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CLIMATIC DRIVERS OF WILDFIRE REGIMES IN NORTHERN IDAHO

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ON MY HONOR I HAVE NOT RECEIVED UNAUTHORIZED AID ON THIS THESIS.

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Abstract

Wildfire plays an important role in ecosystem processes of many forest types. Dendrochronological techniques can be used to examine the relationship between climatic events and fire patterns. Previous studies in South America and the southwestern United States have concluded that climate is an important driver of fire regimes. These studies have found significant relationships between La Niña events and/or significantly dry years and fire events in these regions. Such investigations are beginning in the Northern Rocky Mountains, but little is known about the regional drivers of fire regimes in this area. Preliminary studies indicate a relationship between dry years and/or El Niño years and fire events in the region. I investigated the climatic drivers of historical fire regimes in northern Idaho to add to the understanding of these forces in the Northern Rockies region. Using crossdating and other dendrochronological techniques I determined the historical fire regime on the University of Idaho Experimental Forest. I used superposed epoch analysis (SEA) to demonstrate a significant relationship between fire years and historical drought periods. I found that mean precipitation was lower in regional fire years than in other years. Additional analysis showed a relationship between fire years and El Niño events. Synchrony among the fire histories established on my site and sites in the Blue Mountains of Washington and Oregon also suggests that climatic events are drivers of the regional fire regime. These findings are consistent with other results from studies in the Northwest, Southwest, and South America.

Introduction

Many forest types depend on wildfire for regulation of their ecosystem processes. Ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*) forests are known to depend on periodic fires to maintain their successional patterns (Swetnam and Dieterich 1985; Turner et al. 1997; Johnson and Miyanishi 1991), return nutrients to the soil (Perry 1994; Kaye et al. 1999), maintain biodiversity (Perry 1994), and minimize fuel accumulation (Perry 1994). Both these tree species and many others, such as jack pine (*Pinus banksiana*) and long-leaf pine (*Pinus palustris*), flourish following moderate to severe fires due to increased nutrient, sunlight, and water availability and decreased competition with other plants (Perry 1994). In the case of ponderosa pine forests, these trees are considered a climax species in the absence of fire suppression, depending on fire to maintain open stands of larger old growth trees (Perry 1994). On the other hand, the other three species have evolved primarily with stand-replacing fires, and tend to regenerate as even-aged stands following fires (Perry 1994). Additionally, mixed-severity, patchy fire patterns that kill overstory trees in some areas of the forests and not in others lead to more successionally and biologically diverse forests, particularly in mixed conifer stands (Perry 1994).

Fire does not simply affect trees of a forest. Soil, other plants, microbes and animal residents are all impacted as well. Trees and other organic material essentially trap nutrients such as nitrates and phosphates in an unusable form until bacteria, fungi, or fire return these nutrients to the soil for use by surviving or newly-initiating plant species (Perry 1994; Kaye et al. 1999). Such nutrient cycling is imperative to maintain a vital and self-sustaining ecosystem (Perry 1994). Additionally, frequent fires in forest ecosystems can minimize fuel accumulation on the forest floor, reducing the likelihood of large- or catastrophic-scale fires (e.g. Perry 1994). Such fires can cause significantly more dramatic changes in an ecosystem than most historical fires are believed to have caused (e.g. Perry 1994).

Human actions such as settlement, logging, fire suppression, and the construction and use of railroads and roads have also had a great effect on fire regimes, fuels, and successional patterns in forests, particularly in the last century in the United States (e.g. Savage 1991; Barrett 1988). While logging, railroads, and other human use of ecosystems can increase the chance of ignitions, grazing decreases the chance of fire spread due to a reduction in fine fuels (e.g. Savage 1991). Due to the profound ecological importance of fires in these ecosystems, it is important to gain a better understanding of fire dynamics, particularly without the added complexity of human influence. In an attempt to better understand the forest and its cycles without significant human manipulation of the system, fire scientists study the history of these forests before European settlement (Swetnam et al. 1999). Fire history before written records of these forests is primarily studied through dendrochronological research . Trees scarred but not killed by the fires in question are often the best record available for the pre-settlement era (e.g. Swetnam and Baisan 1996; Brown and Shepperd 2001).

Not only can the dendrochronological record hold the key to understanding historical fire regimes, it can also provide some insight into the drivers behind these patterns. There are many variables involved in the determination of a region's fire patterns. Climatic fluctuations and human actions, since European settlement in particular, are two of the most significant sets of influences on fire regimes (e.g. Veblen et al. 1999). These forces affect ignition frequency, fire extent and severity, and fuel characteristics such as species, quantity and moisture (e.g. Veblen et al. 1999; Morgan 2003).

Climate's specific role in the determination of fire regime is complex and, for many of the world's forests, poorly understood. The primary reason for such complexity is the multivariate nature of any region's overall climate. In the western portions of North and South America, these variables include El Niño-Southern Oscillation (ENSO), the southeast Pacific subtropical anticyclone (SPSA), the Pacific Decadal Oscillation (PDO), and other Pacific Ocean temperature patterns. ENSO events are changes in Pacific Ocean currents, surface temperatures, and atmospheric temperatures and pressures causing a variety of changes in climate on the adjacent continents (e.g. Swetnam 1990; Heyerdahl et al. 2002). These events occur every 2-10 years and, along with the SPSA, are considered determinants of interannual variation in climate (Heyerdahl et al. 2002; Philander 1983). While ENSO effects are detected in weather patterns throughout the western coasts of North and South America, SPSA effects are primarily documented in Patagonia, where this force is considered the primary drought-producing mechanism (Kitzberger et al. 1997). ENSO effects serve as a major contributing factor to the patterns of the SPSA (Kitzberger and Veblen 1997). The southeast Pacific subtropical anticyclone is a semi-permanent high-pressure system that pushes south-southeasterly winds toward the west coast of South America (Garreaud and Muñoz 2003). On a decadal scale, the Pacific Decadal Oscillation is a major determinant of climate patterns throughout the western Americas (Mantua et al. 1997). Similar to the two previously defined forces, the PDO involves complex interactions between oceanic and atmospheric temperatures and pressures (Mantua et al. 1997).

The combination of these and other climatic forces has significant and varying impacts on the regional climatic patterns of North and South America. To determine the effect of regional climate on fire regimes, it is best to test each contributing force separately and determine its individual impact. Such separation of variables is particularly important when considering phenomena that occur at different spatial and temporal scales. Additionally, the possible knowledge gained concerning interactions between fire patterns and climate could serve as a useful predictive tool for humans impacted by wildfire.

Relationships between climate forces and fire regimes have been found throughout the Western Hemisphere. In northern Patagonia, Argentina, ENSO and SPSA significantly affect fire regimes through the influence they have on moisture availability in these forests (Kitzberger and Veblen 1997; Veblen et al. 1999). Fire occurrence in this region is found to coincide with ENSO patterns in two ways. Fires occurred most frequently either in the warm summers of the year following a severe El Niño year or in the year following a La Niña event, which is characterized in Patagonia by below-average winter-spring precipitation (Kitzberger and Veblen 1997; Veblen et al. 1999). The severity and position of the SPSA strongly influence fire regimes in this region (Veblen et al. 1999). The changes in placement of the low-pressure systems associated with this phenomenon lead to alterations in precipitation and storm patterns in Patagonia (Veblen et al. 1999). Such changes in precipitation cause alterations of fuel density and moisture in the forests of this region, leading to higher fire occurrence in years following significantly lower precipitation or higher temperatures than average (Veblen et al. 1999). All these factors considered, a distinct relationship is exhibited between major fire years and high frequency variation in climate in northern Patagonia (Kitzberger et al. 1997).

Similar interactions between climatic variation and fire regime have been found in North America. The influence of ENSO on the climate of Colorado, New Mexico, and Arizona is similar to the ENSO influence in Patagonia (Heyerdahl 2002). Despite the fact that a study of the interactions of ENSO events and wildland fire throughout the United States found that a significant relationship between these entities occurs only in the southeastern United States (Simard et al. 1985), further research has suggested otherwise. Specific studies of climate-wildfire interaction in Colorado and the southwestern United States have shown definite influences of climatic factors in fire regimes (Veblen et al. 2000; Swetnam 1990; Swetnam and Betancourt 1990). Some critics of the Simard et al. study claim that, while the connections found between Southeastern climate and ENSO may be valid, a rejection of such hypotheses in other regions of the United States based on this study is unwise (Swetnam and Betancourt 1990; Swetnam 1990). The Simard et al. (1985) research was at a very coarse regional scale and only incorporated 73 years of fire history data, all in the 20th Century, which may not be a long enough time period to achieve an accurate interpretation of this relationship, particularly considering human interaction with fire patterns (Swetnam and Betancourt 1990; Swetnam 1990). For these reasons, scientists such as Swetnam and others have continued the study of ENSO-fire pattern relations in the United States in modern and pre-settlement periods.

In Colorado, Veblen et al. (2000) found that there was an increased fire frequency 1-4 years following El Niño events, which in this region result in greater than average moisture availability in the spring and summer. Often the peak of these fire occurrences coincides with a La Niña event, or drier than average spring (Veblen et al. 2000). It is thought that the increased precipitation linked with major El Niño events leads to an increase in fine fuel growth, consequently increasing the fuel load that desiccates in dry La Niña years and causes larger conflagrations (Veblen et al. 2000). Swetnam and Betancourt found similar relationships to those in Colorado in Arizona and New Mexico, where ENSO events are expressed in much the same way as Colorado. Climate is responsible for severe, regionally synchronous fires in the southwestern United States (Swetnam 1990). Swetnam and Betancourt found a consistent correspondence between El Niño-Southern Oscillation (ENSO) events and the years in which the least area burned in all but one ENSO year studied (Swetnam 1990; Swetnam and Betancourt 1990 and 1992). This study also showed a pattern of large fire years often occurring one to three years after extreme ENSO events (Swetnam 1990; Swetnam and Betancourt 1990).

The findings of Veblen and Kitzberger in Patagonia and Colorado, and Swetnam and Betancourt in the Southwest, though very compelling, cannot be directly extrapolated to other regions of the Americas. This limitation is primarily due to noticeable differences in the climate, forest structure, and fire patterns throughout these areas. While ENSO and fire interact similarly in Patagonia and the southwestern United States, this does not hold true for all regions. In their assessment of such relationships in the Southwest Swetnam and Betancourt claimed "ENSO-fire teleconnections may be expected in other regions where fire occurrence is related to seasonal precipitation influenced by ENSO" (Swetnam and Betancourt 1992). The existence of such relationships has yet to be determined in many regions of the United States. The Northern Rocky Mountains is one such area in need of more exploration. Within this region, the forests of northern Idaho have very different composition and ecological patterns, particularly related to fire, than do the forests of Colorado or the Southwest. Northern Idaho forests are primarily composed of mixed conifers, dominated by subalpine fir (*Abies lasiocarpa*), grand fir (*Abies grandis*), western larch (*Larix occidentalis*), *Pinus ponderosa*, *Pinus contorta* and Douglas-fir (*Pseudotsuga menziesii*), with western hemlock (*Tsuga heterphylla*) and western red cedar (*Thuja plicata*) in the moister locations.

Climatic patterns in the northern Rockies are quite different from those in the Southwest, particularly due to different influencing factors. This region of the country receives much more precipitation and experiences harsher winters than the Southwest, whose warmer, drier climate is unlikely to support mesic species such as firs, hemlock or cedar. ENSO, which certainly has an effect on the weather in this region, actually has the opposite effect as that felt in the southern portion of the United States (Redmond and Koch 1991; Cayan et al. 1999). An El Niño year in the Pacific Northwest is very dry with a shallow snow pack that melts early, while a La Niña year is characterized by increased moisture and cooler temperatures (Heyerdahl et al. 2002; Cayan et al. 1999; Redmond and Koch 1991). The PDO also has significant effects on the climatic patterns of this region at a decadal scale, a variable not affecting southwestern forests (Heyerdahl et al. 2002; Mote et al. 1999). All these factors make the forests of the Northern Rockies and the fires that occur within them very complex. Historically, fires in these ecosystems occurred relatively infrequently compared to ponderosa-dominated forests, with drier forests burning on average every 25-50 years and more mesic forests burning much less frequently, every 70 to 250 years (Arno 1980). Fires in this region were a mixture of severities, ranging from small ground fires to large-scale crown fires (Arno 1980). Fire suppression, while at first decreasing fire size and intensity after its implementation around the 1940's, has caused a build-up in fuel in these forests leading to the modern tendency toward a much higher percentage of intense and highly severe fires (Barrett et al. 1997).

Many dedicated individuals have researched fire and fire history in the forests of northern Idaho. While much has been learned from these studies, the utility of the fire histories for modern comparison is limited. This restriction is due to the fact that the majority of fire histories done in the past in northern Idaho are not crossdated, a method of comparing cores to one another and to established chronologies to ensure that the dating the fire history provides is correct. The samples from these studies were unfortunately destroyed, leaving researchers with no way of confirming the dates reported in that research. Without such assurance, non-crossdated fire histories cannot be compared to climate event dates that have been dated using modern techniques. In some ways, therefore, determination of the Northern Rockies' fire history must start anew. Fire history research has been and is being done throughout the region, from the Cascade Mountains of Washington and Oregon to the Continental Divide in Montana and Wyoming. Pooling of this research is currently underway for a large-scale study assessing climate as a driver for fire and fuels in the region (Morgan et al. 2003).

In order to achieve such a large goal, many sites from throughout the region must be assessed for historical fire regime and climate patterns. There are several such sites in western Montana and eastern Idaho, along with eastern Washington and Oregon. Heyerdahl et al. (2002) reported climate forcing of fire regimes in the Blue Mountains of eastern Washington and Oregon (Heyerdahl et al. 2002). Overall, relations between ENSO and fire regimes were the inverse of those found in Patagonia and the southwestern United States (Heyerdahl et al. 2002, Kitzberger et al. 2001). Large fires generally occurred in dry and El Niño years due to low summer precipitation and/or a shallow snow pack in those years (Heyerdahl et al. 2002). Due to the fact that this area is generally moister than Colorado, Arizona, or New Mexico, annual precipitation has less impact on fine fuels from year to year, and does not create a buildup as it does in those other locations (Heyerdahl et al. 2002). Heyerdahl et al. (2002) found that fire years were affected only by the climate of that year in particular or, in some cases, by a particularly dry decade caused by the PDO. PDO-related events occurred during the fire suppression era, indicating that this force has been influential despite human efforts to minimize fire activity (Heyerdahl et al. 2002). The work of Heyerdahl et al. in this region is incredibly informative, but cannot be assumed to accurately describe fire dynamics for all of the Northern Rockies. While research is also being done in Montana and central Idaho, little has been researched in northern Idaho, a location which serves as an important link in the region, helping to create a complete picture of the Northern Rockies fire drivers.

I wished to add to this data bank and gain a better understanding of fire and its drivers in these northern mixed-conifer forests with my research. Specifically, my goal was to determine if climate was a significant driver for historical wildfire on the

University of Idaho Experimental Forest in northern Idaho. Not only will such research assist scientists and managers affiliated with the property itself, but it will also aid regional ecologists and fire scientists exploring the larger fire patterns throughout the Northern Rockies. My hypothesis was that climate, in the form of ENSO and historical drought periods, has had a statistically significant effect on the historical fire regime of the U of I Experimental Forest. If this hypothesis is supported, my data set can be added to the information collected on other sites in the region to achieve a more complete picture of this region's fire regimes and their drivers. Gaining a better understanding of why fire occurs when and in the way that it does would greatly increase our ecological understanding of this complex region. Additionally, this information would assist in humans' ability to work with, rather than against this ecologically important force. In realizing the potentially significant role that climate plays in this region's fire patterns, better decisions concerning forest and fire management may be made. If fire is found to occur in conjunction with specific climatic conditions, then it is quite possible that fire occurrence could be modeled and predicted for the future. As our understanding of the effects of ENSO and other climatic forces expands, so too does our capacity to predict such phenomena. Modeling climate patterns can help our abilities to predict major fire years; such a possibility could be useful for managers and residents of the forests involved.

Alternatively, if I do not find a direct relationship between historical fire episodes on the Experimental Forest and historical drought periods, other possible drivers for fire regime must be examined. A possible reason for not finding such a relationship is that perturbations from increased human use of the property has been a greater determinant of fire regime than regional climate. Human use on the property has ranged for centuries, beginning with Native Americans and since then ranging from logging to the construction and use of railroads, roads, and highways. Fires started by Native Americans, sparks from railroads and logging, and other human uses facilitated by easy access via roads and trails could have had a major effect in the historical fire record found on the property. Additionally, climate may indeed be the primary driver of fires in the region, but perhaps the climate that most affects fire patterns is more spotty and localized in nature, rather than the broad-scale pattern examined. While climate plays an important role in the determination of lightning ignitions, these events remain stochastic in nature and difficult to predict, even with a good understanding of the climatic patterns of an area. Though a particularly dry year may lead to more dry lightning strikes, it is always difficult to predict where such strikes will occur and in what frequency. It is quite possible, therefore, that my study area did not have an ignition source in every prime fire year, and did not record all fires. Alternatively, it is possible that fires were ignited on my site in wetter years and did not spread beyond a few trees, and by chance these were the only trees available for sampling. Such an occurrence would lead to recorded fires in years that were not regionally significant fire years.

Study Area

The study site for this project is located on the Flat Creek and East Hatter Creek Units of the University of Idaho Experimental Forest (UIEF), north of Moscow, between Harvard and Deary, Idaho, at approximately 46°52’N 116°45’W. I used two sites, known as Leef’s Hill and Basalt Hill, to determine the fire history of this forest. I combined the samples from these sites into one large data set to increase my sample size. The sites are approximately four kilometers apart with a large draw now containing a highway and railway separating the two. While this draw is likely to have historically served as a natural firebreak, fire events in major fire years would be expected to occur on both slopes. For these reasons, I consider the sites two smaller subsets of a larger site representing the fire patterns of the UIEF accurately. I will refer to the combination of these sites as this research's study site. With elevation ranging from 500 to 1500 meters, the terrain of the site is best described as gently to steeply rolling. The total area of the combined sites is 55 hectares. All samples were taken from south- or southwest-facing slopes ranging from 15-40%, though most samples were found in approximately 15-30% slope regions. Species composition on the two sub-sites is very similar, dominated in the overstory today primarily by *Abies grandis*, *Pinus ponderosa*, *Pseudotsuga menziesii*, and *Larix occidentalis*. The understory of the site is composed of mallow ninebark (*Physocarpus malvaceus*), oceanspray (*Holodiscus discolor*), and a variety of forbs and graminoids. The site has been heavily used by humans throughout history, most significantly affected in the 20th Century by heavy logging.

Methods

Sample Collection and Preparation

I determined historical fire regimes on the University of Idaho Experimental Forest (UIEF) using fire-scarred stumps from previously logged trees on the sites. University of Idaho Professor Harold Osborne and his students identified and collected all Leef's Hill samples. They found these samples were found via a baseline survey of the study site. They collected samples from all fire-scarred stumps found by cutting a "cookie", or cross-section of the stump using a chainsaw. Professor Penny Morgan and I identified the majority of Basalt Hill samples were identified as good candidates for this study. We explored this study area using walking surveys, tagging each scarred stump and recording the location in a GPS unit. As the forest is not dense, stumps were fairly easy to find, and it is believed that the majority, if not all, of the scarred stumps were identified. As these sites have been heavily logged essentially since 1900, there are very few trees older than 150 years remaining on these sites. Due to the fact that the focus of this study was, in particular, fire patterns preceding 1900, sampling only stumps and no live trees was seen as acceptable for attaining a good representation of pre-settlement fire regimes.

Following identification of these potential samples on Basalt Hill, a University of Idaho sawyer and I returned to collect cookies from the samples exhibiting the clearest scar record. The sawyer took full cross sections from what remained of each stump, which in some instances was only a partial cross section of the original tree. Approximately 80-90% of those stumps initially identified were used in final analysis. Some Basalt Hill samples proved too decayed to withstand sawing and sanding, and some Leef's Hill samples were not usable due to misidentification or lack of identification by the collectors. I used a total of 21 samples, eleven from Leef's Hill and ten from Basalt Hill. The sixteen cookies collected from younger stumps were of known harvest dates, either 1999 or 1992, depending on site. All five older samples had unknown outer ring years. Sample preparation followed the standard procedures of modern dendrochronology (Heyerdahl and Sutherland 2003). Some sample surfaces were particularly uneven and required planning with a hand planer to prepare them for sanding. All cross-sections were sanded with a belt sander until the cell structure of each annual ring was clearly visible. To attain such a surface, samples were sanded beginning with 40 grit sand belts, using progressively finer grits until the final 400 grit belt achieved a glass-like surface on the samples.

Sample dating and analysis

Once such a surface was achieved, the annual ring patterns of each sample were crossdated using a binocular microscope and skeleton plotting techniques (Stokes and Smiley 1968; Swetnam et al. 1985). These techniques allowed me to give each annual ring a calendar year through careful comparison of tree growth patterns in the form of annual rings. Regional climate is the primary determinant of ring size in the tree species sampled on these sites (Phipps 1985, Stokes and Smiley 1968). As the sites are relatively close in distance from one another, I was able to assume the ring patterns were consistent among trees on both sites. Comparing ring patterns from trees of known harvest dates confirmed this assumption.

Often scientists exploring fire history through dendrochronology are able to use preexisting tree ring-based chronologies as a basis for their crossdating procedures. While some chronologies have been established for areas near the UIEF, after comparing these chronologies to one another I discovered that they may not be as reliable a source of dates for my sites as is necessary for crossdating. The majority of the significant "marker years," or particularly small rings, were not found consistently among the chronologies. While occasional significant years appeared in all four chronologies, these were not frequent enough to allow me to depend solely on these dates for this project. Of particular concern was the fact that many of the dates in the chronologies did not match the samples of known harvest date. While this could be an indication of inaccurate determination of harvest date, the lack of synchronicity among chronologies supports otherwise. To overcome this problem I in essence created my own chronology. Using the marker years that appeared in the majority of the chronologies and/or a significant number of my known-date samples, I created a master chronology for the Experimental Forest. With this chronology I was able to date younger samples with unknown harvest dates.

In the case of older samples with an unknown harvest date, a measuring machine and COFECHA, a computer crossdating program, were used (Grissino-Mayer 2001_B). By measuring each ring through a microscope with special instruments made to move the sample fractions of a millimeter at a time and a computer recording the width of each ring, dendrochronologists can achieve precise representations of each sample's unique pattern (Swetnam et al. 1985). Once the pattern is digitized it can be compared to other chronologies in COFECHA. This program divides the sample's pattern into overlapping segments and compares these segments to the chronology to find the most likely beginning date for the sample according to each segment (Grissino-Mayer 2001_B). Several dates are found for each segment, and the program determines the starting dates that appeared most often as matches for the chronology. After determining these possible starting dates I was able, with the assistance of my produced chronology, to determine the dates of these samples. Once calendar years were assigned to each ring on the sample, I dated the fire scars with a year and often a season (Heyerdahl and Sutherland 2003). I then entered fire years into FHX2, a computer program that compiles the data from each scarred section to plot the fire history of each site (Grissino-Mayer 2001_A). This program also includes the ability to perform superposed epoch analysis (SEA), a statistical program used in this study to determine the climatic patterns in and surrounding fire years (Grissino-Mayer 2001_A). Fire historians worldwide consider SEA the best means of clarifying climate's role in historical fire regimes (Fire 2002). I compared the fire events from this study to the Palmer Drought Severity Index (PDSI) data for PDSI grid point 17, located in northern Idaho (Cook et al. 1999) and ENSO data from the Southern Oscillation Index (SOI, e.g. Stahle et al. 1998) through superposed epoch analysis to determine climatic influence over the fire regime on the University of Idaho Experimental Forest. Fire events in two different subsets were compared separately to this climate data in SEA. All fires that scarred two or more trees in the record from the UIEF were run in these analyses. Additionally, I ran separate superposed epoch analyses for all those fire years on the UIEF in which fires were also recorded in the Blue Mountains of eastern Washington and Oregon (Heyerdahl et al. 2002). These sites vary from 95 to 197 km from my site and are located at a range from nearly directly east to northeast of the UIEF site. I only used three of the four sites from the Heyerdahl et al (2002) study in my analyses. The sites used were the three closest to my site and appeared to display the most synchrony among themselves.

Results

Historical Fire Regime

The samples analyzed in this study spanned 478 years of fire history, beginning in 1522 and continuing until 1999. The 21 samples displayed 84 fire scars appearing in 63 years of the chronology. The earliest fire recorded was in 1626, while the most recent was in 1963. The 1963 fire event was the only event from 1935 on. Once a tree has been scarred once by a fire or other injury it is more likely to scar again due to fire because of increased resin content in the scar area and decreased bark thickness (Grissino-Mayer 2004). Dendrochronologists consider these trees that have been previously scarred to be "recording" (Grissino-Mayer 2004). From 1726 to 1992 five or more samples were recording scars, meaning they had recorded at least one scar and were therefore likely to record fire events. Fifty-six of the sixty-three recorded fire years were observed in greater than ten percent of the recording samples. Fourteen of the fire years scarred two or more samples. The mean fire intervals, or average number of years between consecutive fire dates, for these samples ranged from 6.9 to 72 years. It should be noted, however, that the mean fire intervals of the five older samples, ranging from the year 1522 to 1949, ranged from 6.9 to 18.4 years. The more recently established samples, of which the earliest starting date was 1808, ranged from 20.5 to 72 years. The average of all samples' mean fire intervals was 13.7 years. Fire were recorded with fairly regular frequency from 1661 to 1935, with a maximum interval of eleven years in this time span. From 1935 to 1999, however, only one fire was recorded, in 1963.

Climatic influences on fire regime

Superposed epoch analysis(SEA) of fires scarring two or more samples and Southern Oscillation Index data was not conclusive (Figure 2). Analysis of these fire events versus PDSI data indicated the drought severity index was significantly higher, or more positive, than normal five and three years preceding the fire events at the 95.0% confidence level (Figure 1). This difference represents more rainfall than average in these years. Due to the fact that the PDSI and SOI chronologies used in these analyses began later than the fire history used, 51 of the 63 fire dates were used in the SOI analysis and 56 were used in the SEA with PDSI. Over half (53.6%) of the fire years recorded occurred in drier than average years, meaning years assigned negative PDSI values (Figure 3). 10.7% of these fires occurred in years with PDSI values less than –2.0 (Figures 3 and 5), which represents moderate drought (NOAA 2004). Exactly two-thirds of the fire events occurred in El Niño years, defined as years with negative SOI values (Figure 4). As the SOI has a normal range of 20 to –20, none of the fires occurred in what would be considered extreme El Niño event years. Only one fire event had an SOI above 10, and 27.5% of the fire event years had SOI values higher lower than –5.0 (Figure 6).

Comparison of my findings with those of similar research in the region was quite informative. By noting which of the fires on my site were also recorded on other sites in the region I was able to determine which of the fires on the UIEF were regionally significant. Nearly half of the UIEF fires recorded were also recorded by trees on three sites in the Blue Mountains of eastern Washington and Oregon (Heyerdahl et al. 2004). Of these 31 regional fire years, comprising 49.2% of the fire record, five of the years were earlier than PDSI records and six years dated before the beginning of SOI records. A comparison of the 26 and/or 25 remaining fire years and those climatic data sets is revealing, however. PDSI values were negative for 65.4% of these regional fire years, and SOI values were negative for 68.0% of these years. While seventeen of these fire years recorded lower than average PDSI values and seventeen years also registered El Niño conditions according to the SOI, these were not all recorded in the same years. In fact, all but two of the regional fire years, representing 92.3% of these events, were either an El Niño or a drier than average year. Ten of these regional fire years had negative PDSI and SOI values.

Superposed epoch analysis of regional fire years and these climatic factors showed a relationship between climate and fire regimes. SEA of these regional years and PDSI demonstrates a significant difference in the drought index during these fire years and five years following the event. The drought index in fire years was significantly lower than average to the 99.0% confidence level, while PDSI values were less than average to the 95.0% confidence level five years following the event (Figure 8). The SEA of SOI and the regional fire years showed that the index was significantly higher to the 95.0% confidence level five years following the fire events (Figure 9).

Discussion

I found a significant relationship between climate and the historical fire regime on the University of Idaho Experimental Forest through superposed epoch analysis (SEA) of PDSI data and the fire history compiled in this study. This analysis demonstrated greater than average moisture three and five years preceding fire events. The fact that over half of the fire years recorded occurred in years with lower than average precipitation and over ten percent of the fires occurred in moderate to severe drought years provides additional support for a connection between climatic patterns and the fire regime on this study site. While SEA did not demonstrate a significant relationship between ENSO and fire regimes on this site, two-thirds of the fires recorded occurred in El Niño years. A connection between regional climate and fire regimes is also supported by synchronous fire activity among sites in the northern Rocky Mountain region (Heyerdahl et al. 2002). I found such synchrony between the fires on my site and those on sites in the Blue Mountains of eastern Washington and Oregon (Heyerdahl et al. 2002). Nearly half of the fires recorded on my sites were also recorded on these sites. Of these 31 fire events recorded in both locations all but two were either El Niño years or drier than average according to the PDSI record. SEAs run of these regional fire events versus PDSI and SOI records showed precipitation to be significantly less than average in fire years.

My hypothesis was that climate, in the form of ENSO and historical drought periods, has had a statistically significant effect on the historical fire regime of the U of I Experimental Forest. SEAs run for fires appearing both in my fire chronology and chronologies from other sites in the region supported this hypothesis. The analysis of these fire dates and the PDSI data revealed a significant relationship between dry years and fire occurrence in those years. This hypothesis was not supported in that SEA of my fire data alone did not demonstrate a statistically significant relationship between ENSO and the fire events on my study site. Also, while a statistically significant relationship was found between PDSI data and the site's fire regime, it was historically wet years, not historically dry years, that were significant in the determination of this site's fire history. It is likely that not all the years I considered regional fire years in this study will be considered such years after further research. Fires rarely occurred on my site and on all three sites in the Blue Mountains simultaneously, and often these fire years were only recorded on my site and one of the Blue Mountain sites. Due to my small sample size and the few sites currently available for comparison in the Northern Rockies, the findings of this study cannot be extrapolated to the entire region at this point. As research of this nature continues in the region a better approximation of regional fire patterns and relationships with climate can be attained. As Swetnam (1990) discovered in the Southwest, it is likely that the Northern Rockies' fire-climate relationship will be better understood after the compilation of fifteen or more sites throughout the area.

While decisive statements about the climate-fire relationship throughout the Northern Rockies cannot be made based on this study, the findings of this research reveal a great deal about the role of climate as a driver for fire on the University of Idaho Experimental Forest. The relationship between dry years as recorded by PDSI data and regional fire event years serves as one of the most important indicators of such a relationship, along with the fact that these regional fire years exist at all. Such synchrony among fire sites far enough from one another that one fire would not be expected to burn both sites is an indication of a greater, regional-scale driver of these fire events. The most obvious such driver is climate in these regions.

That climate served as a major driver for these fire events is also supported by the fact that all but two of these 31 regional fire years were either El Niño or lower than average precipitation years. When considering all my fire dates, the majority of these years were drier than average according to PDSI data, and two-thirds of these years were El Niño years. As stated earlier, El Niño years in the northwestern United States are often drier and warmer than average with a shallower snowpack and longer fire season (Heyerdahl et al. 2002, Cayan et al. 1999, Redmond and Koch 1991). Fire occurrence in PDSI-recorded dry years and El Niño event years is not surprising, as a longer season and drier fuel load increases the probability of fire occurrence.

The SEA I ran using fire years in which more than two trees on my site were scarred also has potentially important implications. Significantly more moisture than average five and three years preceding fire events could lead to a build up of fuel, but this is unlikely as the region is fairly moist as a whole and precipitation has less of an impact on fine fuel build-up as moisture in the Southwest does (Heyerdahl et al. 2002). I consider the results of this SEA to be less reliable than those related to the regional fire years due to my small sample size. With 21 samples and only five of these recording before 1800, determining important fire years to be assessed in the SEA is difficult. While I am confident of the fire dates recorded in these samples, it is difficult to determine major fire years on this site with a small sample size. With a larger sample size I would have determined these fire years using a minimum percentage scarred or a minimum samples scarred classification. The effectiveness of such measures is limited in this case due to my shallow sample depth. For these reasons, I do not consider the results of the SEAs run based on these fire dates as a particularly sound basis for a fuel building argument on this site. By comparing my fire dates to those of another study in the region with a greater sample depth I was able to determine regionally important fire years and run more statistically sound analyses, as previously described.

The presence of regional climatic drivers of fire in the Northern Rockies supports research done in Patagonia, the Southwestern United States, and elsewhere in the world (e.g. Veblen et al. 1999, Swetnam 1990). My findings are also consistent with these studies in that the influence these climatic factors have over fire regimes is primarily precipitation-based. Drier fuels in fire years and the possibility of fuel loading from increased precipitation in years preceding fire years seems to be a consistent pattern among these forests. The specific years in which fires occurred, however, differ from the findings in the Southwest and Patagonia. While these studies found a higher fire frequency in La Niña years preceded by strong El Niño events, I observed the opposite trend in the University of Idaho's fire history (e.g. Veblen et al. 1999, Swetnam 1990). This difference is likely due to the opposite effect of ENSO in the Northwestern United States as compared to these other parts of the world (Heyerdahl et al. 2002). Fires are occurring in drier years in all these regions, but it is El Niño events that cause decreased precipitation in the Northwest and La Niña events that bring drier conditions in the Southwest and Patagonia (Heyerdahl et al. 2002).

The results from my regional fire year analyses are consistent with Heyerdahl et al.'s (2002) Blue Mountain study in the Northwestern United States, in which they found that fires occurred in dry and El Niño years. Though I used chronologies from this study to gain more power from my comparisons, I do not believe this affected my results. I did not actually combine my fire chronology with these sites, but simply recorded the years in which fires occurred on my site and on at least one of these other sites. This consistency between their results and mine, therefore, is certainly significant. While long suspected, concrete support for the idea of regional drivers of fire in the Northern Rockies has been lacking. Barrett et al.'s (1997) inquiry into this question revealed the likelihood of such a regional force, but as the chronologies used in that study were not crossdated, the results of the study are not taken as absolute. In their study, Barrett et al. (1997) compiled all published and unpublished fire history studies available to create a regional picture of this fire history. They found a great number of regional fire events in the Interior Columbia Basin region, an area encompassing the Northern Rockies and northern portions of the Great Basin Desert (Barrett et al. 1997). The combination of my data, that of Heyerdahl et al. in the Blue Mountains, and many other studies underway in this region assists ecologists and managers in their quest for a more complete and crossdated view of the forests of this region and the fire regimes that play a critical role in their ecosystem processes.

While the findings of this study are consistent with the idea of a regional climate-driven fire regime on the UIEF, this does not exclude other possible influences on the fire patterns of this forest. My findings indicate that regional climate had a greater effect on fire patterns than local climate anomalies such as lightning strikes, Native American and modern human use of the property. These other possible drivers were not tested by this study, however, so the degree of their influence on the fire regime relative to regional climate is unknown.

Management Implications

The findings of this study have numerous implications for ecologists, forest managers, and residents of the UIEF area and the Northern Rockies as a whole. All these groups are affected by the increased predictive capabilities these results grant scientists. El Niño and La Niña events can currently be predicted three to six months in advance, and significant dry years can be anticipated fairly accurately in the preceding year (Andrade and Sellers 1988). With the better understanding of relationships between ENSO, dry years and fire, the prediction of these climatic events can lead to the better anticipation of upcoming major fire years in the region. Such forewarning can assist homeowners in the preparation of property for fire protection, can aid the decisions of local managers concerning prescription burning and thinning operations, and can help local and federal managers in their allotment of funding for fire suppression in the upcoming year. With the discovery that major fire years in the Northwest alternate with those events in the Southwest, perhaps better distribution of resources such as fire fighting crews could occur, stationing the majority of crews to the Southwest in La Niña years and the Northwest in El Niño years rather than preparing large crews in both locations. Clearly more research must be done on these relationships before major decisions are made on this subject. While a link was found between climate and fire events in this study, not all fires that occurred were in these climatic event years. As the number of Northern Rockies sites studied for these patterns increases and researchers gain a better understanding of these relationships, perhaps more certain statements about our predictive capabilities can be made.

More research should also be done in the University of Idaho Experimental Forest and the surrounding area. The small sample size of this experiment was primarily due to the sparse distribution of stumps or scarred trees available for sampling on the site. With the high likelihood of continued logging and an increase in prescribed and wild fires on the property, the availability for trees to sample may be limited in the future. Obtaining a fire record dating earlier than 1800 was one of the challenges of my study due to the intense logging in this area in the late 1800s and early 1900s. While a record can often be obtained from remaining stumps of older logged trees, this is contingent upon the stump's survival despite decay and fire pressures. In this study, stumps that survived fires through 1930 were likely to remain available for collection due to fairly effective fire suppression since that time. As attitudes change toward fire suppression and prescribed burning, fire frequency is once again increasing in these forests. While such changing attitudes toward the role of fire in this ecosystem are to be encouraged, it is also important to collect what remains of the fire record in these forests. As relatively few living trees older than 200 years remain in this region, the stump record must be explored thoroughly. Additionally, all fire-scarred trees suspected to be older than 200 years should be sampled for the record they hold. I would recommend expanding the size of the study area in future research to obtain both a larger sample size and a larger-scale look at the fire patterns in the area. More time and/or a larger research crew would be necessary to undertake such a study, but I believe the results would be well worth the effort.

Acknowledgements

I would like to thank Harold Osborne of the University of Idaho for giving me the idea and opportunity for this project and sharing his passion for the forests of northern Idaho with me. I would also like to thank U of I's Dr. Penny Morgan for her undying support of this project and me and for her willingness to talk whenever I needed her. Without Dr. Emily Heyerdahl and Dr. Henri Grissino-Mayer's assistance, patience, and expertise, I would have no results or analysis to discuss. Many thanks to my advisors at Colorado College, Dr. Marc Snyder and Dr. Alex Vargo, who provided advice, support, and patience throughout this process, but especially in the most stressful of times. I am also grateful to Dr. Tass Kelso for allowing me to use space in the Colorado College herbarium for sample analysis and storage. Thanks also to Dr. Peter Brown of Rocky Mountain Tree Ring Research, Inc. for his assistance in the harrying world of crossdating. Special thanks to the Dean's Committee for the Venture Grant which funded my travels to Idaho, allowing me to complete my research. I would like to acknowledge everyone in the University of Idaho Departments of Forest Resources and Forest Products in the summer of 2003 for their support and kindness. Finally, I would like to thank my grandmother, Jean Peterson, for her delicious meals, comfortable lodging, and excellent company (especially during Mariner's games) in the summer and fall of 2003.

Figures

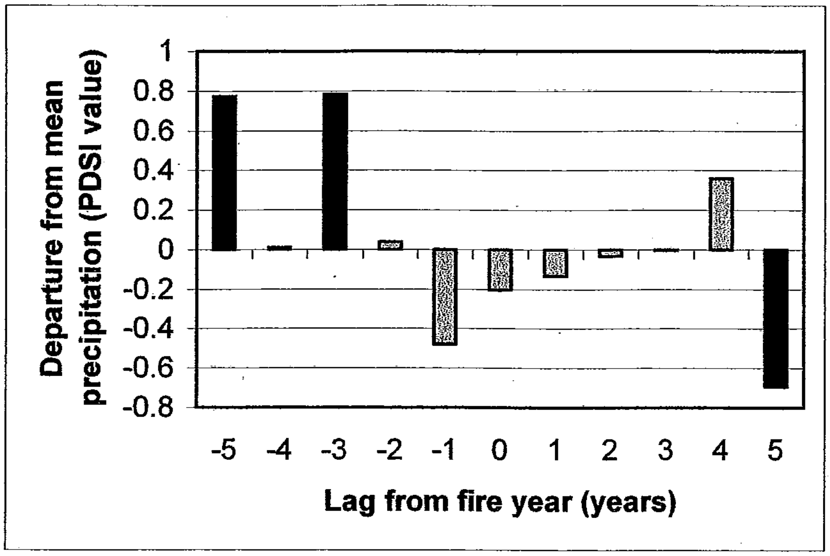

Figure 1. Average PDSI value (representing departure from mean precipitation) for 56 UIEF fire event years scarring two or more samples and for the five years preceding and following fire events. Striped bars represent a statistically significant difference from mean at a 95.0% confidence level.

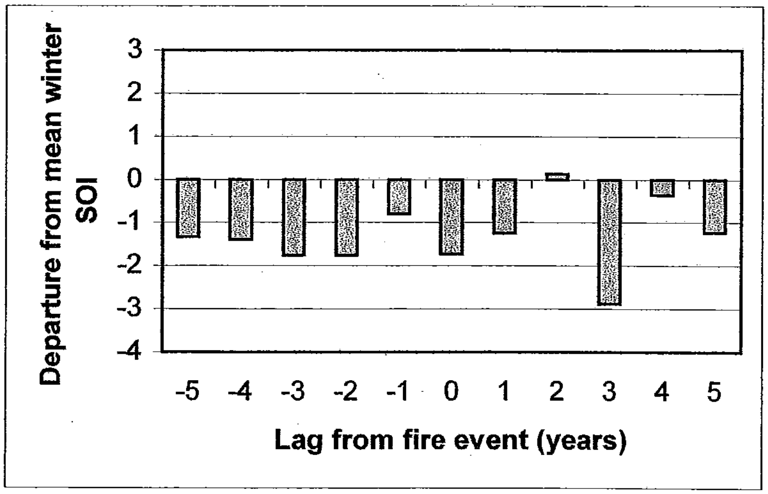

Figure 2. Average SOI value (negative representing El Niño, positive La Niña) for 51 UIEF fire event years scarring two or more samples and for the five years preceding and following fire events.

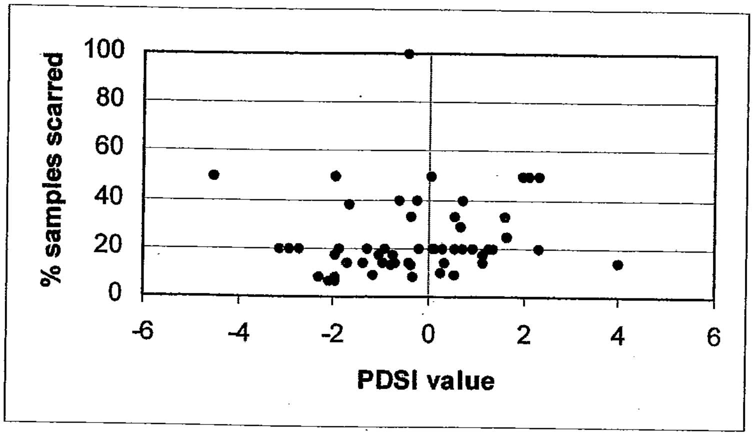

Figure 3. The 63 UIEF fire years and their PDSI values. Negative PDSI values indicate years in which mean precipitation was less than the mean for all years. Sample size = 21 trees.

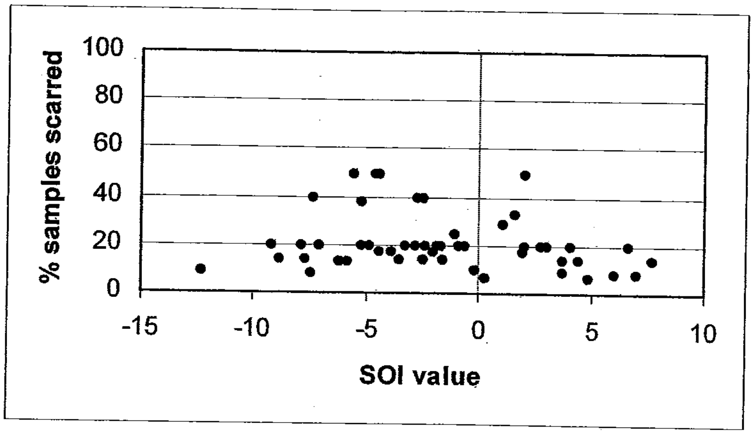

Figure 4. The 63 UIEF fire years and their SOI values. Negative SOI values indicate El Niño years; positive SOI values indicate La Niña years. Sample size = 21 trees.

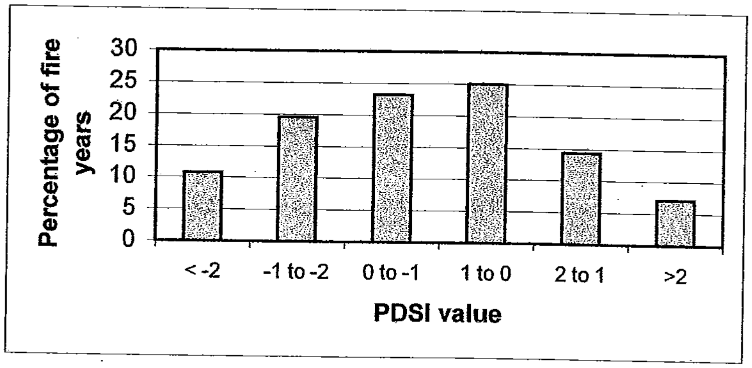

Figure 5. PDSI values and the percentage of UIEF fires occurring in years with those values. Sample size = 56 fire years from 21 trees.

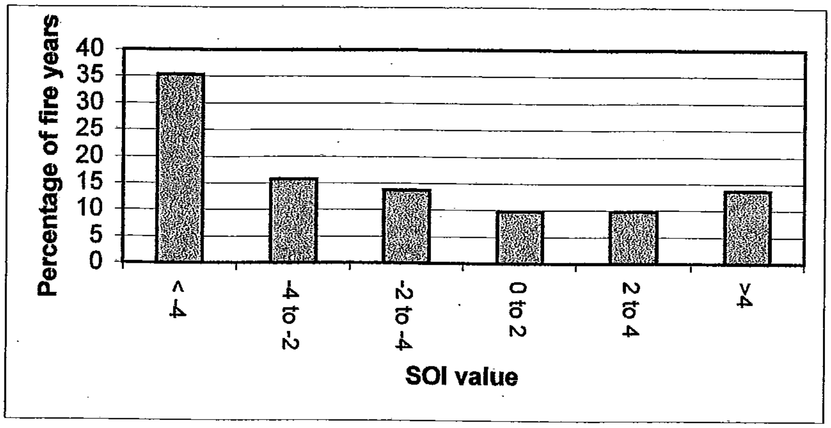

Figure 6. SOI values and the percentage of UIEF fires occurring in years with those values. Sample size = 51 fire years from 21 trees.

Year	PDSI value	SOI		Year	PDSI value	SOI
1678	1.96	n/a		**1829**	**-0.252**	**-2.807**
1682	0.054	n/a		**1830**	1.33	1.985
1690	**-0.462**	n/a		**1835**	2.319	**-3.33**
1692	0.544	n/a		**1836**	0.685	1.04
1703	**-0.36**	n/a		**1838**	0.323	**-1.593**
1707	2.301	2.022		**1839**	1.146	**-7.744**
1718	**-1.991**	**-4.631**		**1844**	**-1.365**	**-2.473**
1721	**-4.525**	**-4.417**		**1849**	**-0.969**	**-3.522**
1724	1.643	**-1.085**		**1850**	**-1.061**	**-2.07**
1726	0.92	**-7.089**		**1860**	1.138	1.947
1728	**-1.312**	**-0.628**		**1865**	**-1.961**	**-4.463**
1731	1.352	**-1.728**		**1871**	**-0.423**	4.425
1736	**-3.128**	2.708		**1882**	**-0.633**	**-2.501**
1749	**-0.907**	**-7.922**		**1889**	**-1.724**	**-8.922**
1760	0.292	**-2.414**		**1894**	3.986	7.666
1770	0.526	**-9.214**		**1897**	**-0.793**	**-6.24**
1771	0.699	**-4.915**		**1903**	**-0.365**	**-5.858**
1772	**-0.221**	4.017		**1908**	2.099	**-5.618**
1777	0.107	**-0.896**		**1911**	0.24	**-0.181**
1783	**-2.924**	**-7.076**		**1915**	0.556	**-12.314**
1792	0.729	**-7.333**		**1917**	**-1.163**	3.738
1796	0.091	**-1.851**		**1925**	**-0.325**	6.977
1797	**-1.876**	3.033		**1926**	**-2.287**	**-7.502**
1800	**-2.738**	**-5.286**		**1929**	**-1.981**	5.968
1806	1.249	6.619		**1930**	**-1.697**	**-5.255**
1814	0.309	**-2.876**		**1934**	**-1.988**	4.864
1818	1.586	1.564		**1935**	**-2.087**	0.228
1824	**-0.775**	**-3.947**		**1963**	**-0.707**	3.741

Figure 7. All UIEF fire years occurring after PDSI chronology beginning date (1676). Years highlighted in blue are regional fire years. Yellow highlighted values indicate negative SOI and PDSI values, representing El Niño and drought years, respectively.

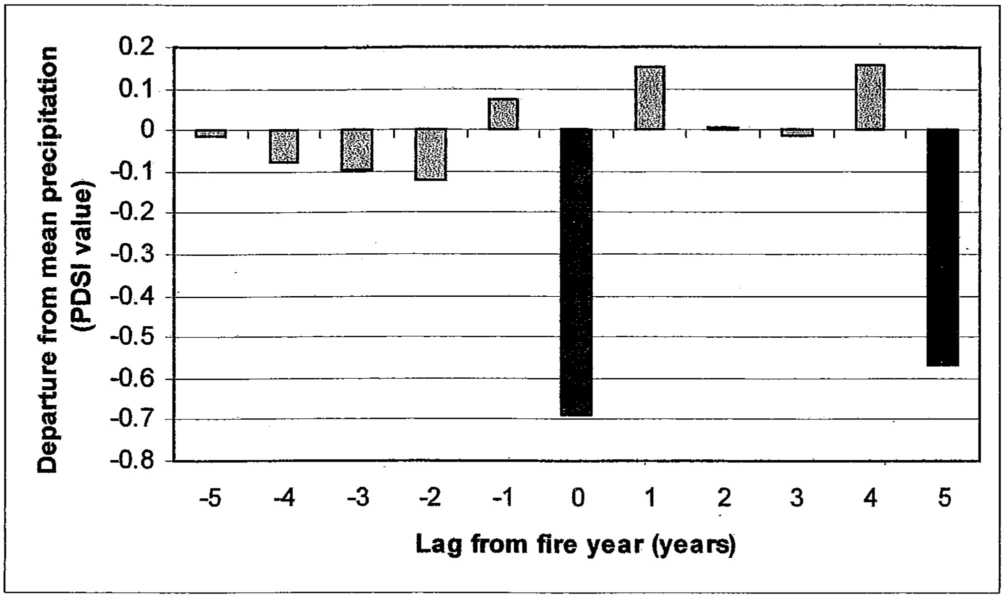

Figure 8. Average PDSI value (representing departure from mean precipitation) for 26 regional fire event years and for the five years preceding and following fire events. Striped bars represent a statistically significant difference from mean at a 95.0% confidence level. Checked bars represent a statistically significant difference at the 99.0% confidence level.

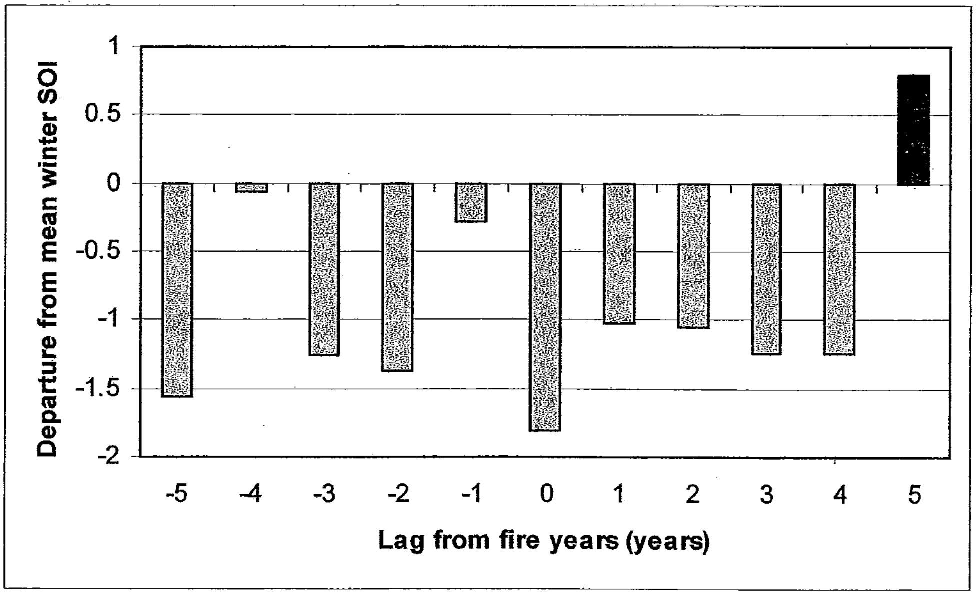

Figure 9. Average SOI value (negative representing El Niño, positive La Niña) for 25 regional fire event years and for the five years preceding and following fire events. Striped bars represent a statistically significant difference from the mean at a 95.0% confidence level.

Appendix I: Raw fire history data from UIEF

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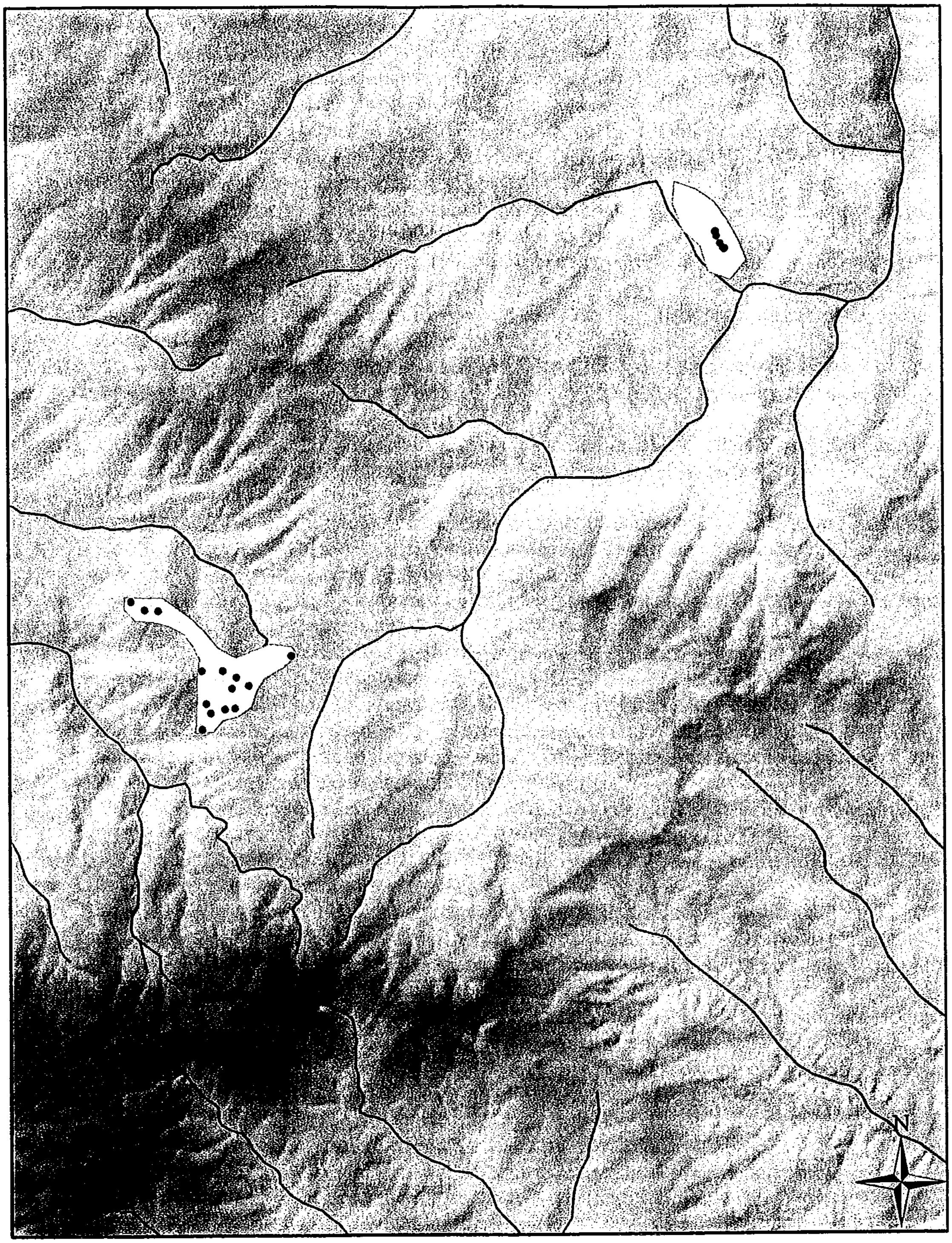
Appendix II: Map of Study Site



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Legend

- ● Collected Samples
- —— Regional Streams
- ☐ Study Area

Created by Liesl Peterson and Eva Strand
August 14, 2003

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