

Climate variability at inter-annual to centennial time-scales has been shown to be a forcing mechanism for fire regimes in the Southwest, Central Rockies and the Pacific Northwest (Swetnam and Betancourt 1990a; Swetnam 1993; Veblen et al. 1999; Grissino-Mayer and Swetnam 2000; Kitzberger et al. 2001; Heyerdahl et al. 2002). Drought during the fire year is strongly associated with fire occurrence, but lagging relationships between fire occurrence and antecedent moisture conditions that drive fine fuel production have also been demonstrated for surface fire regimes in the intermountain west and the Southwestern U.S. (Knapp 1995; Swetnam and Baisan 1996; Westerling et al. 2002). This pattern of fire occurrence in the Southwestern U.S. has been shown to vary with synoptic-scale oscillations in the climate system. The wet and dry phases of the El Nino-Southern Oscillation (ENSO) have been shown to significantly influence and synchronize the probability of fire occurrence in the Southwestern U.S. (Swetnam and Betancourt 1990b; Swetnam and Betancourt 1998) and northern Patagonia, Argentina (Kitzberger et al. 2001; Kitzberger 2002). This link between surface fires and regional, inter-annual climate variability has led to attempts at fire forecasting (Westerling et al. 2002) and preliminary results have been made available to land management agencies to prepare for high-risk fire years (Garfin and Moorehouse 2001). Similar analysis of fire-climate relationships with a regional, stand-replacing fire data set may reveal robust patterns useful in forecasting patterns of the large, severe fire events.

Aspen Ecology

Extensive quaking aspen (*Populus tremuloides* Michx.) stands are present in the upper montane forests throughout the Southwestern U. S. Aspen in upper elevation forest community types often exhibits life-history traits of a seral species, sprouting profusely following stand-replacing fire events (Barnes 1966; Peet 1978; Mitton and Grant 1996). Stem densities can increase by greater than two orders of magnitude following fire in the Southwestern U.S. (Patton and Avant 1970), and reach densities of up to 160,000 per hectare (Schier et al. 1985). The post-fire asexual regeneration, often referred to as “suckers,” exhibits high initial growth rates that facilitate accurate age determination. Stem heights of greater than 1m are common one year post-fire (Crouch 1981; Bailey et al. 1990; Romme et al. 1995). This regeneration strategy provides an initial competitive advantage for the shade-intolerant aspen, which are eventually outcompeted by shade-tolerant conifers that germinate below the aspen canopy. The high density and rapid growth rates of post-fire aspen reproduction are life-history traits particularly important for dating stand-replacing fire events.

The importance of quaking aspen extends well beyond its potential as a record of stand-replacing fire events in the Southwestern U.S. Quaking aspen is the most widely distributed native tree in North America and the second most widely distributed worldwide (Jones 1985). Aspen is the dominant deciduous tree species in high elevation forest of the western U.S. and often exists as the only species filling this important ecological niche (Mueggler 1985). The genetic diversity of aspen, present between as well as within clones (Tuskan et al. 1996) is unparalleled in the botanical world (Cheliak and Dancik 1982; Mitton and Grant 1996). Aspen is also a valuable economic resource that draws tourists to view brilliant fall colors, and recent increases in timber values have made it a desirable silvicultural resource (Mitton and Grant 1996; David et al. 2001).

Numerous researchers have expressed concern over a lack of aspen regeneration and decreased aspen cover in recent decades (Johnson 1994; Romme et al. 1995; Shepperd et al. 2001). There are even claims that aspen is in danger of local extirpation (Kay 1997; Bartos and Campbell 1998). Many hypotheses have been proposed to explain and describe these trends. Fire suppression has been implicated as a cause for observed decreased in aspen regeneration (Houston 1973; Mueggler 1989; DeByle 1990), which is likely in some areas, but not well studied. Other hypotheses to explain reduced aspen regeneration include increased ungulate browsing (e.g., elk, deer, livestock), but this has been shown to be highly variable in space. Elk browsing during winter months significantly hindered aspen regeneration following the 1988 Yellowstone fires in some areas (Baskin 1999), yet no browsing effects were noted in other areas of the park (Romme et al. 1995). Other data suggest similar spatially variable regeneration success, even in areas of high elk density (Suzuki et al. 1999; Barnett and Stohlgren 2001). Hessl and Graumlich (2002) found that fire interacted with elk population variability to affect aspen regeneration, and they discuss this in context of anthropogenic alteration of a top-down regulated system.

An increased susceptibility of aspen to endemic pathogens and insects has also been proposed to explain a perceived decreased in aspen vigor. Aspen is host to many diseases and over 30 pest insect species (Hinds 1985) that are often the final cause of observed stem mortality. Susceptibility to these organisms may be increasing with current warming trends and predicted climate change (Overpeck et al. 1990; DeByle 1990; Hogg et al. 2002). There is evidence in New Mexico that recent outbreaks of the western tent caterpillar (*Malacosoma californicum fragile* Stretch) are anomalous in duration over the last 250 years (E. Q. Margolis et al., *unpublished manuscript*). Six consecutive years of defoliation circa 1980 resulted in severe reduction of annual growth and apical die-back in some stands. All factors affecting aspen survival and regeneration, including fire, climate, and biotic stress, are likely to be interacting in concert with a high degree of spatial variability, with individual stands being particularly susceptible (Romme et al. 1995).

Research Goals and Objectives

The goal of this research was to determine annually resolved dates of historic stand-replacing fires at a landscape scale in the upper Rio Grande Basin and use these data to test for fire-climate relationships and interactions with surface fire regimes. A combination of dendroecological techniques were used to develop a method for dating past stand-replacing fire events with annual accuracy and precision (Chapter 2). The new method was used to date past stand-replacing fires at a network of aspen sites in the upper Rio Grande Basin, thereby developing a regional stand-replacing fire data set (Chapter 3). The regional data set was used to assess relationships between stand-replacing fires and regional drought, as well as relationships between regional surface fire years and stand-replacing fire years (Chapter 3).

CHAPTER TWO

USING MULTIPLE LINES OF EVIDENCE TO RECONSTRUCT STAND-REPLACING FIRES IN UPPER MONTANE FORESTS

Introduction

Knowledge of fire history is vital when attempting to understand the dynamic complexities of ecosystem function (Romme 1982; Turner et al. 1993; Turner and Romme 1994) and to make well advised land management decisions (Swetnam et al. 1999). The recent occurrence of large crown fire events in the Southwestern U.S. have emphasized the need to develop and apply methods to research the stand-replacing fire history of the region. Contemporary crown fire events have occurred in the overstocked ponderosa pine forests where little evidence of stand-replacing fires of recent magnitude exists (*but see* Brown et al. 1999; Kaufman et al. 2000). Large, seral aspen stands in upper elevation forests of the Southwestern U.S. are evidence of past stand-replacing fire in the region, yet little is known about these events. Much of the past and present fire research in the region is focused on the ponderosa pine forest type (Weaver 1947; Cooper 1960; Swetnam and Baisan 1996; Brown et al. 1999; Veblen et al. 2000; Allen et al. 2002). Information regarding past stand-replacing fire events in the upper montane forests can be useful to test whether current fires are larger than have occurred in the past. Determination of stand-replacing fire-climate relationships may be useful in predictive models. Data describing historical stand-replacing fire regimes would be useful in guiding the management of upper elevation forests of the region.

A variety of methods have been developed to collect and analyze fire history data, including analysis of charcoal in sediments (Clark 1990; Meyer et al. 1992), remote sensing (Minnich 1983), and historical accounts (Bahre 1985; Shinneman and Baker 1997), yet the most common long-term fire history data source is tree-rings (Heinselman 1973; Arno and Sneck 1977; Swetnam and Baisan 1996). All methods have unique strengths and weaknesses, thus a combination of methods can help improve confidence in reconstructed scenarios. Amongst the suite of methods, tree-rings provide a moderately long record, moderate research time and financial investment, and have the potential to produce highly accurate and precise data. Crossdating of tree-rings using dendrochronological techniques (Douglass 1941; Stokes and Smiley 1968) is the only method that can reliably reconstruct pre-settlement fire history with sub-annual accuracy and precision (Madany et al. 1982; Dieterich and Swetnam 1984).

The application of dendrochronology-based fire history methods tends to vary along the spectrum of fire regimes, from low intensity, surface fire regimes to stand-replacing, crown fire regimes. Two general classes of tree-ring based fire history reconstruction methods exist: (1) fire scar analysis and (2) age structure analysis. The two methods are often combined, but fire scar analysis is most appropriate for surface fire regimes, while age structure analysis is most appropriate for stand-replacing fire regimes. This is due to the most common type of evidence created by surface fires (fire scars) and stand-replacing fires (post-fire cohorts). Fire history reconstruction methods have been applied across a wide geographic range from Siberia (Swetnam 1996), to northern Patagonia, Argentina (Veblen et al. 1999), and throughout North America (Johnson and

Fryer 1987; Baisan and Swetnam 1990; Heyerdahl et al. 2002) encompassing surface fire regimes, crown fire regimes and varying combinations of the two, termed "mixed regimes."

In the U.S. there is a general geographic division in the development and use of dendrochronology-based fire history methods. Fire scar analysis is the most common fire history reconstruction method in the Southwestern U.S. This region is dominated by forest types historically structured by surface fire regimes (Swetnam and Baisan 1996; Moore et al. 1999). In contrast, the large number of fire history studies in crown fire-dominated subalpine forests of the Rocky Mountains and boreal forests of Canada rely heavily on age structure data (Van Wagner 1978; Romme 1982; Kipfmueller and Baker 2000). As this geographic ordination of fire history methods suggests, little is known about the ecological history of stand-replacing fires in the Southwestern U.S.

Some recent studies in the Southwestern U.S. have begun to use aspen age structure to reconstruct stand-replacing fire history. Abolt (1997) estimated aspen stand ages in mixed-conifer forests using increment cores and compared these dates to adjacent fire scar dates to reconstruct fires in the Gila Wilderness of southwestern New Mexico. "Probable fire origin dates" extending back to 1748 are reported, indicating the potential for a 250 year stand-replacing fire history in the Southwestern U.S. Touchan et al. (1996) employed a similar method in mixed conifer forests of the Jemez Mountains, New Mexico and found fire scar dates that corresponded to adjacent aspen recruitment pulses at some sites and no correspondence at other sites. It was concluded that the area likely had a mixed fire regime, with fine-scale stand opening events associated with some of the surface fires recorded by fire scars. Romme et al. (1996) developed a method based on aspen age structure to reconstruct fire history where fire-scarred trees were lacking, on the west flank of the La Plata Mountains in southwestern Colorado. The absence of fire scars and aspen ages that were pooled into ten year classes, limited the resolution of the fire history to decadal precision. Methods that have been successful at determining annual fire dates combined fire scar evidence with aspen age structure, but this is limited to areas where well preserved, fire scarred material is present.

In this paper I describe a new methodology that combines four lines of dendroecological evidence to date stand-replacing fire events represented by seral quaking aspen (*Populus tremuloides* Michx.) stands in upper montane forests. The utilization of conifer death dates, growth change/injury dates, and aspen regeneration dates allows the method to be applied to forest types where annually resolved fire history is unknown. The benefit of the methodology is the annually resolved stand-replacing fire data that can be used to analyze fire-climate relationships and interactions between surface fire and stand-replacing fire occurrence. The method is applicable at landscape scales throughout the Southwestern U.S. and potentially other regions where seral aspen stands exist. This chapter describes the new methodology and the results of a stand-replacing fire history reconstruction at an aspen site in the Southern Rocky Mountains. The method was applied to eleven additional aspen sites throughout the upper Rio Grande Basin to reconstruct a regional stand-replacing fire history (see chapter 3 of this document).

Study Area

The method was developed and tested on an approximately 1,000 ha study area containing large quaking aspen stands, approximately 25 kilometers northeast of Santa Fe, New Mexico (Figure 2.1). The site is reported to have burned circa 1880 in a crown fire event (Debuys 1985:291). The study area is located on the Santa Fe National Forest in the Sangre de Cristo Mountains. The site is characterized by a predominant west aspect and elevations between 2820 m and 3460 m. The upper montane vegetation is dominated by quaking aspen. The adjacent forest at the upper elevations is comprised of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* [Hook] Nutt.). Douglas-fir (*Pseudotsuga menziesii*[Mirb.] Franco.) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) are present on south aspects below the aspen stand.

The precipitation regime at the study site is characterized by frontal storms in the winter months and very localized, intense thunderstorms in the summer months. Greater than 50 percent of the annual precipitation occurs between July and October, with much of the winter precipitation falling as snow. Annual average precipitation (1953-1979) recorded at a site with similar elevation (3258 m) approximately 100 km to the south was 583 mm. The monthly precipitation maximum occurs in August and minimum in February. The annual average temperature (1953-1979) was 3.0°C, with the warmest month being July (19.1°C) and the coolest in January (-10.5°C) (Western Regional Climate Center, 2003).

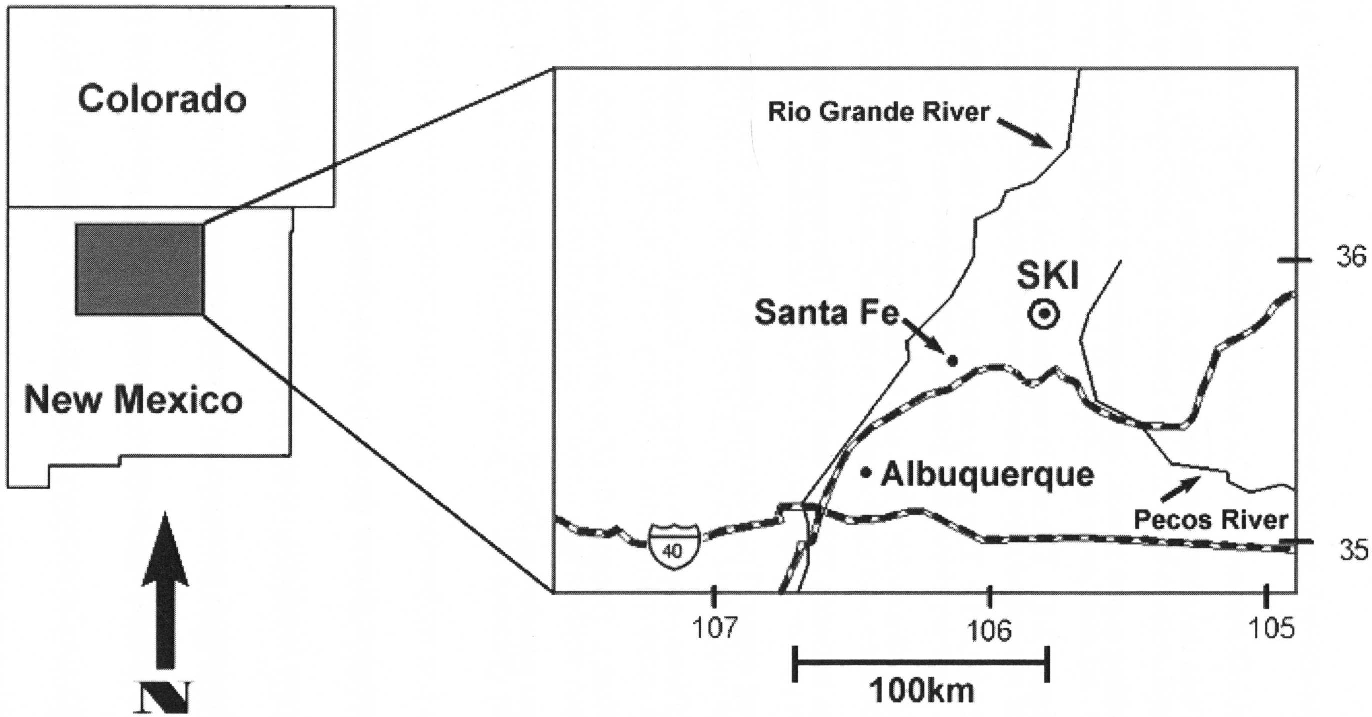


Figure 2.1. Location of stand-replacing fire study site (SKI) in the southern Sangre de Cristo Mountains, northeast of Santa Fe, NM.

The geology of the region is dominated by the Rio Grande Rift that runs south from the San Luis Valley of southern Colorado to the Texas border (Kues and Callender 1986). The study site is located on the eastern side of the basin at the southern end of the Sangre de Cristo Mountains. This range consists primarily of Precambrian igneous and metamorphic formations overlain by late-Paleozoic and lower Cenezoic sedimentary rock (Hawley 1986). Soils were generally mollisols in the aspen stands with inceptisols present at the higher elevations (Maker and Daugherty 1986).

There is archaeological evidence of Paleo-Indian presence in the Rio Grande Basin over 10,000 years before present (b.p.). The Oshara culture occupied the valley 3000 years b.p., followed by the most recent indigenous group, the Pueblos (Wolf 1995). Evidence of the Pueblo culture in the Santa Fe area dates circa 1100 and the Spanish made modern-day Santa Fe the capital of New Mexico in 1609 (Debuys 1985:49). Widespread Euro-American settlement in the valley dates circa 1870, attributed to the mining boom in the Sangre de Cristos (Debuys 1985:149; Wolf 1995). No specific citations were found describing interactions between human settlement and fire during the nineteenth century in the Santa Fe area. An analysis of 400 years of interaction between land use and surface fire regimes in the Sandia and Manzano Mountains near Albuquerque, NM indicates that human activities (e.g., livestock grazing, fuelwood gathering, active fire suppression) modified past fire regimes (Baisan and Swetnam 1997).

Field Methods

Sampling was conducted to obtain four lines of tree-ring evidence for stand-replacing fire dating: 1) aspen inner-ring dates, 2) death dates of fire-killed conifers, 3) conifer growth changes or other morphological indications of injury and 4) conifer fire scars. Digital Ortho Quarter Quads (DOQQ's) were used to estimate aspen aerial extent and to systematically locate potential sample points to provide extensive sample coverage of the aspen stands. Adjustment of potential sample point location was made in the field due to site specific topographic impediments and hazards (e.g., rock outcrops, cliffs, etc.). Additional sample points were added when patches appearing to have originated from different fire events were encountered in the field (Romme 1982). Approximately 20 dominant aspen stems were collected at approximately 10 sample points for every 200ha of aspen. A minimum of 15 stems were sampled in small stands. This was based on a method developed for dating analogous post-fire cohorts in lodgepole pine (Kipfmueller and Baker 1998).

Increment cores from dominant aspen were collected at all sample points to determine inner-ring dates. The two aspen of greatest dbh, within a 10m radius of the sample point were cored. Two increment cores were extracted from each stem at $\leq$0.3 m core height, until one core with pith was obtained at the sample point. Aspen were cored perpendicular to the bole, which is the first step for accurate determination of annual rings. Cores were extracted from the downslope side of the bole to get as close to the root crown as possible. When stems with rotten centers were encountered, stems with similar dbh were cored until a solid core was obtained even if this was beyond the 10m radius. All increment cores were labeled and stored in paper straws for transport to the laboratory.

Conifer samples matching the three other lines of evidence (tree death date, tree-ring growth change or injury, and fire scar) were collected when encountered throughout the study area. Conifer evidence of fire was rarely present at sample points. It was necessary to search the site for this material, thus it was collected opportunistically and by searching between sample points. Fire-killed conifers were carefully sampled with a hand saw, with the goal of retaining the bark/outer-ring interface. Plastic wrap was used to secure the fragile samples (often in multiple pieces) for transport to the lab. Increment cores were collected at breast height from potential fire-surviving conifers. These "fire survivors" were sampled to identify the timing of post-fire growth changes and for the presence of cambial injury. Fire survivors typically had elevated crowns, partial crowns, irregular bark patterns on the bole or undersides of branches, unilateral branch mortality, and larger dbh than the post-fire recruitment. Fire scarred trees at the edges of the aspen patches or burn boundaries were sampled with a chain saw using standard procedures (Arno and Sneck 1977).

Laboratory Methods

Conifer samples were prepared and crossdated according to standard dendrochronological procedure (Stokes and Smiley 1968; Dieterich and Swetnam 1984). The diffuse porous wood of aspen required specific, but not elaborate, methods to ensure proper viewing of annual ring patterns. Numerous methods have been proposed for preparation of aspen, often including the use of stains to enhance ring boundaries

(Campbell 1981). The most recently published method also recommends the use of stains (Asherin and Mata 2001). Contrary to these recommendations I found that a razor-cut, hand sanded surface was the best way to reveal the details of ring structure and that staining did not enhance the visualization of properly surfaced cores. Asherin and Mata (2001) do thoroughly emphasize the need for proper sample collection, mounting, and preparation. These steps are a key determinant of the utility of the samples and the quality of the tree-ring data.

The following preparatory steps proved adequate for crossdating aspen samples from the Southwestern U.S. Increment cores were mounted in wooden core mounts with tracheids perpendicular to the plane of the core and parallel to the viewing plane of the microscope. Cores that were twisted during the extraction process were completely straightened with a steam-generating device before mounting. Straightened cores were glued into core mounts and cut with a razor to level the surface. The razor cut and subsequent hand sanding were used to alleviate the "flattening" of ring structures by mechanical sanding, which obscures the visibility of ring boundaries. Progressively finer sand paper (220, 320, 30micron, 15micron) was used to reveal ring structures. Staining of a properly hand sanded surface did not enhance ring boundary visualization. Changing the angle of the light source or shading the surface was helpful when ring boundaries were difficult to determine. These methods allowed visualization of extremely suppressed ring growth, consisting of only a single row of cells.

All aspen cores were crossdated to determine an inner ring date (Stokes and Smiley 1968). Pith estimation techniques were not used for cores without the pith ring.

Pith estimation techniques are useful for estimating the year of tree establishment, yet estimation of any highly variable, biotic parameter (e.g., annual tree-ring growth) has limitations. Simple geometric pith estimation techniques (Applequist 1958) assume concentric, equal-interval ring growth. This does not accurately represent the variability observed in the tree-rings. More elaborate methods that combine geometric and calibrated growth curve estimates have been developed, yet errors of +/- 2 years are still inherent in these methods (Villalba and Veblen 1997). The potential for overestimating the number of years to pith was a concern. This would inaccurately date aspen recruitment before the year of the fire. I was confident that the high percentage of pith rings collected (~50%) would be adequate to reconstruct the fire date when combined with the conifer evidence and therefore did not use pith estimates.

Dates from the four lines of tree-ring evidence were combined to determine the most probable stand-replacing fire dates. Spatial information was collected with a GPS for all samples and used to map the fire evidence. Aerial extent of the sampled aspen patches was estimated with DOQQ's, combined with field notes and 35mm photographs. In panchromatic images, aspen stands were substantially lighter in color and had smoother texture than the adjacent conifer stands. Using this signature, polygons were digitized in a GIS. All data were integrated into a database associated with the GIS to produce a spatio-temporal representation of stand-replacing fire history for the site.

Results

Santa Fe Ski Basin

Four converging lines of crossdated tree-ring evidence were used to reconstruct two stand-replacing fire events at the Santa Fe Ski Basin. Inner-ring dates were determined for 63 dominant aspen stems from 128 increment cores, with 48% containing the pith ring. Seven conifers were sampled and crossdated, and death dates, growth change, and fire scar evidence were identified where possible. A histogram containing the four lines of fire history evidence was plotted to determine stand-replacing fire dates (Figure 2.2).

Two peaks of aspen inner-ring dates were present in the histogram, representing two post-fire recruitment events beginning in 1861 and 1880. All inner-ring dates were included in the graph and some dates were likely greater than ten years from pith, explaining most dates not associated with the two fire events. The conifer death date, growth change and fire scar evidence matched the initiation of both aspen peaks. Five conifer death date samples matched the initiation of aspen recruitment in 1861. No samples collected contained fire scar evidence of this event. Only one growth change sample and one fire scar sample matched the initiation of aspen recruitment in 1880. All aspen inner-ring dates that matched conifer evidence of fire were pith dates, suggesting that the aspen stems present at the site regenerated post-fire and that aspen surviving the fire were not common.

The map of sample locations and digitized aspen boundaries indicates location of evidence for two fire events at the Santa Fe Ski Basin (Figure 2.3). The location of 1880 fire evidence inside of the aspen polygons suggests that the digitized aspen represents only the 1880 post-fire cohort. Tree-ring evidence of the 1861 event was located outside of the digitized aspen perimeters and often on the opposite side of the ridge from the 1880 cohort. Field notes indicated that extensive conifer encroachment was present at the points with 1861 fire evidence. This infill of conifers explains why these areas were not digitized as aspen. This finding has implications for future attempts to map stand-replacing fire area using aspen cohorts. In this case, the digitized aspen patches are only a minimal estimate of the 1880 stand-replacing fire area. Adjacent conifer patches would need to be dated and mapped to derive a more complete estimate of historic fire extent.

Discussion and Conclusions

Agreement between the multiple lines of tree-ring evidence demonstrates that annually accurate stand-replacing fire dates and precise fire locations are attainable. The aspen regeneration pulse beginning in 1880, combined with the fire scar and growth change evidence on the same year, agrees with the historical accounts of a fire circa 1880. More importantly, the tree-ring evidence dated the exact year of the fire to 1880. In addition, a previously undocumented fire event in 1861 was dated. This event was dated without fire scar evidence, using a combination of aspen age structure and conifer death dates. Locations of dated material provided spatial information for both events that has potential use for reconstructing spatial components of stand-replacing fire events.

Methods for reconstructing stand-replacing fire events are subject to a variety of errors, and hence the results must be analyzed with respect to these errors. Kipfmueller

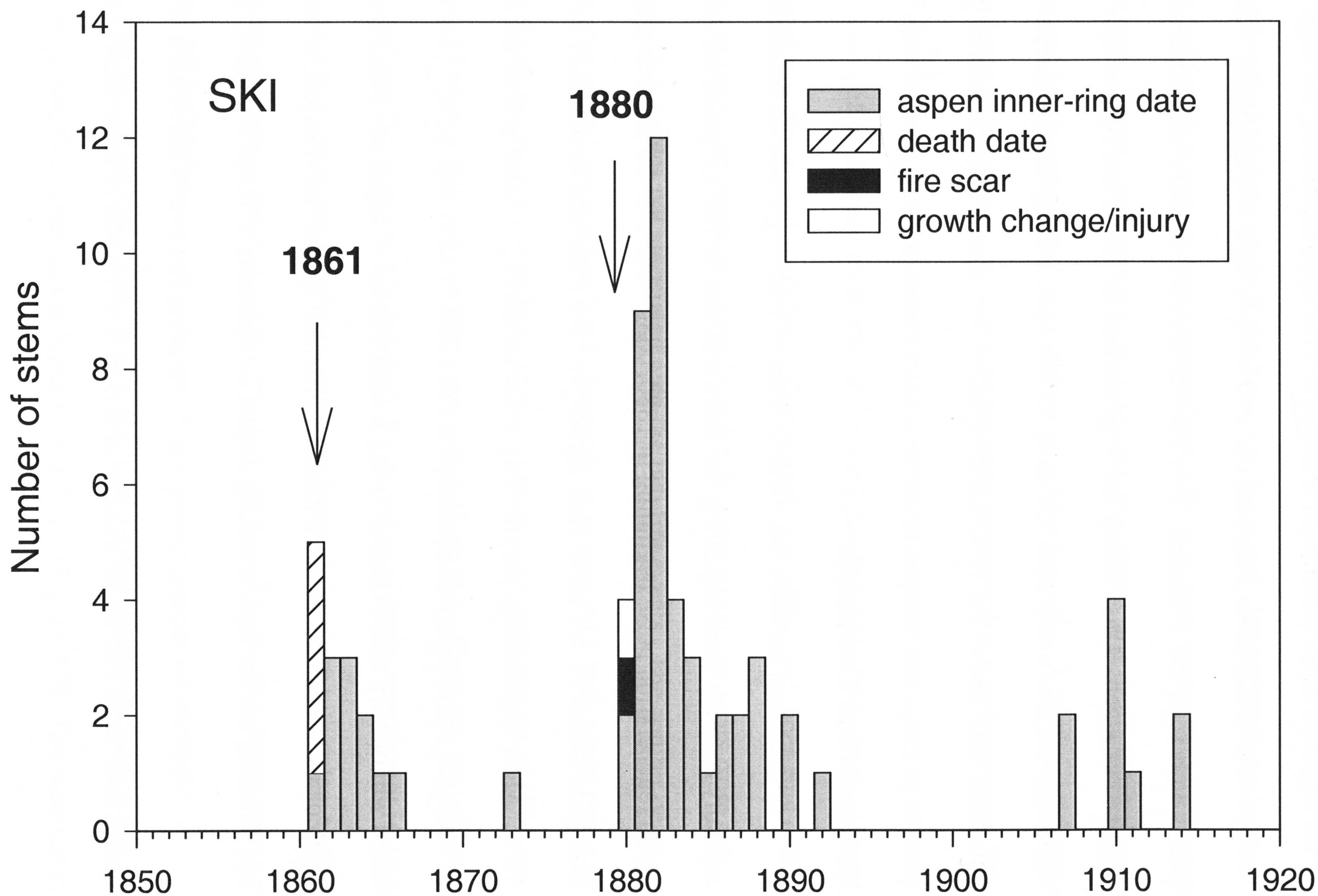


Figure 2.2. Multiple lines of tree-ring evidence for two stand-replacing fire events at Santa Fe Ski Basin.

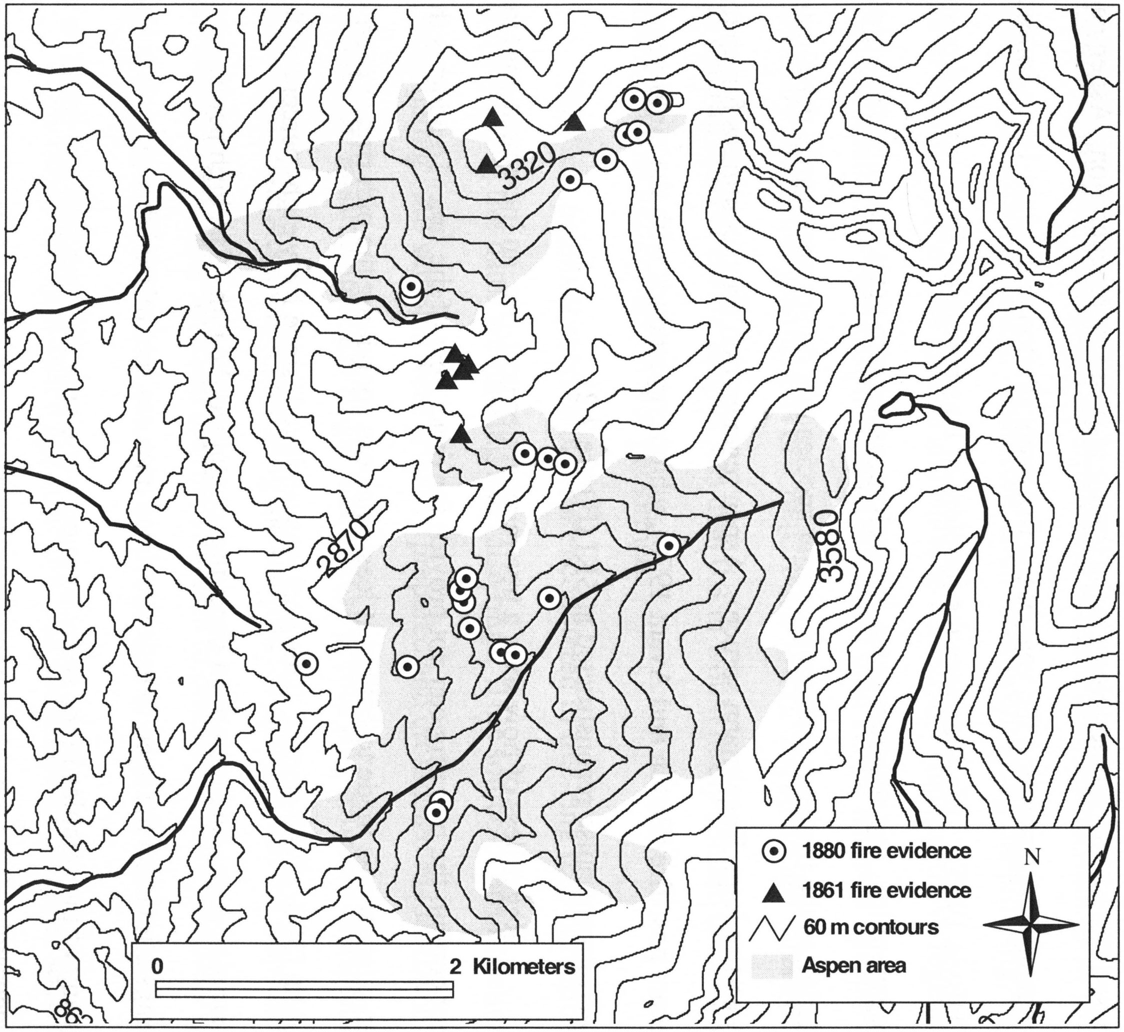


Figure 2.3. Spatial distribution of tree-ring evidence for two stand-replacing fire events at the Santa Fe Ski Basin.

and Baker (1998) for example, summarized four sources of fire dating error: 1) lag between fires and tree regeneration, 2) estimating pith dates, 3) age corrections for coring height, and 4) missing or false rings. Due to the unique life-history traits of aspen, the new methodology presented in this chapter addresses all four sources of error to increase the probability of obtaining annually resolved fire dates.

Perhaps the most important attribute of quaking aspen relating to age structure-based fire history methodology is the timing of post-fire regeneration. Aspen can begin vegetative regeneration the year of the fire event (Patton and Avant 1970; Jones and DeByle 1985). This addresses the problem of lags between a fire event and post-fire regeneration, age structure dates. Therefore, aspen pith dates have a greater likelihood of dating to the fire year than most conifer species that do not necessarily germinate rapidly post-fire (e.g., Engelmann spruce). Aspen regeneration often continues for up to five years post-fire (Patton and Avant 1970), which corresponds with the multi-year recruitment pulse reconstructed at SKI (Figure 2.2).

Regardless of how soon a tree regenerates post-fire, an increment core that does not contain the pith ring can not provide the exact year of the fire. To address this issue an attempt was made to collect at least one core containing the pith ring at each sample point (50% of the stems). This goal was achieved, since forty eight percent of the sampled stems had increment cores that contained the pith. The high percentage of pith rings alleviated the need to estimate dates on cores that missed that pith. It is likely that many of the samples in the study were only one year off from pith and could be estimated accurately. This would have increased the number of aspen stems dating to the fire year

(Figure 2.2). Pith estimation techniques were not used because of the possibility of overestimating the pith date (i.e., the pith ring would date before the fire event, falsely suggesting that the stem survived the fire or that the fire occurred at an earlier date).

A third source of error common to tree age determination is the age of the tree at coring height. Extraction of a solid increment core low on the bole (< 0.3m above the ground) is difficult due to the swing of the increment borer handle and butt rot. This becomes a problem for tree-age determination because saplings may not grow to this height in one growing season. Therefore, even a core containing the pith ring, may not date to the first year of tree growth and must be corrected. The vegetative regeneration of aspen can attain first-year growth heights of greater than 1.5 m, and new sprouts commonly attain first year heights of 1 m (Crouch 1981). Based on this information, it was determined that coring heights less than 0.3 m would likely contain the first year of growth, thus no age correction was performed.

The final potential sources of error encountered in tree-ring reconstructions of stand-replacing fire dates are missing and false rings. This source of error is eliminated by crossdating. All samples were properly prepared and crossdated to identify and corrected for missing and false rings. The diffuse porous ring structure of aspen did require additional steps when preparing the samples for analysis, but the steps outlined in the methods adequately revealed the ring structure to produce annually accurate and precise dates.

Utilization of aspen-based age structure data addressed all potential sources of error, yet the number of stems dating to the year of the fire was small. Thus, a fire reconstruction based on the aspen age structure would have dated the fires correctly in this example, but with limited confidence. This emphasizes the importance of additional lines of evidence, particularly the tree death dates and growth change/injury dates, for confirmation of age structure-based fire dates. These two lines of conifer evidence are particularly important in the upper montane vegetation types where well-preserved fire scar material is rare.

Conifer death dates, fire scars, and dates of growth changes and morphological indicators of injury not only confirm fire dates indicated by the aspen, they may provide additional information about prior fire events. The inherent limitation of post-fire age structure data is that evidence of previous post-fire cohorts is erased by the stand-replacing fire. The three lines of conifer evidence contain information that could be used to estimate the length of the prior stand-replacing fire-free period, at the very least, and may contain exact information regarding the previous fire event (e.g., fire scar). These data sources may prove to be useful in estimating fire return intervals in the upper montane forest types of the Southwestern U.S.

The new stand-replacing fire history method presented in this chapter is applicable to seral aspen patches in upper montane forests throughout the Southwestern U.S. The method also serves as a framework for site-specific temporal and spatial analysis of historic stand-replacing fire events, regional stand-replacing fire-climate relationships, and regional fire regime relationships (chapter 3 of this document). The annually resolved data allow: (1) comparison of fire dates between sites (Swetnam and Dieterich 1985), (2) analysis of fire occurrence and inter-annual variations in climate

(Fritts and Swetnam 1989), and (3) comparison between regional surface fire occurrence (Swetnam and Baisan 1996) and stand-replacing fire occurrence. Historical stand-replacing fire extent and pattern could be estimated with spatial integration of tree-ring data and vegetation data attained from DOQQ's and aerial photos (Heinselman 1973; Romme 1982). Data describing historic stand-replacing fire size and spatial patterns, fire-climate relationships and interactions with surface fires are needed to address management issues and ecological questions associated with recent stand-replacing fire events in the Southwestern U.S.

CHAPTER THREE

A STAND-REPLACING FIRE HISTORY IN THE SOUTHERN ROCKY MOUNTAINS

Introduction

Large, stand-replacing fires have occurred in recent decades in the Southwestern United States (e.g., La Mesa Fire 1977, Cerro Grande Fire 2000 and Rodeo-Chedeski Fire 2002). These events have highlighted the need to improve our understanding of the historical and ecological role of stand-replacing fires in the Southwestern U.S. The ubiquitous occurrence of surface fires in Southwestern U.S. ponderosa pine forests prior to the 20^{th} century has been well documented by historical accounts and tree-ring studies (Cooper 1960; Bahre 1985; Baisan and Swetnam 1990; Swetnam and Baisan 1996; Moore et al. 1999; Brown et al. 2001; Allen et al. 2002). However, there are relatively few studies of fire history in the upper elevation mixed conifer, aspen, and spruce-fir forests. Fire history of these upper montane vegetation types is necessary to understand the historical role of stand-replacing fires in determining ecosystem structure and processes, post-fire species composition and successional trajectories (Turner and Romme 1994). Annually resolved stand-replacing fire history may also reveal fire-climate relationships that could be useful for long-term forecasting.

Extensive quaking aspen (*Populus tremuloides* Michx.) stands in the upper montane forests are thought to be evidence of past stand-replacing fire in the Southwestern U.S. These seral aspen stands contain post-disturbance vegetative regeneration resulting from the death of above-ground stems. Stem mortality alters the hormonally controlled apical dominance mechanism and stimulates sprouting (Barnes 1966; Mitton and Grant 1996). The shade intolerant aspen stems grow vigorously in dense thickets to gain an initial competitive advantage. Without subsequent disturbance, the aspen are often overtopped and outcompeted by shade-tolerant conifers. Many of the aspen stands in the Western U.S. exist in late-successional stages, with increasing conifer densities and aspen stem mortality. A 46% decline in aspen cover over a 25-year period in Arizona and New Mexico has increased concern for the species (Johnson 1994). The decreased vigor of these aspen stands and observations of little or no regeneration in some areas has raised concern for this highly aesthetic, ecologically important species (Romme et al. 1995). Some researchers even claim the potential for local extirpation of aspen (Kay 1997; Bartos and Campbell 1998).

Multiple hypotheses have been proposed to explain the observed changes in aspen communities, including increased ungulate browse, fire suppression, and increased susceptibility to pathogens. Elk browse in Rocky Mountain National Park, CO was associated with a reduction in successful aspen regeneration in specific locations (Baker et al. 1997). Increased susceptibility of aspen to pathogens and insect pests relating to stand age and warmer climate was observed in northwestern Alberta, Canada (Hogg et al. 2002). The cessation of stand-regenerating fire circa 1900 was suggested as the cause of aspen decline near Jackson Hole, Wyoming (Houston 1973). It is likely that a combination of all factors act in concert to affect aspen regeneration and survival.

The cause of changes in aspen communities of the Southwestern U.S. has received less attention. Similar mechanisms likely affect aspen regeneration in this region, yet minimal data exists to support the various hypotheses. In particular, very little is known about the historical role of fire in upper montane aspen communities of the Southwest.

The natural range of variability of historical fire regimes is best studied with dendrochronology-based methods (Swetnam 1993; Johnson and Gutsell 1994; Swetnam and Baisan 1996; Veblen et al. 2000). Fire history studies in the Southwestern U.S. have relied almost exclusively on fire-scar samples from living and remnant conifers to reveal the high-frequency fire regimes of ponderosa pine forests. Fire history reconstructions in the upper montane forest types require different methods due to the lack of well-preserved, fire scarred trees. This is due to the predominant occurrence of stand-replacing fires that leave little direct evidence of the disturbance event.

Several tree-ring studies have examined stand-replacing fire events associated with aspen stands in the upper-elevation forests of the Southwestern U.S. (Touchan et al. 1996; Romme et al. 1996; Abolt 1997). These studies were based primarily on age structure data from post-fire cohorts. This is an approach that has been used to reconstruct stand-replacing events in the subalpine and boreal forests of the central and northern Rocky Mountains (Heinselman 1973; Romme 1982; Kipfmueller and Baker 2000)

Reconstructing annually resolved fire dates with age structure-based fire history methods has proven to be difficult. Romme et al. (1996) report fire data with decadal resolution for aspen stands in the San Juan National Forest. They emphasize the lack of fire scarred trees in aspen forests as a limitation to fire dating precision. Fire scar dates are important to increase the accuracy of a stand-replacing fire history based primarily on age structure data (Johnson and Gutsell 1994; Kipfmueller and Baker 2000).

Touchan et al. (1996) encountered similar problems of fire date resolution that was attributed to small, patchy, stand-replacing fires in mixed conifer stands of the Jemez Mountains, NM. The most robust stand-replacing fire date in the study was determined from aspen age structure and adjacent fire scars in the largest contiguous aspen patch sampled (Quemazon Canyon - 1893). The large aspen patch size increased the number of aspen inner-ring dates that were synchronous with adjacent fire scar dates. Converging lines of evidence are important to increase confidence in the reconstruction of annually resolved fire dates. Abolt (1997) successfully reconstructed stand-replacing fire events from large aspen patches in the Gila Wilderness, NM using aspen age structure, fire scar evidence, and historical records. Prior fire history research in upper montane aspen stands highlight the need for large aspen patches and multiple lines of evidence, to assure annual precision of fire dates.

Annually precise fire dates at regional scales are necessary to investigate inter-annual fire-climate relationships (Swetnam 1990; Swetnam and Baisan 1996). The existing fire history reconstructions in aspen forests did not have appropriate data for a regional analysis of intererannual fire-climate variability. Romme et al. (1996) produced a decadal-scale fire history that was not analyzed for fire-climate relationships. Abolt (1997) reconstructed local fire origin dates for aspen patches, but did not conduct fire-climate analyses. Touchan et al. (1996) were not able to confidently reconstruct enough stand-replacing fire dates in the aspen stands for fire-climate analyses, yet they did use fire scars from adjacent mixed-conifer stands to reveal a relationship between fire occurrence and drought during the fire year.

Annually resolved, regional fire data sets are extremely valuable for investigating the potential role of climate forcing on stand-replacing fire regimes. Climate variability at inter-annual to centennial time-scales has been shown to be a forcing mechanism for fire regimes in the Southwest, Central Rockies and the Pacific Northwest (Swetnam and Betancourt 1990a; Swetnam 1993; Grissino-Mayer and Swetnam 2000; Veblen et al. 2000; Kitzberger et al. 2001; Heyerdahl et al. 2002). These studies have shown that drought during the fire year is strongly associated with fire occurrence. Lagging relationships between fire occurrence and antecedent moisture conditions that drive fine fuel production have also been revealed for surface fire regimes in the Intermountain west and the Southwestern U.S. (Knapp 1995; Swetnam and Baisan 1996).

Variability of fire occurrence in the Southwestern U.S. has been shown to be synchronous with synoptic-scale oscillations in the climate system. The wet and dry phases of the El Nino-Southern Oscillation (ENSO) significantly influence and synchronize fire occurrence in the Southwestern U.S. (Swetnam and Betancourt 1990b; Swetnam and Betancourt 1998) and northern Patagonia, Argentina (Kitzberger et al. 2001; Kitzberger 2002). This link between surface fires and regional, inter-annual climate variability has led to attempts at fire forecasting (Westerling et al. 2002) and preliminary results have been made available to land management agencies to prepare for high risk fire years (Garfin and Moorehouse 2001). Similar analyses of fire-climate relationships with a regional, stand-replacing fire data set from the Southwestern U.S. may reveal robust patterns with potential use in stand-replacing fire forecasting and modeling.

In this paper I apply dendroecological techniques to develop a regional reconstruction of stand-replacing fire history in the Southern Rocky Mountains. A method is used that combines multiple lines of evidence (described in Chapter 2 of this document). The resulting regional fire data set is analyzed to evaluate the role of climate in stand-replacing fire occurrence and to explore possible relationships between surface fire and stand-replacing fire.

Study Area

The study area was located in the upper Rio Grande Basin of northern New Mexico and southern Colorado (Figure 3.1). The northern portion of the basin is generally characterized with elevations ranging from 2100 m in the San Luis Valley to >4200 m on the peaks of the San Juan and Sangre de Cristo Mountains. The southern portion of the study area ranges from 1500 m in the river valley at Albuquerque to >3200 m at the crest of the Sandia Mountains. Average elevation of the sites ranged from 2794 m to 3251 m, with samples collected at a minimum elevation of 2695 m and a maximum elevation of 3479 m (Appendix B).

In the northern portion of the study area the annual average precipitation was 1180 mm (1971-2000), recorded at a site with similar elevation to the study sites (Wolf Creek Pass, CO; elevation 3243 m). Forty eight percent of the annual precipitation falls

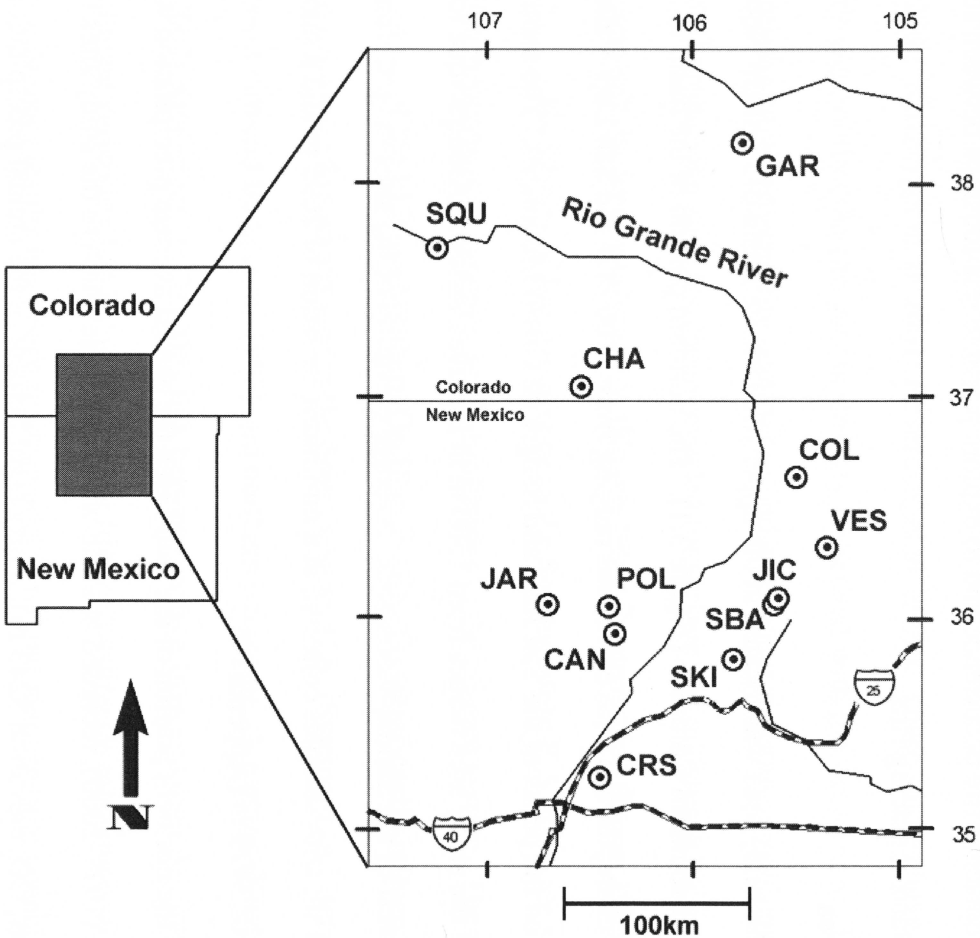


Figure 3.1. Location of ~75,000 km^2 study area and twelve study sites (e.g., CHA) in southern Rocky Mountain Ecoregion of North America.

between July and October. The annual average temperature was 0.8°C (1971-2000), with the warmest month being July (11.7°C) and the coolest January (-8.1°C) (Western Regional Climate Center, 2003). In the southern portion of the study area the annual average precipitation was 583 mm (1953-1979), recorded at similar elevation and < 20 km from the CRS site (elevation 3258 m). Greater than 50 percent of the annual precipitation occurs between July and October. The monthly precipitation maximum occurs in August and minimum in February. The annual average temperature was 3.0°C (1953-1979), with the warmest month being July (19.1°C) and the coolest January (-10.5°C) (Western Regional Climate Center, 2003).

The latitudinal and elevation gradient of the study area encompassed a range of vegetation types. All sites were selected based on the presence of large, contiguous aspen stands, but the current vegetation associations varied. The majority of the sites had some spruce-fir component, but the lowest site (JAR) was composed primarily of mixed conifer vegetation (Table 3.1). The range of associated tree species bordering the aspen stands included ponderosa pine (*Pinus ponderosa* Lawson), Douglas-fir (*Pseudotsuga menziesii*[Mirb.] Franco.), white fir (*Abies concolor* [Gord. & Glend.] Lindl. Ex Hildebr.), Englemann's spruce (*Picea engelmannii* Parry), subalpine fir (*Abies lasiocarpa* [Hook] Nutt.), and bristlecone pine (*Pinus aristata* Engelm.).

The geology of the region is dominated by the Rio Grande Rift that runs south from the San Luis Valley of southern Colorado to the Texas border (Kues and Callender 1986). The Rio Grande, the fifth longest river in North America, originates in the San

Table 3.1 Site information table listed by ascending elevation.

SITEID	SITE NAME	STATE	NATIONAL FOREST	VEG. TYPE	ASPEN AREA (ha)	SAMPLE PTS	MEAN LATITUDE	MEAN LONGITUDE	MEAN ELEV. (m)
JAR	Jarosa Springs	NM	Santa Fe	MC	30	8	36° 2' 51''	-106° 42' 14''	2794
CHA	Chama River	CO	Rio Grande	MC	1142	12	37° 3' 30''	-106° 32' 21''	2841
CAN	Quemazon Canyon	NM	Santa Fe	MC	66	20	35° 54' 33''	-106° 22' 55''	2929
SBA	Santa Barbara River	NM	Carson	MC/SF	1173	19	36° 2' 50''	-105° 36' 39''	2954
COL	Columbine Creek	NM	Carson	MC/SF	274	14	36° 38' 23''	-105° 29' 59''	2963
VES	Valle Escondido	NM	Carson	MC/SF	163	21	36° 18' 39''	-105° 21' 14''	2984
CRS	Sandia Crest	NM	Cibola	SF	30	15	35° 14' 14''	-106° 27' 7''	3033
SQU	Squaw Creek	CO	Rio Grande	SF	219	11	37° 42' 18''	-107° 14' 37''	3097
JIC	Jicarita Creek	NM	Carson	SF	243	10	36° 4' 19''	-105° 35' 23''	3111
SKI	Santa Fe Ski Basin	NM	Santa Fe	SF	823	44	35° 47' 9''	-105° 48' 26''	3124
POL	Polvadera Peak	NM	Santa Fe	SF	59	15	36° 2' 7''	-106° 24' 41''	3242
GAR	Garner Creek	CO	Rio Grande	SF	285	11	38° 11' 48''	-105° 45' 44''	3251

Juan Mountains at Stony Pass and generally flows south for 3,030 km through the rift valley to the Gulf of Mexico (Scurlock 1995). The upper Rio Grande Basin drains the four mountain ranges sampled in the study. The southernmost is the Sandia uplift, an east-tilted, fault-block range composed of Precambrian plutonic and metamorphic rocks overlain by Paleozoic limestone and sandstone sedimentary sequences (Hawley 1986). In the central portion of the basin, west of the Rio Grande, are the volcanic Jemez Mountains. The pumice and tuff present throughout the area are the result of late Cenozoic volcanism, erupting 1.4 m.y.a. and subsequently collapsing to create the Valles Caldera (Kues and Callender 1986). The eastern side of the basin is defined by the Sangre de Cristo Mountains consisting primarily of Precambrian igneous and metamorphic formations overlain by late-Paleozoic and lower Cenezoic sedimentary rock (Hawley 1986). The San Juan Mountains contain the headwaters of the Rio Grande. This range consists primarily of Precambrian volcanic formations with the most recent volcanic activity and uplift event at the close of the Cretaceous (Curtis 1960). Soils were generally mollisols in the aspen stands, or inceptisols at the higher elevations of the San Juan and Sangre de Cristo Mountains (Maker and Daugherty 1986).

Evidence of human presence in the Rio Grande Basin dates back to the Paleo-Indian cultures (e.g., Clovis), over 10,000 years before present (b.p.). The Oshara culture occupied the valley 3000 years b.p., followed by the most recent indigenous groups, the Pueblos in the south and the Utes and Commanches in the north (Wolf 1995). The Spanish entered the valley from the south, led by Francisco Coronado in 1540 and traveled to the San Luis Valley in 1598 (Debuys 1985:46). Widespread Euro-American settlement, resulting from the mining boom in the San Juan and Sangre de Cristo Mountains, dates circa 1870 throughout the study area (Debuys 1985:149; Wolf 1995). Only two sites, JAR and CHA had evidence of logging within the stand.

Field methods

Site Selection

Twelve sites were selected within the 75,000 square kilometer study area (Figure 3.1). Sites were distributed among the four mountain ranges that define the basin: Jemez, Sandia, Sangre de Cristo and San Juan Mountains. All sites were located on USDA Forest Service land managed by the Carson, Cibola, Rio Grande, and Santa Fe National Forests (Table 3.1).

Study sites were selected to include the twelve largest, seral, aspen stands that provided coarse spatial coverage of the upper Rio Grande Basin. Two GIS data layers, a GAP vegetation map and the Rio Grande National Forest vegetation map, were used to locate the largest aspen stands in the region. Preliminary field reconnaissance identified misclassified stands and aspen stands adjacent to grasslands that were not likely evidence of a stand-replacing fire. Accessibility, land ownership, and prior anthropogenic disturbance history (e.g., logging) was considered when choosing the final study sites. Many of the largest aspen stands identified (>5000 ha) were located in the San Juan Mountains, but were not selected because they were located in areas known to have extensive mining activity (USDA 1999).

Field Sampling

Sampling was conducted to obtain multiple lines of tree-ring evidence to determine stand-replacing fire dates at each of the twelve sites (see chapter 2 of this document for details). The four lines of evidence included: 1) aspen inner-ring dates, 2) death dates of fire-killed conifers, 3) conifer growth changes or other morphological tree-ring indications of injury, and 4) conifer fire scars. DOQQ's were used to systematically locate sample points within stands to provide dispersed spatial coverage of the aspen stands. Aspen inner-ring dates were collected at all sample points. Extensive searching beyond the sample points was necessary to locate the three lines of conifer evidence, since this material is rare in upper montane forests. All sample locations were mapped using a GPS, which reported a maximum error of 15 m. A minimum of 15 aspen stems per site were cored to adequately characterize post-fire regeneration. The minimum sample size was adapted from methods used to date post-fire lodgepole pine cohorts (Kipfmueller and Baker 1998).

To describe the aspen age structure the two stems of greatest d.b.h. within a 10 m radius of the sample point were cored. Two increment cores were extracted from each stem at $\leq$0.3 m core height, until one core with pith was obtained at the sample point. All conifer material matching the three other lines of evidence (tree death date, fire scar, growth change/injury) was collected, since this material was rare and required extensive additional searching to locate. Partial cross-sections were collected using standard procedure (Arno and Sneck 1977), except in designated wilderness areas where hand saws were required (Baisan and Swetnam 1990). Increment cores were collected from potential fire-surviving conifers at a core height of approximately 1.5 m.

All conifer samples were prepared and crossdated according to standard dendrochronological procedures (Stokes and Smiley 1968). The diffuse porous wood of aspen required specific methods to ensure proper viewing of annual ring patterns (see discussion in chapter 2 of this document). All aspen cores were crossdated to determine an inner-ring date. Dormant season fires, indicated by death dates and fire scars, were assigned to the subsequent year, based on the dominant occurrence of spring and early summer fires in the region (Dieterich and Swetnam 1984). Dates from the four lines of tree-ring evidence and associated spatial data were compiled to determine stand-replacing fire dates. These data were entered into a database associated with a GIS to produce a spatio-temporal representation of stand-replacing fire history for all sites.

Data Analysis

The composite, stand-replacing fire history from all twelve sampled stands was analyzed for fire-climate relationships and synchrony with regional surface fire occurrence. Superposed epoch analysis (Baisan and Swetnam 1990; Swetnam 1993) was used to test for relationships between stand-replacing fire occurrence and reconstructed summer Palmer Drought Severity Index (PDSI) (Cook et al. 1999), including antecedent conditions. Spatial representations of reconstructed summer PDSI were assessed to evaluate possible regional drought patterns associated with stand-replacing fire occurrence. The PDSI grid points (50 and 51) centrally located within the study area were averaged to derive a regional PDSI time series to quantify drought conditions during years of stand-replacing fire occurrence.

Stand-replacing fire years were compared with "regional" surface fire years (>20% fire occurrence) from a Southwestern U.S. fire history network (Swetnam and Baisan 1996) using a 2X2 contingency table. The 2X2 contingency table was evaluated with a chi-squared goodness of fit test, but small sample size resulted in expected values less than five. Due to this limitation, a Fisher's exact test was used to test for independence between the data sets (Milton 1999). I tested the following null hypothesis, H_o: stand-replacing fire years and regional surface fire years were independent (i.e., the number of coincident fire dates of the two types was no more frequent than might occur by chance). I set an a priori probability level of $p < 0.05$ to reject the null hypothesis.

Results

A total of 850 increment cores and partial cross-sections were collected from 329 aspen stems and 99 conifers at twelve study sites (Table 3.2). Ninety-one percent of the samples were successfully crossdated and used to reconstruct fire dates. Nine percent of the samples were not datable and excluded, because of low inter-annual ring variability, too few rings present, or severe growth suppressions that prevented accurate crossdating. Synchrony was evident between aspen recruitment pulses and conifer evidence of fire at 11 of 12 sites (Figures 3.2, 3.3). The one exception was GAR, where no conifer evidence was datable. All aspen inner-ring dates matching conifer evidence of fire were pith dates. Right skewed, uni-modal distributions of aspen inner-ring dates were strong evidence of a post-fire aspen recruitment pulse with no fire survivors. Bi-modal distributions

Table 3.2 Number of aspen stems and conifer sample types used in stand-replacing fire reconstructions.

Site	**Aspen samples**	**Total conifer samples**	**Fire scar**	**Death date**	**Growth change/injury**
CAN	31	3	1	2	0
CHA	20	3	1	2	0
COL	25	4	0	4	0
CRS	31	7	0	6	1
GAR	20	0	0	0	0
JAR	14	9	9	0	0
JIC	12	3	0	3	0
POL	22	5	1	0	4
SBA	38	10	0	8	2
SKI	64	6	1	4	1
SQU	20	2	0	0	2
VES	27	20	8	6	6

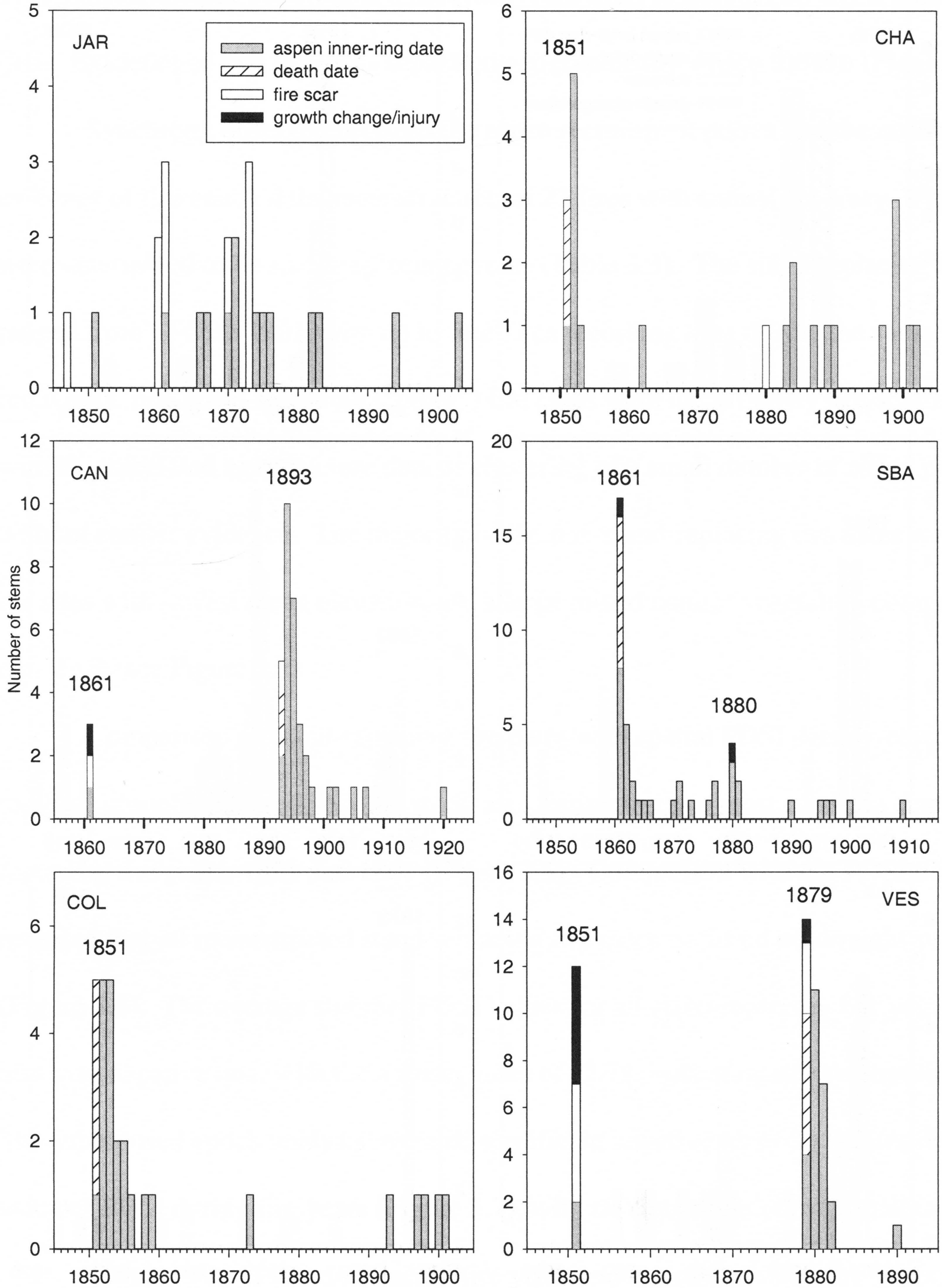


Figure 3.2. Aspen age structure and conifer tree-ring evidence used to reconstruct stand-replacing fire events. Sites listed in ascending order, ranked by mean elevation (< 3000m). The notably different fire evidence distribution at lowest site, JAR, suggests a higher frequency surface fire regime or small stand-replacing events.

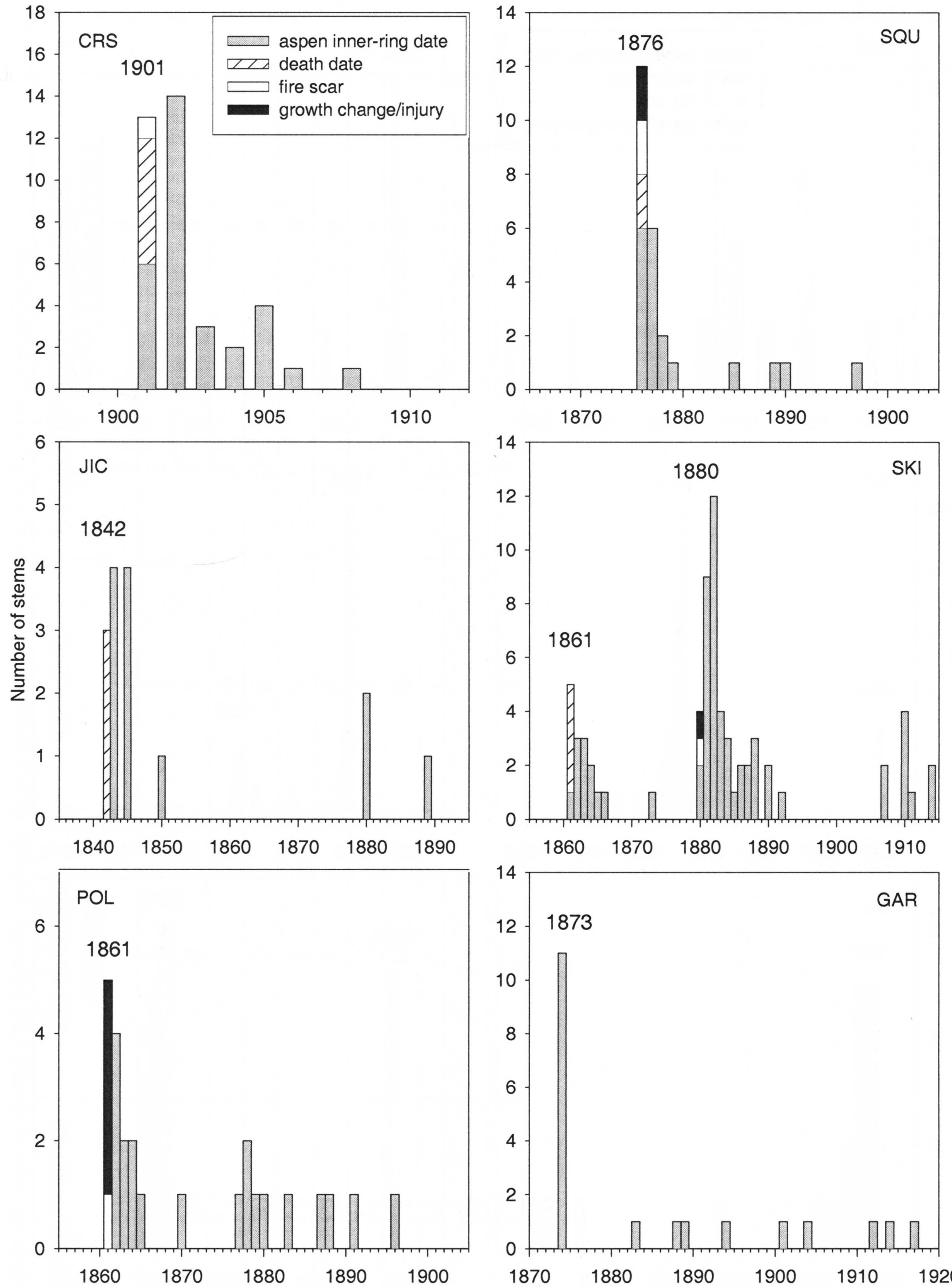


Figure 3.3. Aspen age structure and compiled conifer tree-ring evidence used to reconstruct stand-replacing fire events. Mean elevation of sites is > 3,000 m, with spruce-fir vegetation dominantly associated with the aspen.

of aspen recruitment observed at some sites (e.g., SKI) represent two stand-replacing fires. Evidence of two fires was separated geographically within the site (Figure 3.4).

Synchrony observed between the aspen recruitment pulses and the conifer evidence of fire enabled the reconstruction of 23 fires with annual accuracy. Fifteen fires were determined to be stand-replacing events (Table 3.3). The stand-replacing fire dates ranged from 1842 to 1901, with up to four sites recording fires during the same year. The remaining, non stand-replacing ("other") fire dates were identified by fire-scarred trees with no associated age structure data or clustering of a small number of aspen pith dates without conifer evidence. The majority of the non-stand-replacing fire dates were from the sites with lowest mean elevation and a large mixed conifer vegetation component, e.g., JAR (see Figure 3.2).

Comparison of stand-replacing fire dates with spatial PDSI data revealed extreme regional drought centered near the study area during the two most common stand-replacing fire years, 1851 and 1861 (Figure 3.5). Comparison with the PDSI timeseries revealed that all reconstructed stand-replacing fire dates occurred on drought years (Figure 3.6). The average summer PDSI values for all stand-replacing fire years were less than negative one, with the a mean value of -2.78, indicating severe regional drought. The superposed epoch analysis revealed significant negative (dry) departures of average summer PDSI during fire years (Figure 3.7), with no antecedent climate relationships.

Comparison of stand-replacing fire years and regional surface fire years revealed that 78% of these fire years were coincident (Figure 3.8). The null hypothesis of independence between stand-replacing fire occurrence and regional surface fire

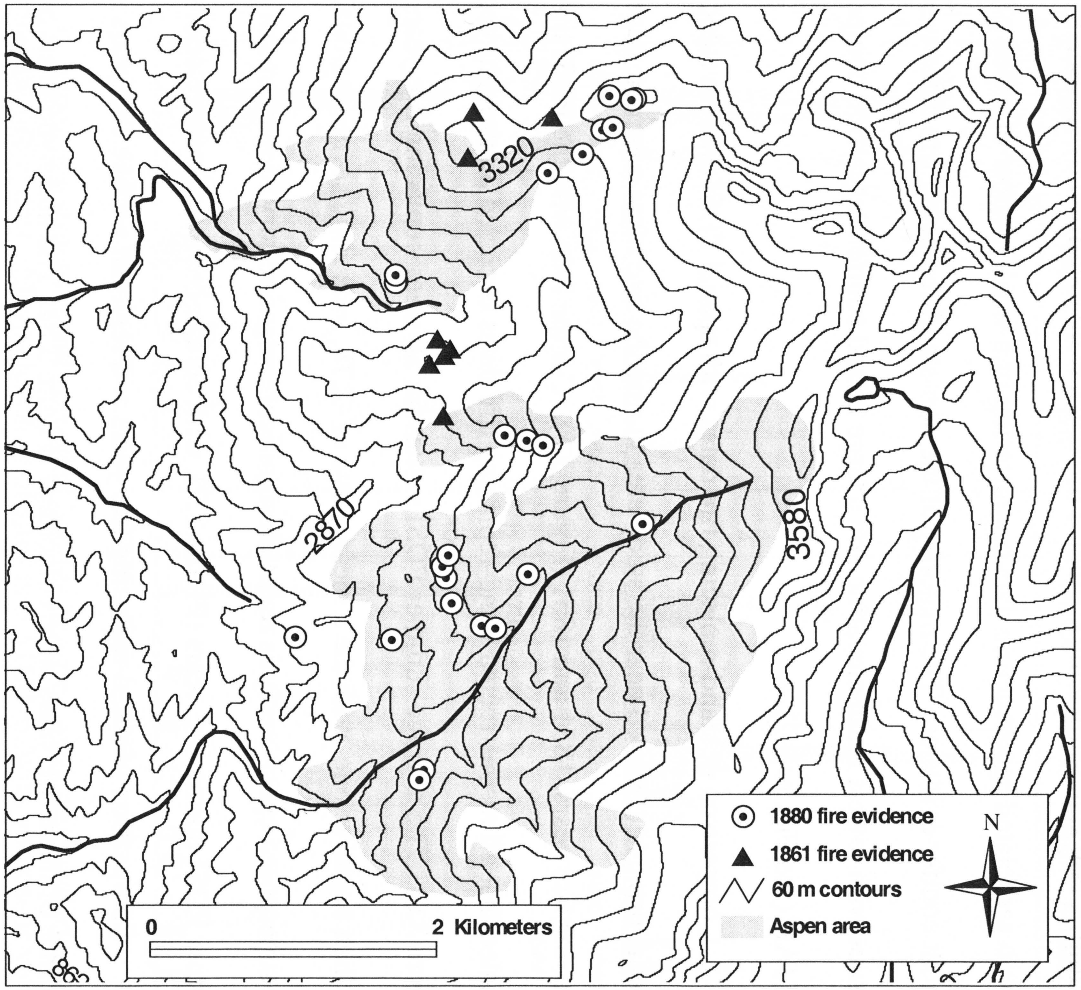


Figure 3.4. Spatial partitioning of tree-ring evidence for two stand-replacing fire events at the Santa Fe Ski Basin has implications for reconstructing fire area. Note the 1880 fire evidence located within the mapped aspen areas.

Table 3.3 Stand-replacing fires and "other" fire dates reconstructed from multiple lines of tree-ring evidence in the upper Rio Grande Basin. Sites are stratified by descending latitude and synchronous fire dates discussed in the text are in bold.

Site	Stand-replacing fire dates	Other fire dates*
GAR	1873	
SQU	1876	
CHA	**1851**	1880
COL	**1851**	
VES	**1851**, 1879	1748
JAR	----------------	1847, 1860, 1861, 1870, 1873
POL	**1861**	
JIC	1842	1880
SBA	**1861**, 1880	
CAN	**1861**, 1893	
SKI	**1861**, 1880	1806
CRS	1901	

* "Other" fire dates indicate dates when surface fire occurrence was likely or only one line of evidence was collected (e.g., only aspen inner-ring dates).

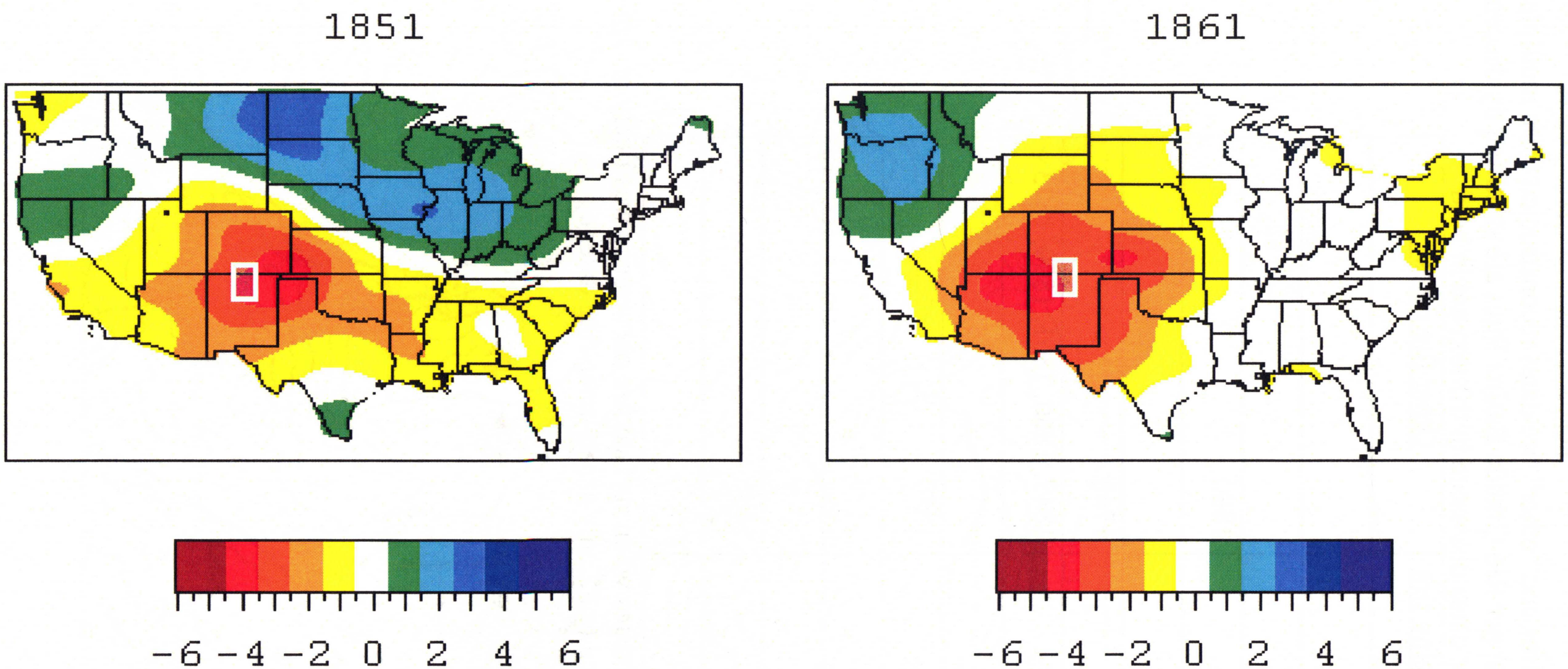


Figure 3.5. The two most common reconstructed stand-replacing fire years, 1851 and 1861, coincide with severe regional drought in the Southwest. This is illustrated by a spatial reconstruction of summer PDSI (from Cook et al. 1999). The white rectangle indicates the study area location.

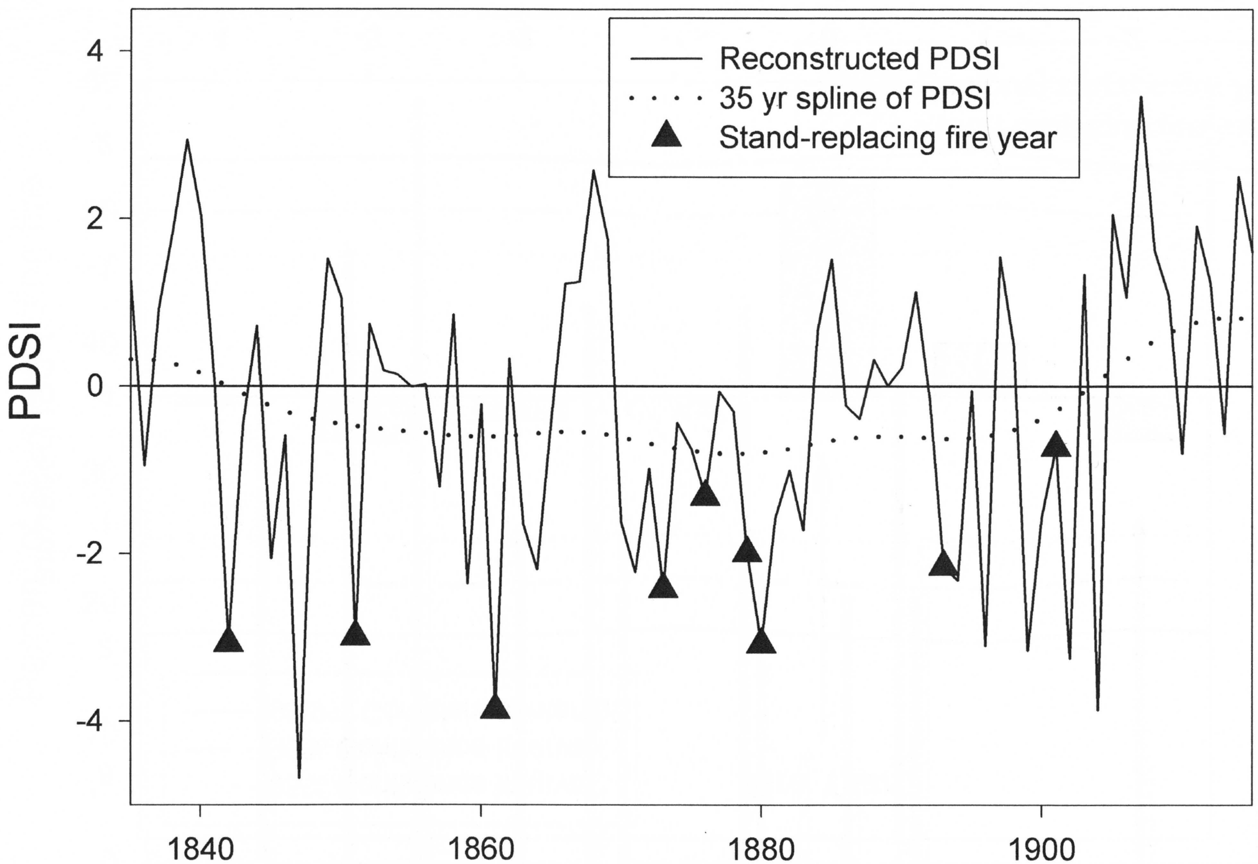


Figure 3.6. Stand-replacing fire years plotted on reconstructed PDSI time-series (1835-1915), indicating drought during fire year. A 35-year spline of the PDSI data indicates multi-decadal drought conditions coinciding with the period of reconstructed stand-replacing fires (1840-1900). PDSI data from Cook et al. (1999) grid points 50 and 51.

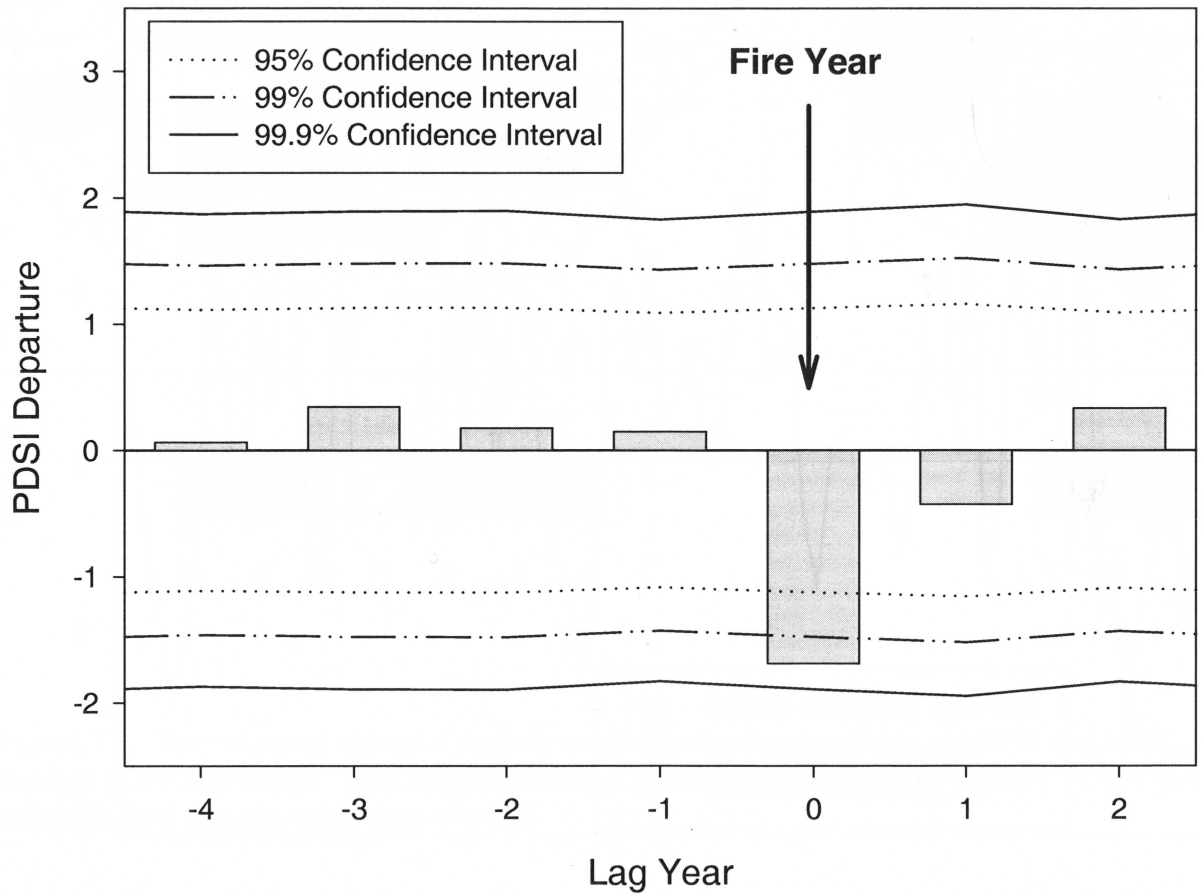


Figure 3.7. Superposed epoch analyses (SEA) using reconstructed PDSI and stand-replacing fire years (1842-1901); N=9. Confidence intervals (CL) indicate a significantly dry fire year (99% CL) with no lag relationship with climate.

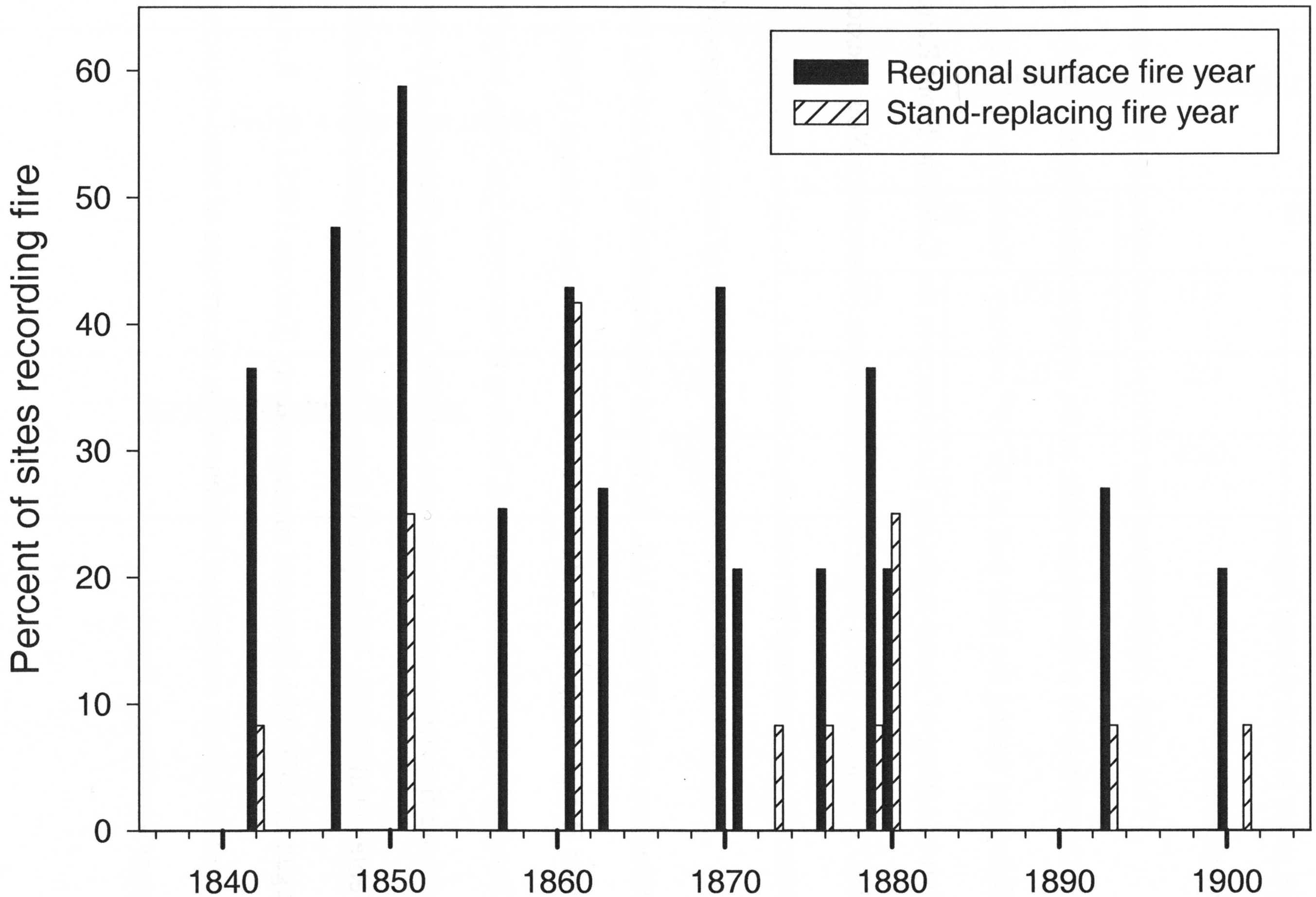


Figure 3.8. The percent of Southwestern U.S. sites recording fire each year (total sites = 63) compared with percentage of sites recording stand-replacing fire (total sites = 12) shows significant synchrony.

occurrence was rejected (Table 3.4). This suggests a probable association between low elevation surface fire occurrence and upper elevation stand-replacing fire occurrence. Stand-replacing fires were not evident on all regional surface fire years (e.g., 1847), but the small number of study sites would not be expected to document all stand-replacing fire years in such a large region.

Discussion

This study demonstrates that multiple stand-replacing fires occurred synchronously on a landscape-scale in the upper montane forests of the southern Rocky Mountains during the later half of the 19th century. Veblen et al. (2000) also reported high incidence of stand-replacing disturbance in the Colorado Front Range in the late 1800's. Choate (1966) made similar statements for northern New Mexico based on historical accounts and personal observations.

The mid-to-late 19th century is also a period of increased Euro-American settlement in the Western U.S. Increased stand-replacing fire activity in the Colorado Front Range was partially attributed to human land use changes (Veblen et al. 2000). Changing human land use patterns, leading to increased ignitions, have been shown to increase fire occurrence in other site-specific locations (Baisan and Swetnam 1997; Veblen et al. 1999). Widespread Euro-American settlement in the Rio Grande Basin began in 1870 with increased mining activity (Debuys 1985:149). It is possible that increased human occupation influenced the occurrence of stand-replacing fires in the upper Rio Grande Basin.

Table 3.4 2x2 contingency table testing for independence of observed *(O)* and expected *(E)* synchrony between stand-replacing fire years and regional surface fire years (1842-1901). Observed synchrony between regional surface fires and stand-replacing fires was significantly different than expected by chance (p = 0.0001).

Fisher's exact test results		**Regional surface fire year**			
		Yes		No	
		(O)	(E)	(O)	(E)
Stand-replacing fire year	Yes	7.0	2.0	2.0	7.1
	No	6.0	11.1	45.0	40.0

To examine this hypothesis, fire dates were determined to be pre-settlement or post-settlement using 1870 as the break. The data indicate that 50% of the reconstructed stand-replacing fire events occurred prior to widespread Euro-American settlement, including two of the most synchronous years, 1851 and 1861 (Table 3.3). The occurrence of stand-replacing fires before widespread Euro-American settlement in the region suggests that humans were not the cause of stand-replacing fire occurrence. When this is considered with the synchrony of extreme regional drought and stand-replacing fire occurrence it suggests that climate is the driving force behind the observed patterns.

The co-occurrence of stand replacing fire, regional surface fire and extreme regional drought can be explained in terms of ignition and fire spread. It is likely that drought increased the probability of lightning ignition and spread of fire within the upper montane vegetation types. It is also likely that extreme drought allowed the spread of fire from lower elevations into the upper elevation forests. Both mechanisms are strongly tied to the effect of drought on fuel moisture.

Increase in successful ignition and fire spread within the upper elevation forests relates to the reduction of live and dead fuel moistures in these mesic vegetation types. Decreased fuel moistures caused by the drought increased the availability of fuel for ignition and fire spread. Thus, it is likely that extreme regional drought increased the probability of fire occurrence within the upper montane forests of the region. Lightning strikes in May or June above 3000 m may occur in areas that have snow on the ground during a normal or even moderately dry year. Even if sufficient, successful ignitions occurred, extreme drought is needed to decrease fuel moistures to allow sustained stand-replacing crown fire events.

Fire spread from lower elevations into upper elevation forests is also strongly influenced by drought severity. It is likely that during extreme droughts, fuel moisture in the upper elevation mixed-conifer and spruce-fir forests decrease to the point to allow fire spread from the lower elevations into these mesic forest types. Therefore, to explain the co-occurrence of stand-replacing fire and regional surface fire, I suggest that increased regional surface fire activity increased ignition sources for fires in the upper montane forests of the region. The additional ignitions further increased the probability of stand-replacing events.

This proposed linkage between fire regimes suggests that low elevation surface fire occurrence may be crucial for the perpetuation of fire regimes and ecosystem function in the upper montane forests of the Southwestern U.S. If lower elevation surface fires influenced the occurrence of high elevation stand-replacing fires, then fire suppression circa 1900 may have effects across the elevation gradient in the Southwestern U.S. The effect may not yet be evident, due to the typical century-scale fire return intervals in spruce-fir vegetation types. However, decreased numbers of stand-replacing fire at regional scales in the 20th century versus earlier centuries may be evident if a large enough data set were compiled for the entire region.

Kipfmueller and Baker (2000) observed a decrease in fire frequency following 20th century fire suppression in an upper elevation forest in the Southern Rocky Mountains. Yet, other studies in the Canadian Rocky Mountains and the Central Rocky

Mountains have shown no fire suppression effect (Johnson and Fryer 1987; Romme and Despain 1989). The potential for alteration of upper elevation forest disturbance regimes due to the cessation of fire in adjacent forest types warrants consideration and further investigation.

The superposed epoch analysis revealed a strong relationship between fire occurrence and drought, with no significant antecedent relationships. This type of fire–climate relationship was evident in the upper elevation mixed conifer forests of the Jemez Mountains, NM (Touchan et al. 1996). The proposed hypothesis was that the upper elevation forests are not fuel limited and therefore only require sufficient desiccation of the fuels for fire occurrence. This is in contrast to systems where surface fuels may limit fire spread. This is the proposed model for the lower elevation pine forests, where antecedent wet years enhance fuel production and increase the probability of fire spread in subsequent dry years (Swetnam and Baisan 1996).

It must be noted that nine fire year "events" were used in the SEA analyses, which is below the minimum recommended number of events (10). Therefore, the confidence intervals produced from the Monte Carlo simulations may be exceeding the power of the test due to the small sample size. I argue, however, that the results of the SEA are consistent with Figure 3.6 showing that the fire events only occurred drought years nad often during extreme drought years. Future work should focus on increasing the number of reconstructed stand-replacing fire events to increase the utility and confidence in fire-climate anlysis methods.

The relationships identified between climate, surface fires, and stand-replacing fires may be important to consider when developing fire-related management plans. The results support allocation of fire resources to locations where extreme drought conditions currently exist and are forecasted (Swetnam and Betancourt 1998). A potential long-term management implication of this study relates to fire suppression effects on upper montane forests and fire regimes, and whether restoration is needed in these areas.

Currently, managers, scientists and policy makers are debating over the best restoration treatments (e.g., prescribed fire, thinning) for the pine forests of the Southwestern U.S. that were altered from grazing and fire suppression (Allen et al. 2002). The potential for alteration of the upper montane forests of the region also warrants consideration. If subsequent research reveals that the upper montane forests are not functioning within the range of natural variability then restoration will have to be considered. This would potentially include something as drastic as prescribed crown fire.

This study of stand-replacing fire in the upper Rio Grande Basin describes only a small number of historic stand-replacing fires in the region. Increasing the number of study sites and expansion of the study area will help determine if similar fire-climate relationships exist in other regions of the Southwestern U.S. Superposed-epoch analysis of a larger number of reconstructed stand-replacing fire events may reveal a more detailed set of climatic variables, possibly including antecedent conditions, associated with stand-replacing fire occurrence. Geographic expansion throughout the Southwestern U.S. may reveal important spatial variability in fire-climate relationships (Swetnam 1993).

Ideally, robust inter-annual fire-climate relationships resulting from future analyses would have predictive value, similar to the prior wet years that relate to surface fire activity in ponderosa pine forests (Swetnam and Baisan 1996; Swetnam and Betancourt 1998; Veblen et al. 2000). For example, fire-climate analyses in the Central Rocky Mountains have revealed that two consecutive dry years are associated with stand-replacing fires in the Selway-Bitterroot Mountains of Montana and Idaho (Kurt Kipfmueller, *unpublished manuscript*). This suggests that prolonged drought, not just single dry years may be associated with stand-replacing fire occurrence in some areas. A few of the fire climatology questions that remain unanswered include: (1) is there a quantifiable climatic threshold that limits stand-replacing fire occurrence, (2) are there any lagging climatic relationships with stand-replacing fire occurrence that would have predictive power, and (3) do climatic factors determine which subset of regional surface fire years have stand-replacing fire occurrence?

Remnant Douglas-fir

The presence of fire-killed Douglas-fir at 75% of the sites is worth noting. Evidence of fire, including charred bark and branch stubs, was present on all samples. The mere presence of bark and intact sapwood was quite remarkable considering some snags have persisted on the landscape for over 160 years after death by fire. The d.b.h. of many of the samples was greater than 100 cm with the remaining bark measuring up to 20 cm in thickness. The intact sapwood beneath the bark was often discolored due to the presence of resin that was seemingly “cooked” into the wood, which acted as a preservative. The presence of these large, surface fire resistant trees is evidence that the site was likely burned in a crown fire event.

Death date evidence was not collected, or was not able to be crossdated at 25% of the study sites. This is why the term "stand-replacing fire" was used. This term encompasses crown fire and high intensity surface fire occurrence, accounting for the possibility that tree mortality may have occurred in some instances without "crown fire." This is particularly true of spruce trees. This species is easily girdled and killed by heating around the lower bole. Yet, the death date samples indicated that at least 75% of the aspen stands were most likely evidence of crown fire events.

The presence of fire-killed Douglas-fir also revealed the potential for point estimates of crown fire frequency based on inner-ring dates. This is based on the assumption that a crown fire did not occur during the life of the tree. Therefore, the interval between germination and the fire induced, death date would represent a fire-free interval. Inner-ring dates of many of the samples extended back into the 1500's, suggesting a coarse, point-based estimate of a fire-free interval of approximately 250 years. Sampling specifically for these remnant trees could reveal important information regarding long-term crown fire frequency in the region. The state of preservation of all remnant samples was poor and fire occurrence in the area would likely consume these samples, thus there is some urgency to collect this evidence before it is lost.

Conclusions

Fire dates derived from annually precise dendroecological data indicate significant relationships between regional surface fire occurrence, extreme regional drought, and stand-replacing fire occurrence in upper elevation mixed conifer, aspen, and spruce-fir forests of the Southern Rocky Mountains. Multiple reconstructed fire dates (1851, 1861) were synchronous throughout the basin at sites located in different mountain ranges separated by the Rio Grande. The fire-climate relationships evident suggest the documented stand-replacing fire occurrence is not likely due to increased Euro-American settlement in the region, but that drought severity is the driving force behind these fire events in the upper Rio Grande Basin. The co-occurrence of regional surface fire and stand-replacing fire provides evidence for fire spread between the lower and upper elevation forests. If low elevation surface fire affects high elevation stand-replacing fire, this suggests that the cessation of surface fire circa 1900 may have effects across the elevation gradient in the Southwest.

CHAPTER FOUR

SUMMARY

Stand-replacing fires occurred historically in the upper elevation mixed-conifer, aspen, and spruce-fir forests of the southern Rocky Mountains. In the upper Rio Grande Basin large, seral, quaking aspen stands are proxy evidence of large, severe fire events. Stand-replacing disturbance events are very influential in shaping the ecological characteristics of these forest types and greatly affect human activity in proximate areas, yet little is know about these events in the Southwestern U.S. Surface fire research in the region has revealed the highly anomalous, anthropogenic alteration of the disturbance regime, as well as important fire-climate relationships that may be useful in predictive models. Initial attempts to study stand-replacing fire events in the region have encountered methodological problems related to temporal precision of fire dates. This prevented the analysis of inter-annual fire-climate relationships for stand-replacing fire regimes in the Southwestern U.S. To evaluate historical stand-replacing fire occurrence, I combined dendroecological techniques to reconstruct annually precise and accurate fire dates in twelve aspen stands distributed throughout the upper Rio Grande Basin. Fire-climate relationships and interactions between fire regimes were also analyzed.

The new method combined four lines of tree-ring evidence and successfully produced an annually resolved, stand-replacing fire data set. To obtain these dates it was necessary to select aspen stands that likely originated after stand-replacing events. Large, contiguous, aspen patches above 3300 m that were adjacent to spruce-fir vegetation were good proxies for stand-replacing fire in the Southern Rocky Mountains. Lower elevation mixed-conifer sites (mean < 2900m) had evidence of a mixed fire regime with a surface fire component and smaller stand-replacing patches. The presence of fire-killed Douglas-fir at many sites was a very important line of evidence that strongly suggested crown fire occurrence. Recruitment dates of these remnants may also have the potential to reveal earlier, stand-replacing fire events.

Analysis of the stand-replacing fire data set revealed regional, inter-annual, fire-climate relationships. Superposed epoch analysis, using fire dates and summer PDSI, indicated that drought on the fire year was strongly related to stand-replacing fire occurrence. Synchrony of fire occurrence was evident throughout the study area, with up to four widely separated sites recording stand-replacing events on the same year. Half of the reconstructed stand-replacing fires occurred before large-scale Euro-American settlement in the region (1870), further supporting the fire-climate relationship.

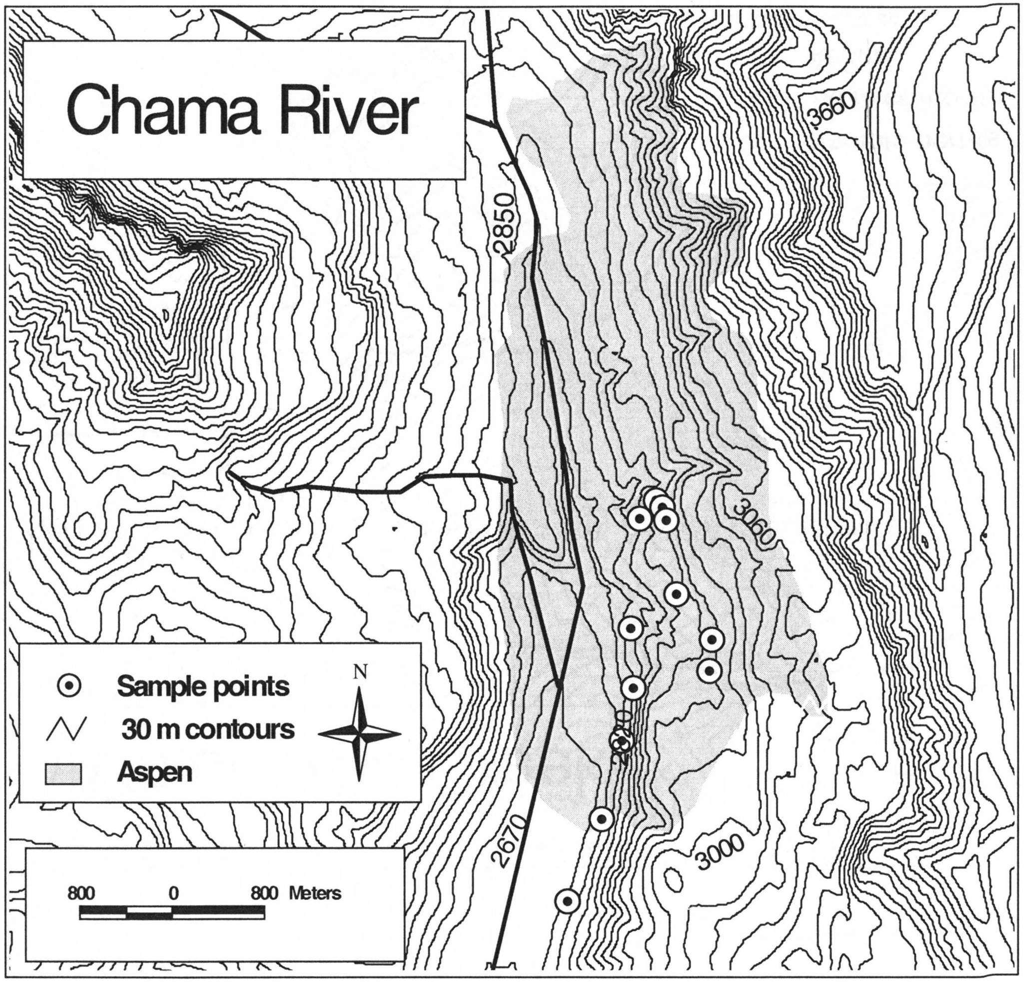
Analyses of stand-replacing fire occurrence and regional surface fire activity in the Southwestern U.S. revealed a relationship between these different fire regimes. Seventy eight percent of the years recording stand-replacing fires were also regional surface fire years. The primary reason for the synchrony between fire regimes is hypothesized to relate to the climate forcing for both types of fire regimes. Regional surface fire occurrence is correlated with drought occurrence (Swetnam and Baisan 1996), a relationship that was also evident for stand-replacing fire occurrence. Mechanistically, it is hypothesized that extreme drought sufficiently desiccated the upper montane vegetation to allow successful ignition and fire spread within these mesic forests. In addition, the increased availability of successful ignition sources from adjacent lower elevation forests, subject to widespread surface fires during drought years, may increase probabilities of stand-replacing fire occurrence during drought years.

The implications for the proposed fire-climate and fire regime interactions may be important for management, specifically fire management, of upper montane forests of the region. The proposed interaction between surface fire occurrence and stand-replacing fire occurrence has potential implications for the alteration of upper montane fire regimes based on our understanding of the effects surface fire exclusion has in the pine forests of the Southwestern U.S. The strong relationship between severe regional drought and stand-replacing fire occurrence may be useful when determining resource allocation for upcoming fire seasons, particularly as climate prediction skill improves.

The small sample size of this initial study limited the ability to quantify the details of the stand-replacing fire-climate relationships, yet interesting preliminary relationships are evident. More importantly, a mechanism describing the relationships is consistent with knowledge of fire behavior and fire-climate relationships. Further analyses with a larger data set may quantify in more detail the climate scenarios related to stand-replacing fire occurrence. This could include the delineation of a drought threshold related to stand-replacing fire occurrence. Further analyses may also reveal antecedent conditions at inter-annual or decadal time scales that would have potential use in predictive models, which would be of great benefit for management decisions and to increase the understanding of changes in ecological communities relating to large, severe disturbances and climate variability.

APPENDIX A

Site Maps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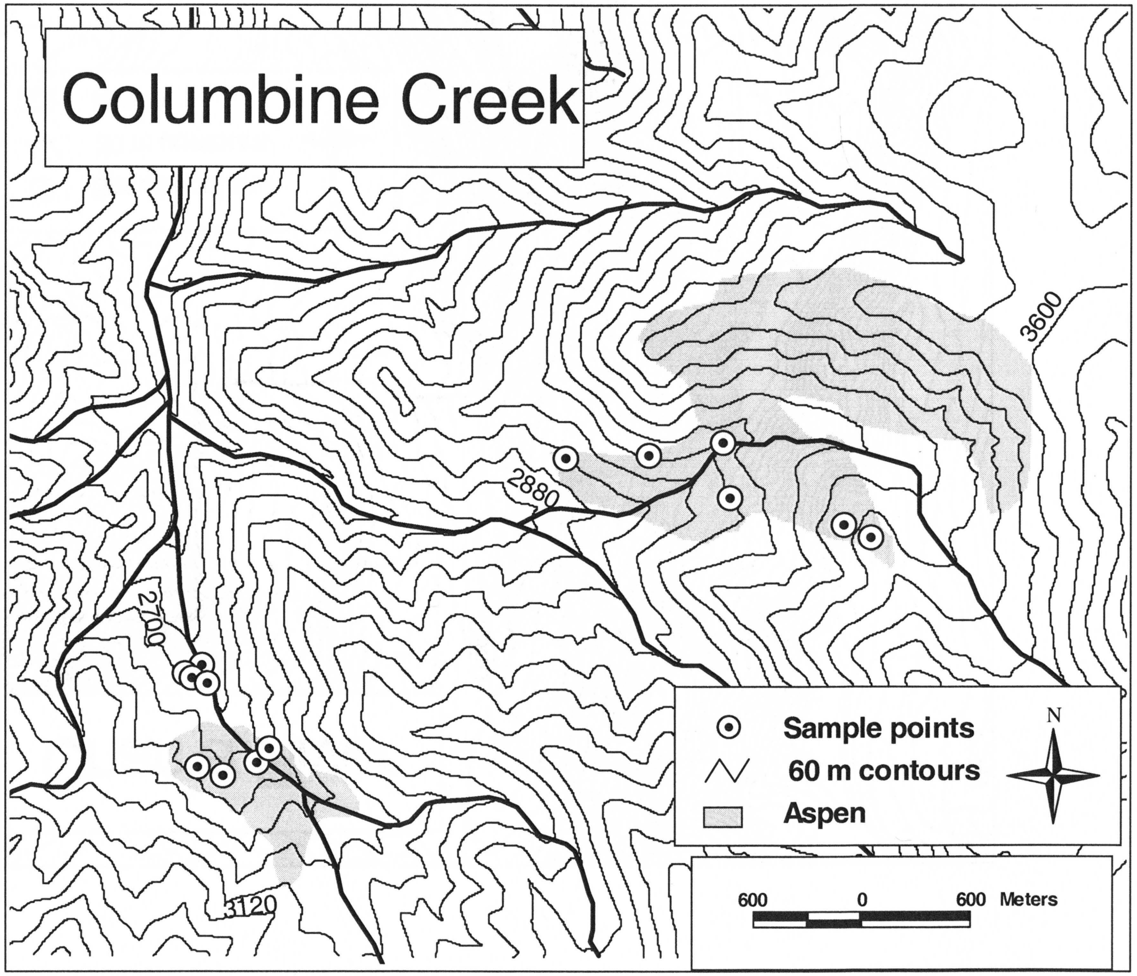
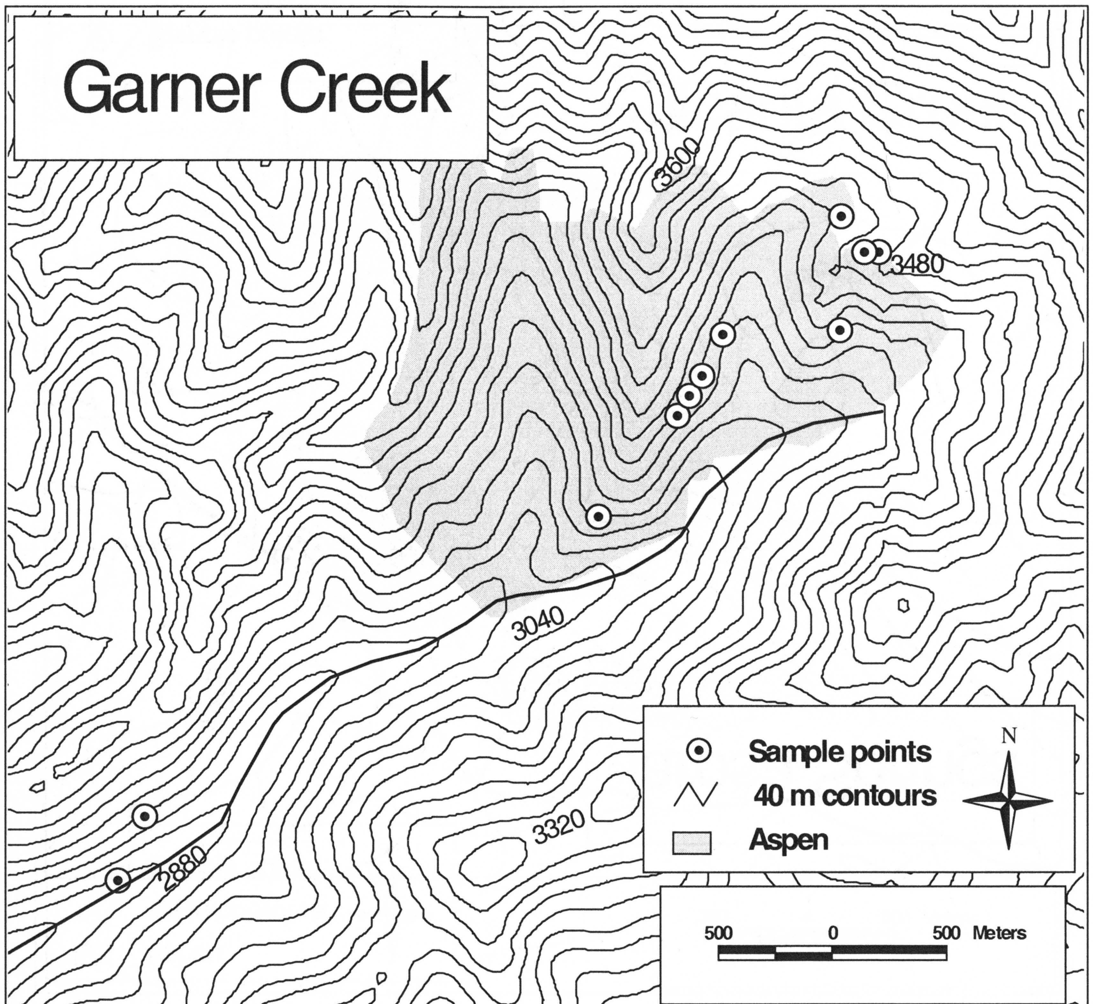
3660
2850
3060
3000
2670
Sample points
30 m contours
Aspen
N
800
0
800 Meters


Columbine Creek
3600
2880
2700
3120
Sample points
60 m contours
Aspen
N
600
0
600 Meters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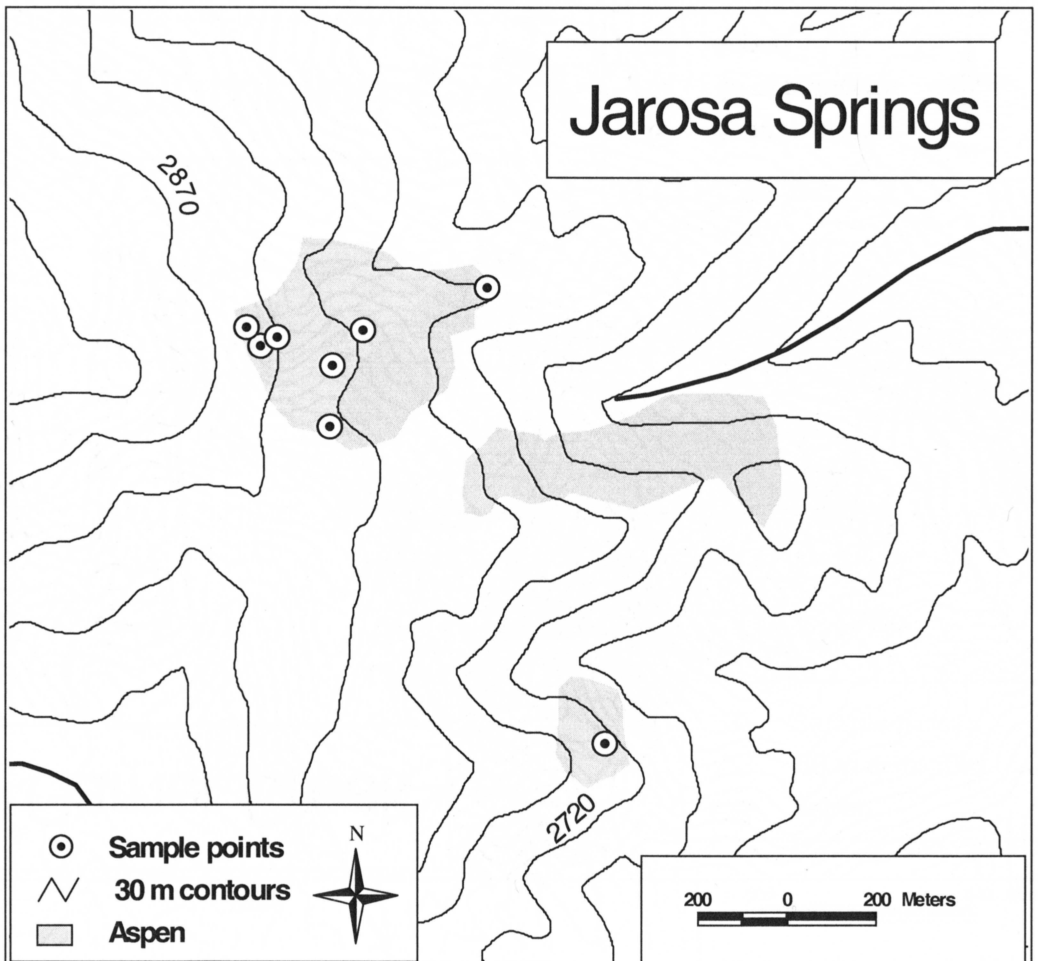
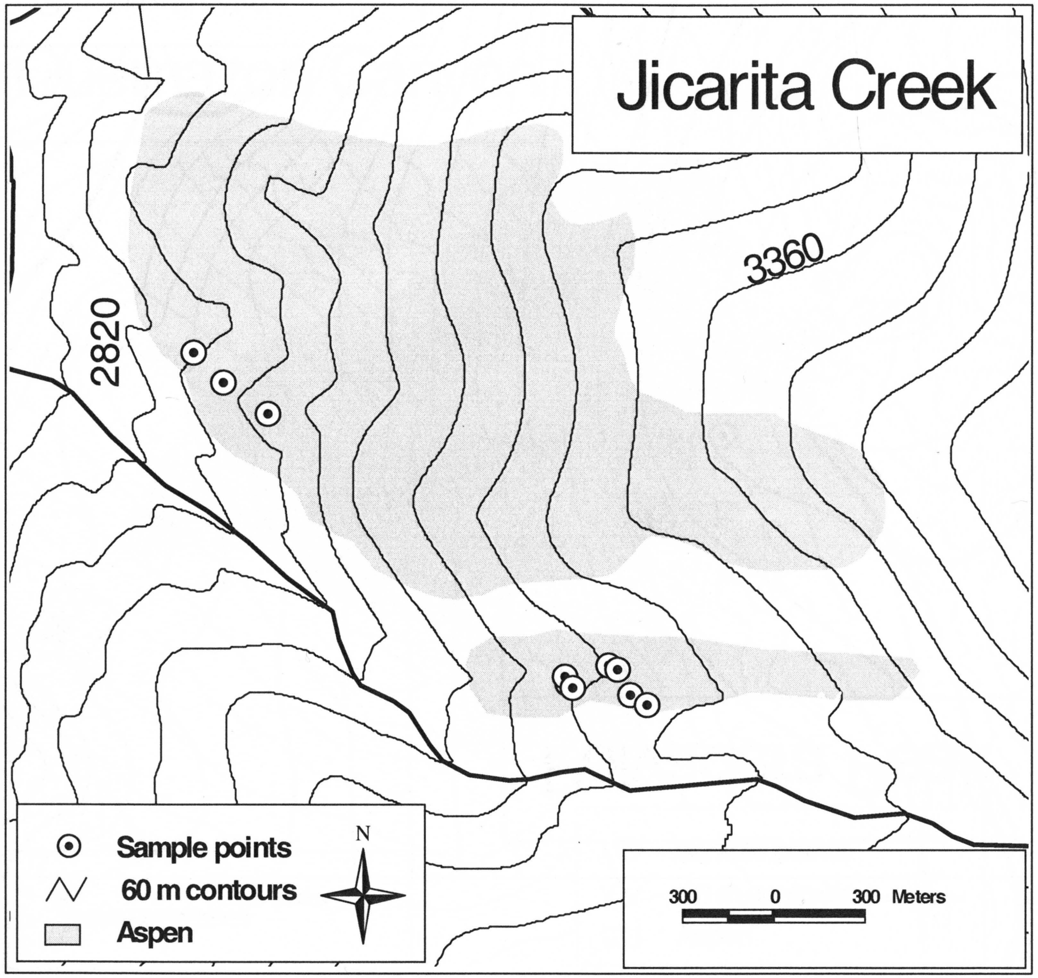
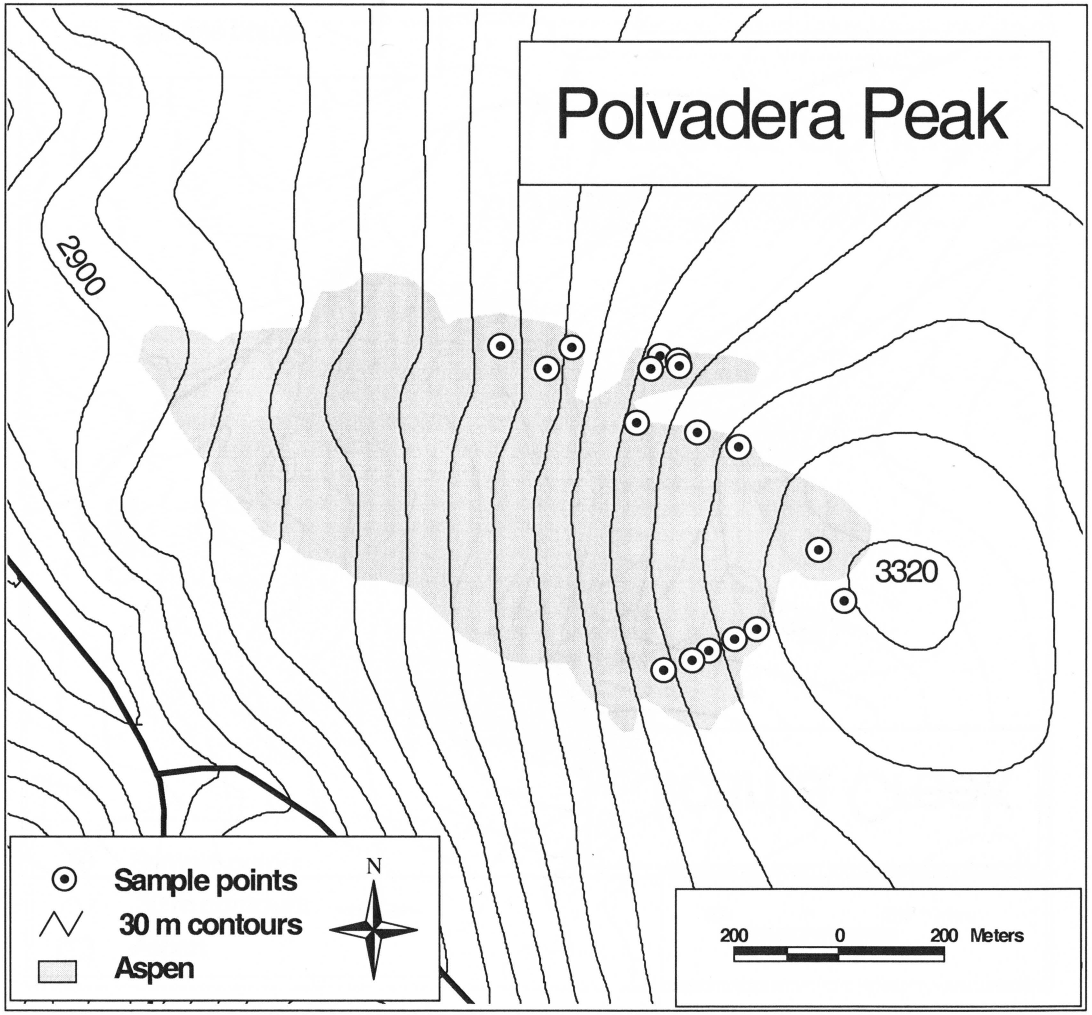
3600
3480
3040
3320
2880
Sample points
40 m contours
Aspen
N
500
0
500 Meters


Jarosa Springs
2870
2720
Sample points
30 m contours
Aspen
N
200 0 200 Meters


Jicarita Creek
3360
2820
Sample points
60 m contours
Aspen
N
300 0 300 Meters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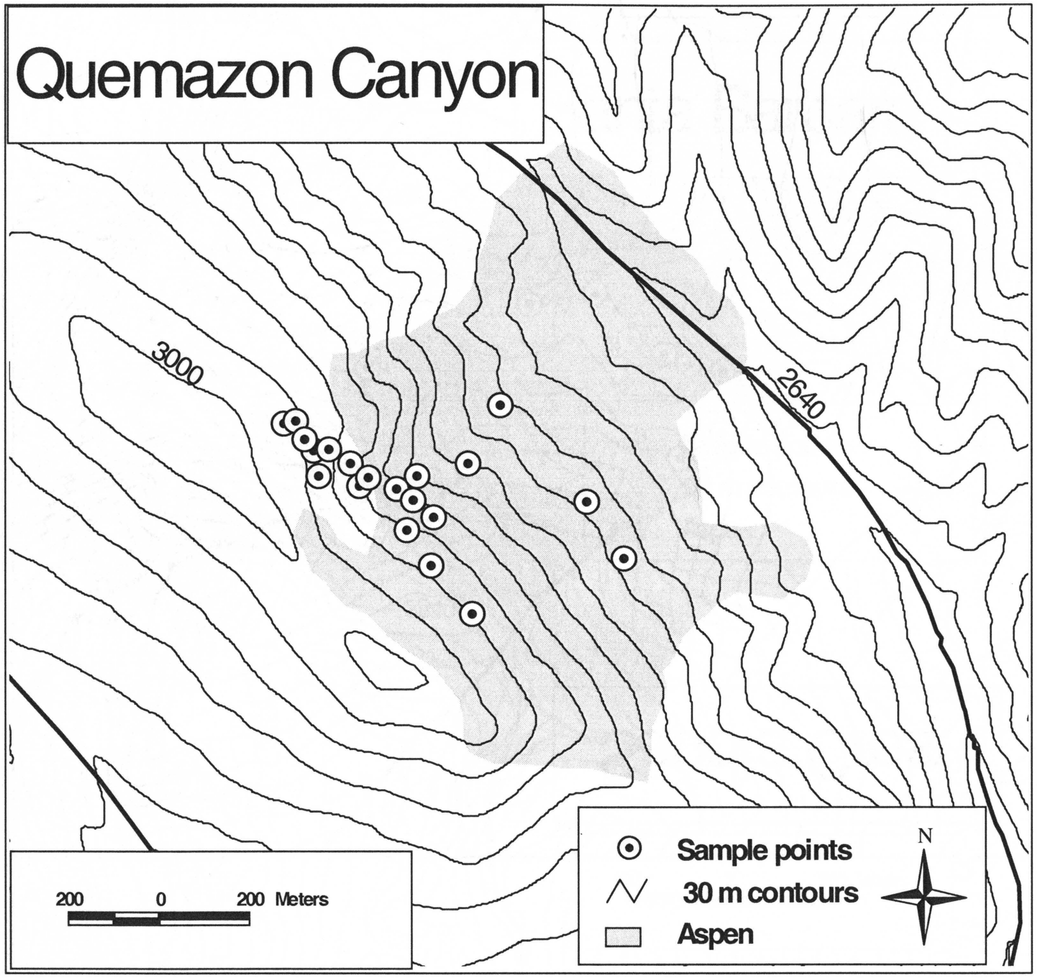
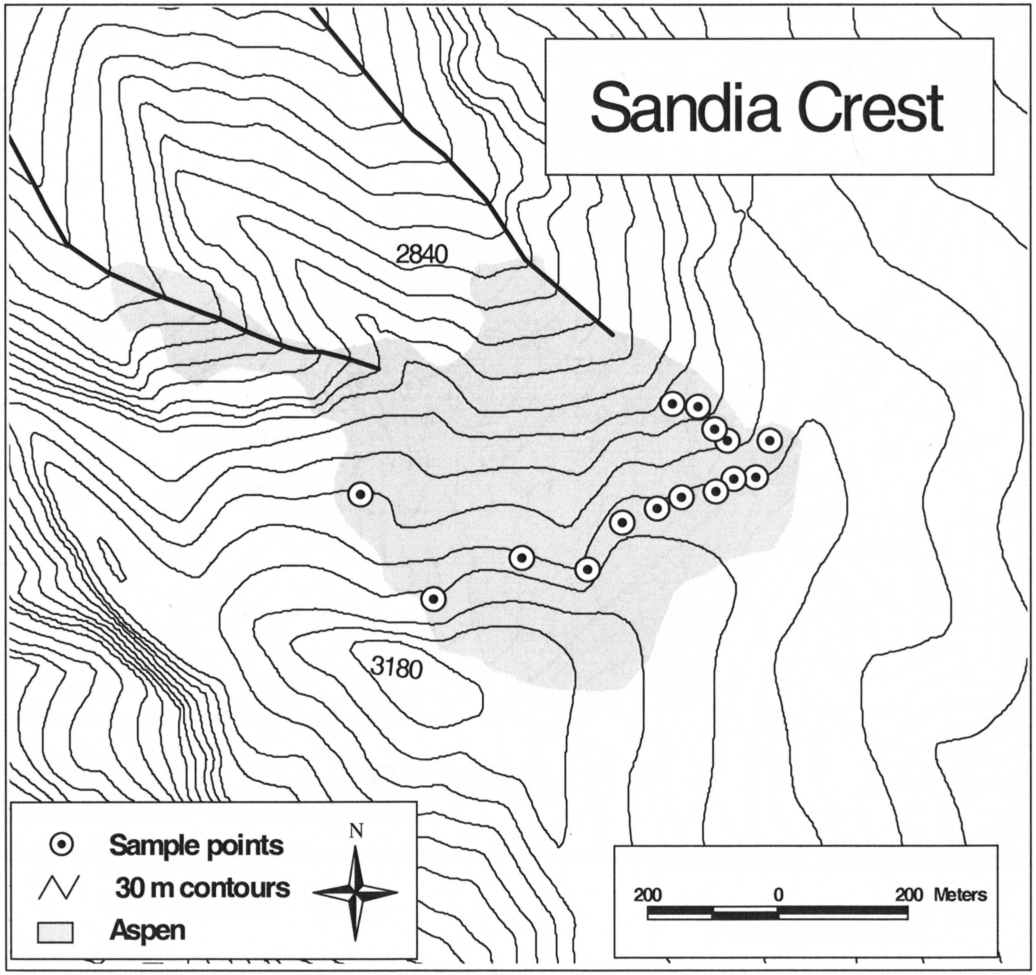
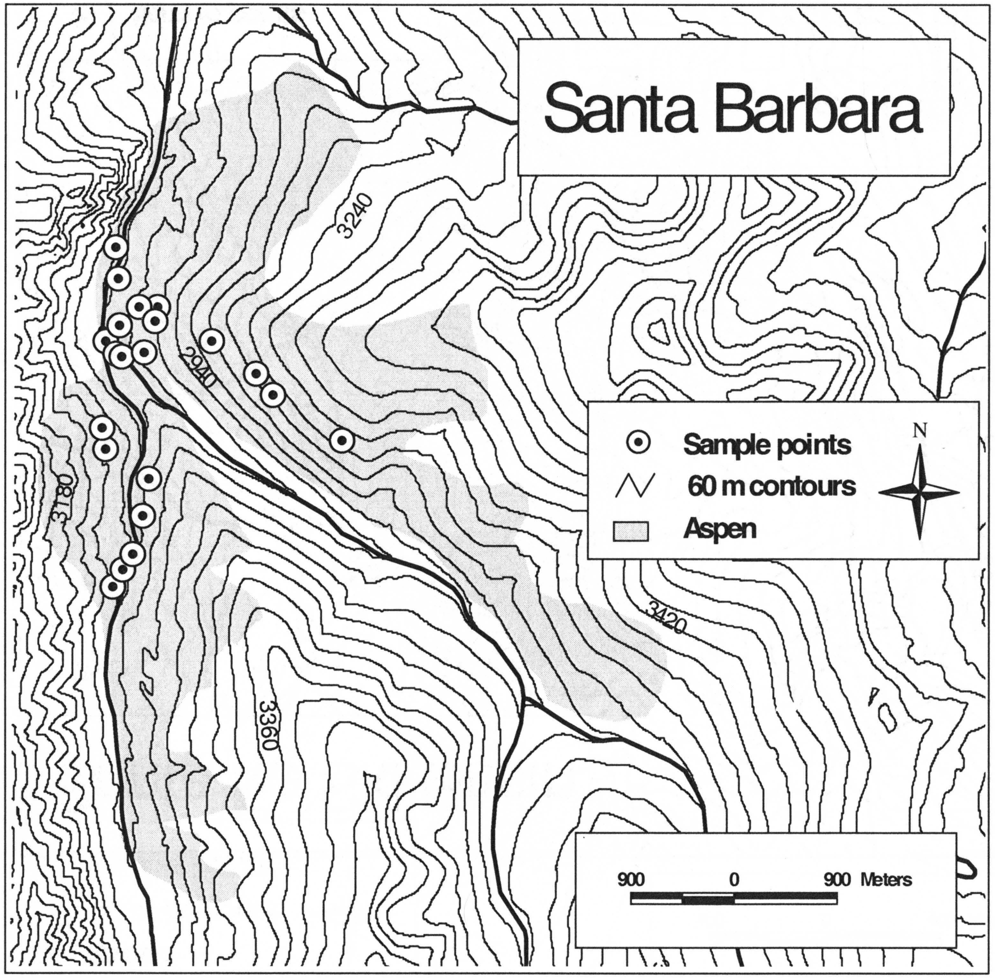
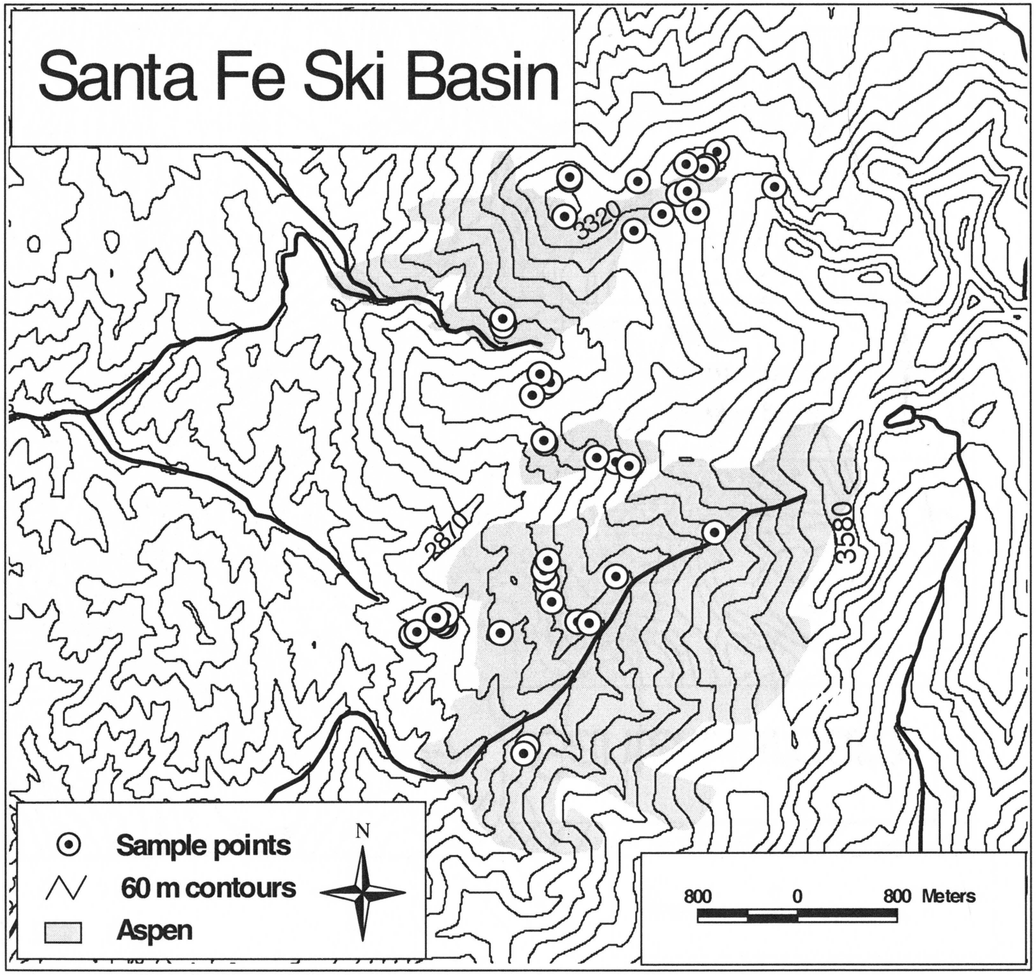
3320
Sample points
30 m contours
Aspen
N
200
0
200 Meters


Quemazon Canyon
3000
2640
200
0
200 Meters
Sample points
30 m contours
Aspen
N


Sandia Crest
2840
3180
Sample points
30 m contours
Aspen
N
200
0
200 Meters


Santa Barbara
Sample points
60 m contours
Aspen
N
3240
2940
3180
3360
3420
900 0 900 Meters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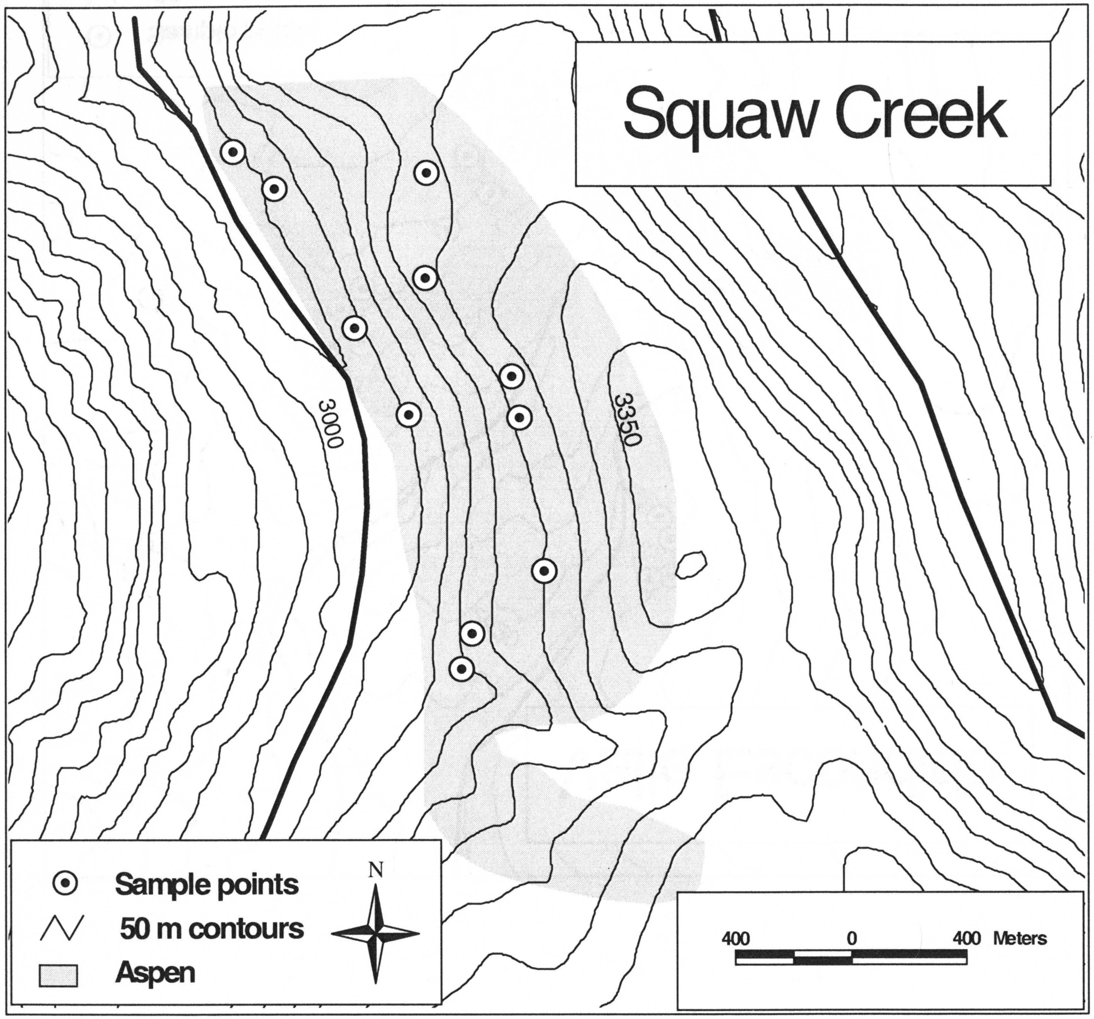
3320
2870
3580
Sample points
60 m contours
Aspen
N
800
0
800 Meters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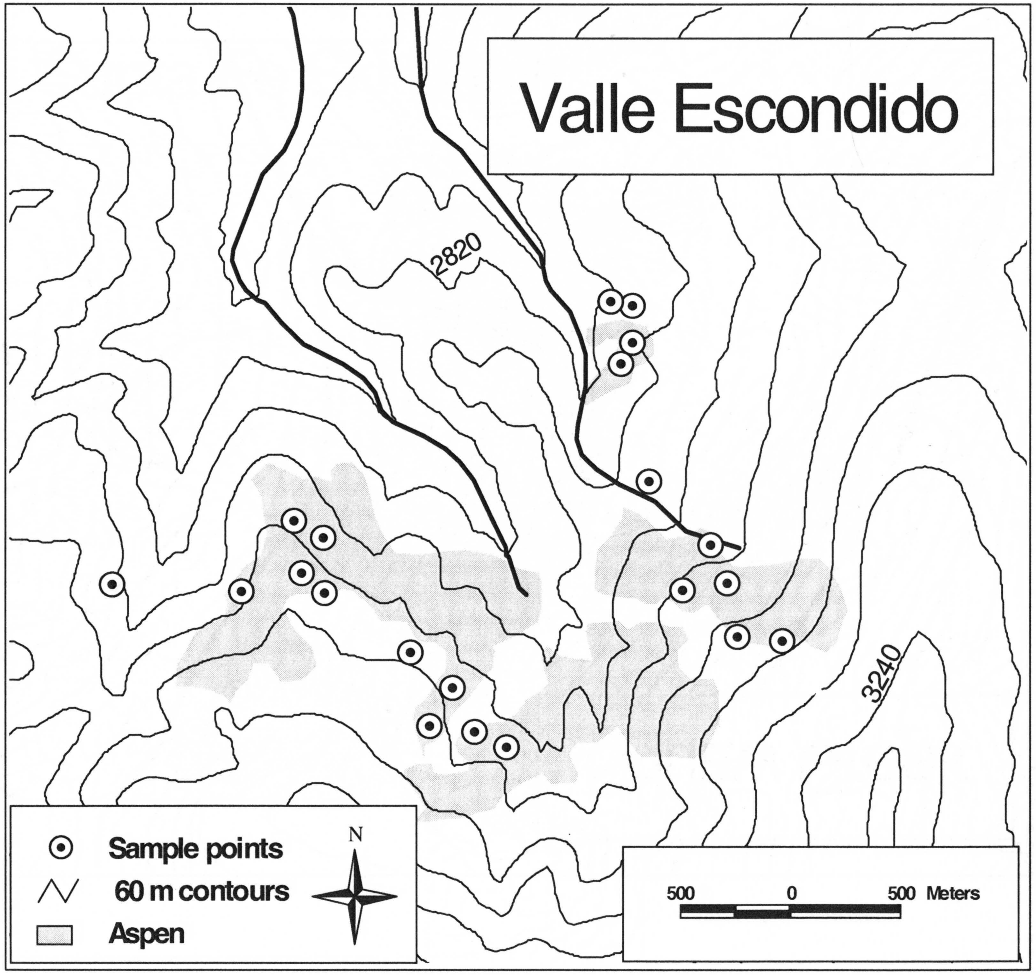
3350
Sample points
50 m contours
Aspen
N
400
0
400 Meters


Valle Escondido
2820
3240
Sample points
60 m contours
Aspen
N
500
0
500 Meters

APPENDIX B

Site Information Table

SITEID	SITE NAME	STATE	COUNTY	NATIONAL FOREST	USGS 7.5' QUAD	GEN VEG TYPE	SAMPLE PTS	MEAN NORTHING *	MEAN EASTING *	MEAN ELEV (m)	MIN ELEV (m)	MAX ELEV (m)
JAR	JAROSA SPRINGS	NM	RIO ARRIBA	SANTA FE	JAROSA	MC	8	3990569	346499	2794	2695	2834
CHA	CHAMA RIVER	CO	ARCHULETA / CONEJOS	RIO GRANDE	ARCHULETA CREEK	MC	12	4102477	363148	2841	2700	2924
CAN	QUEMAZON CANYON	NM	SANDOVAL	SANTA FE	VALLE TOLEDO / GUAJE MOUNTAIN	MC	20	3974769	375287	2929	2801	2971
SBA	SANTA BARBARA RIVER	NM	RIO ARRIBA / TAOS	CARSON	JICARITA PEAK / EL VALLE	MC SF	19	3989365	444966	2954	2817	3187
COL	COLUMBINE CREEK	NM	TAOS	CARSON	QUESTA / RED RIVER	MC SF	14	4055034	455324	2963	2736	3376
VES	VALLE ESCONDIDO	NM	TAOS	CARSON	OSHA MOUNTAIN / SHADY BROOK	MC SF	21	4018504	468213	2984	2857	3155
CRS	SANDIA CREST	NM	SANDOVAL	CIBOLA	SANDIA CREST	SF	15	3900326	367868	3033	2968	3082
SQU	SQUAW CREEK	CO	HINSDALE	RIO GRANDE	LITTLE SQUAW CREEK / WEMINUCHE PASS	SF	11	4175463	302200	3097	2928	3224
JIC	JICARITA CREEK	NM	TAOS	CARSON	JICARITA PEAK / EL VALLE	SF	10	3992103	446895	3111	2891	3227
SKI	SANTA FE SKI BASIN	NM	SANTA FE	SANTA FE	ASPEN BASIN	SF	44	3960506	427041	3124	2856	3427
POL	POLVADERA PEAK	NM	RIO ARRIBA	SANTA FE	POLVADERA PEAK	SF	15	3988795	372840	3242	3162	3301
GAR	GARNER CREEK	CO	SAQUACHE	RIO GRANDE	ELECTRIC PEAK / VALLEY VIEW HOT SPRINGS	SF	11	4227930	433243	3251	2835	3479

* UTM zone 13

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