University of Nevada, Reno

A Tree Ring Based Fire History of the Clover Mountains, Lincoln County, Nevada

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By
Mackenzie Kilpatrick

Dr. Franco Biondi/Thesis Advisor

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Abstract

Fire is a dominant form of disturbance in the American west, and is a primary management concern because of its threat to natural resources and human development. Research on fire history of the Great Basin is lacking. Here I summarize the results of a fire history study in the Clover Mountains of Lincoln County, Nevada. Using fire scars from ponderosa pine trees I reconstructed fire history back to 1785 and examined fire frequency, fire extent and fire severity through time. Historically, the Clover Mountains were dominated by frequent (<10 year mean return interval), low severity fires. Fires were often large, with half the fire events scarring greater than 10% of recorder trees. Visual and ecological evidence on the landscape suggests the 1946 fire may have been a high severity event. Fires have not been recorded in sampled trees since 1946. Human fire suppression activities may be the cause of this fire gap in the last 60 years, which suggests the Clover Mountains are moving outside their historic range of variability.

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Introduction

Fire is thought to be the primary ecological disturbance in ponderosa pine forests (Covington and Moore 1994). Fire history studies have been conducted throughout much of the American west; however the Great Basin is a region that has not been adequately studied. Site topography, climate and species composition affect fire activity; therefore, site specific research is normally required for estimating the historic range of variability (HRV), which represents the range of conditions an ecosystem has experienced in the past (Landres *et al.* 1999, Veblen 2003). The Great Basin typically has winter precipitation, whereas the southwest, for example, is influenced by the southwest monsoon, and receives abundant summer precipitation (Evett *et al.* 2007). Species such as single-leaf pinyon are adapted to summer drought and winter heavy precipitation and are mostly restricted to the Great Basin (Cole *et al.* 2008). The basin and range system of the Great Basin is unique in the American west; for instance, it is an area characterized by an upper and a lower treeline, the latter being formed by single-leaf pinyon and Utah juniper (Charlet 1996).

In recent years there has been concern that human activities, such as grazing and fire suppression have moved fire regimes outside their historic range of variability. This concern has been supported by research in the American southwest (Savage and Swetnam 1990, Fulé *et al.* 2003, Heinlein *et al* 2005), but the impact of human activities has not been constant throughout the western USA. Fire history studies in the southwest, the Cascade Mountains and lower ecotones of the Rocky Mountains have shown that human activities, such as fire suppression, pushed fire regimes outside their HRV (Savage and

Swetnam 1990, Taylor 2000, Brown and Wu 2005). In contrast, studies in the subalpine zone of the Rockies have found that fire regimes are still within their HRV (Sherriff and Veblen 2006, Veblen et al. 2000). In some areas high severity fire regimes may form critical components of some ecosystems (Hutto 2008). In the Great Basin fire suppression along with overgrazing may be partially responsible for the current expansion of pinyon-juniper into sagebrush ecosystems (Blackburn and Tueller 1970, Miller and Tausch 2001, Baker 2008). In addition, invasive plants, such as cheatgrass (*Bromus techorum*), have invaded many ecosystems and have significantly impacted fire regimes (Gundale et al. 2008). Fire history studies within Great Basin ecosystems would allow more effective management in the region (Baker and Shinneman 2004, Kou and Baker 2006b) by developing an accurate understanding of spatial and temporal variation in fire regimes (Taylor and Skinner 2003).

Fire regimes are determined by fire return interval, fire extent, seasonal factors, and fire rotation (Taylor 2000). The fire return interval is the length of time between fires, and can be examined at a variety of spatial scales, from a single point to an entire landscape. Fire extent is a measure of area burnt. Seasonal factors such as moisture and sources of ignition determine when fires occur, and may also influence how fires behave. Fire rotation is the amount of time required for fire to burn an area equal in size to the area being studied (Baker and Ehle 2001). Fire severity is a quantitative or qualitative measure of how much biomass is destroyed by a fire (Keeley 2009); it has also been applied to describe fire effects. There are three basic types of fire regime severity, with each regime type entailing differing ecological effects (Agee 2003). The first is low severity, dominated by surface fires, which cause little mortality and often consume forest floor fuels, younger trees and shrubs (Buechling and Baker 2004). Low severity fire can be detected by fire scars because it usually does not kill mature trees. A high severity fire regime is characterized by high tree mortality and is often referred to as ‘stand replacing’. Because high severity fires are lethal, they cannot be reconstructed using fire scarred trees. Instead, high severity fire can be detected by finding pulses of tree regeneration, and also looking for growth releases in adjacent stands (Lorimer 1985). Mixed severity fire, sometimes called variable severity fire, includes both surface fires and stand replacing fires (Sherriff and Veblen 2006). Many individual fires are mixed severity, causing complete mortality in certain areas and merely scarring trees in other areas (Schoennagel *et al.* 2004, Sherriff and Veblen 2006).

Topography, fuels, climate, and species composition all play roles in determining fire regime (Heyerdahl et al. 2001). Topography can affect fire regime by affecting the spread of fires because fires typically burn uphill, with ridgelines often forming a boundary to fire spread. Topography is linked with fuels because aspect can have an affect on species composition and site productivity. South facing slopes are typically warmer and drier than north facing slopes in the northern hemisphere. Climate controls the amount of moisture a site may get, which may constrain the species that can persist at a site. The rugged topography of the Great Basin ensures topographic and climatic variability at the local scale, which can influence stand structure and therefore fuel loads, the primary driver of fire spread after ignition (Lentile et al. 2006). Climate influence on fuels makes it possible for fuel structure to vary over time, hence the fire regime can also vary over time, within the HRV. Climate variation can also affect fire frequency by changing the amount of natural ignitions supplied by lightning (Evett et al. 2007). Successful fire ignitions are determined by fuel availability, fuel moisture and presence of an ignition source (Hall 2007). These climatic and ecological factors can vary temporally and spatially, giving rise to the concept of historic range of variability (Veblen 2003, Landres et al. 1999). Because different fire regimes typically have different effects on ecosystems, fire scars cannot paint a complete picture of fire regime, nor can tree establishment dates. The use of both techniques should yield the best results, especially in regions where limited prior knowledge is available on fire regime.

Within the Great Basin, ponderosa pine typically is found between elevations of 1800 and 2500m. Ponderosa is not as drought tolerant as other Great Basin conifers such as single-leaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*). In the Great Basin, ponderosa pine are often found on north facing aspects or along drainages. Ponderosa pine has thick bark to insulate the vascular cambium and a high crown, which helps it survive surface fire (Heyerdahl *et* al. 2001, Brown and Cook 2006). Ponderosa pine is commonly used in fire history because it accurately records the occurrence of low severity fire via fire scars (Heyerdahl *et* al 2001). Ponderosa pine occurs in several mountain ranges throughout eastern Nevada. Much of this land falls under the jurisdiction of the Ely district Bureau of Land Management (BLM). The Ely district manages 11.7 million hectares of land in parts of Lincoln, White Pine and Nye Counties. Primary concerns for management include wildfire, invasive species, and pinyon-juniper expansion, all of which are strongly tied together in the region.

This study was conducted in the Clover Mountains with the following objectives:

(1) Estimating fire severity, fire frequency, and fire size using fire scarred trees.

(2) Quantifying fire regime pre- and post-Euroamerican settlement.

(3) Comparing our results with those obtained for Mount Irish, which is about 90 km to the west, and with other ponderosa pine fire history studies.

Methods

Study Area

The Clover Mountains (Fig. 1) are located in Lincoln County, in southeastern Nevada. The study area (Fig. 2) reaches its high point at the summit of Ella Mountain (7479 feet; 2284 meters). Unlike many mountain ranges in Nevada, the Clover Mountains are not part of the Basin and Range system, but are the remnants of an extinct volcano composed of limestone, quartzite and volcanic tuff (Wuerthner 1992). The Clover Mountains are within the Colorado River Watershed, and thus are not part of the hydrologic Great Basin, but they are within the ecological Great Basin.

The study area (37° 27’33” N, 114°28’02” W) is centered on Ella Mountain with aspects facing all directions (Fig. 3). Elevations within the study area range from 1800 m to 2284 m. The topography in the study area is complex and steep, reaching up to 70% slope. An average of 260 mm of precipitation falls annually; this data is based on climate data from weather stations in Caliente, NV (1928-2007), Elgin, NV (1965-2007), and Modena, UT (1901-2007). PRISM data for the four cells containing the study area yield an annual average precipitation of 410 mm (Daly *et al.* 2008). The precipitation has a bimodal distribution, with a first winter peak from January to March, and a second smaller one in the late summer (July to September; Fig. 4). Vegetation includes ponderosa pine (*Pinus ponderosa*), single-leaf pinyon (*Pinus monophylla*), pointleaf manzanita (*Arctostaphylos pungens*), and gambel oak (*Quercus gambelii*). This mixture of species indicates the Clovers may be a transition area from Great Basin climate to southwestern/Colorado plateau climate regimes with heavier late summer precipitation than the areas further north and west (Robin Tausch, Personal Communication). In the Clovers, ponderosa typically occurs in relatively homogeneous stands at higher elevations, on north and west facing slopes, or in drainages (Fig. 2). Manzanita and gambel oak seem to dominate areas where trees have been killed by past disturbances, as evidenced by ponderosa logs and snags often found near them. Pinyon can be found on all aspects and on slopes ranging from flat to 60%.

Euroamerican settlement near the Clovers began with Mormon ranchers and farmers settling in the Clover Valley, north of the Clover Mountains, in the late 1860s (Paher 1970). In 1901 construction on the Los Angeles, San Pedro and Salt Lake Railroad began. This rail line ran through the Clover Valley and turned south down the Meadow Valley Wash just west of the Clovers and would ultimately be extended towards Los Angeles (Hulse 1998). In 1901, as railroad construction progressed, a work camp was established on the location of an old agricultural village Culverwell. The work camp persisted and eventually morphed into the present town of Caliente (Mondy and McCaughey 1968, Hulse 1998). By 1910 Caliente had a population of roughly 1700 people (Hulse 1998). In 2007 the population of Lincoln County was estimated at 4759 people spread over 27,550 km^2 (USDC Bureau of Census 2007). Euroamerican settlement of the area surrounding the Clover Mountains is unlike much of Lincoln County where mining was the driving force behind most settlements such as Logan City, Bristol, Pioche, Castleton, Delamar, and Atlanta (Paher 1970).

Automobile access to the Clover Mountains comes via a dirt road leading from the town of Caliente. This road passes through the study area and continues south to Elgin.

Traffic on the road is not heavy, but the road is kept in good condition and provides access to a fire watch tower on Ella Mountain Summit. The fire tower was built in 1964 and is currently operated by the BLM, which oversees the study area. Lower elevations, from 1500-1800m, contain evidence of modern ranch activity in the form of fencing and guzzlers for livestock. We observed no evidence of such activity at elevations above 1800m or near the study area. Further evidence of human activity comes from the presence of cut stumps and downed trees on Ella Mountain. These cut stumps and downed trees are evidence of fire management and suppression in the area, which started in the mid 20^{th} century (Ely Bureau of Land Management 2000).

In the summer of 2007 and 2008, ponderosa stands were sampled for fire history (Fig. 3). Slope, aspect, elevation, and density varied among the stands (Table 1), whose boundaries were determined by field reconnaissance. We compared stand boundaries with data from the Southwest regional Gap analysis project (GAP; Lowry Jr. *et al.* 2005), which is derived from LANDSAT Enhanced Thematic Mapper Plus (ETM+) imagery from 1999 to 2001.

Stand A, about 4 kilometers north of the Ella Mountain summit, is located in and along a wash that drains the northern aspect of Ella Mountain. The stand follows the wash for nearly 3 km. The stream that runs in the wash was dry during our field sampling but there is evidence of debris being carried down the wash, which indicates high stream flow at times. Stand B is located north of the summit on the eastern side of a ridge and is characterized by pockets of ponderosa pines separated by shrubfields of manzanita. Stand B contains numerous dead snags and logs. Stand C is located on a very steep west facing slope north of Ella Mountain. Soils are thin and sandy and vegetation is minimal in tree interspaces, with only manzanita present. Flagged tree tops are evidence of strong westerly winds. Numerous snags and logs are within the stand, some with decayed fire scars. Stand C, like stand B, has numerous snags and logs present, many with decayed fire scars. Stand D runs south from Ella Summit along a ridgeline. There is an access road that runs through the middle of the stand to a radio tower at the end of the ridge. Ponderosa pines are present at the ridge top and extend down the eastern slope approximately 100 meters. Further downslope from the ridge, tree cover changes to pinyon as the slopes steepen. Stand E is located about 1 km east of Ella Summit on north and west facing slopes. Stand E has a relatively steep slope of approximately 40% ponderosa overstory; gambel oak and Manzanita are present in canopy gaps. Snags, logs and cut stumps are present throughout stand E. Stand F is located along a ridge top 5 kilometers to the southeast of Ella Summit. The stand is generally north facing, with a mixed composition of ponderosa and pinyon pine. Stand F showed no evidence of recent human activity.

Companion studies examined stand establishment (Bradley 2009) and forest fuels data (Cheek 2009) in a more focused study area centered on Ella Mtn. Summit containing stands B, C, D, and E.

Field Methods

We reconstructed fire dates in the Clover Mountains using fire scars (Sibold *et al.* 2006). We first targeted trees with multiple scars visible on the “catface”, which is the wounded area left exposed by scarring (Baker and Ehle 2001, Van Horne and Fulé 2006; Fig. 6). Then we completed a census sample in stands B, C, and D. Stands A, E, and F were not included in the census sample. In a census sample, all fire scarred trees within the designated area are sampled, when safe to do so (Van Horne and Fulé 2006). Samples were obtained using a chainsaw following standard procedures (Arno and Sneck 1977). Fire scars from dead trees are often useful for fire history, but suitable dead material was lacking at the study area. A total of 148 wedges (Fig. 7) were collected from ponderosa pines. Among the other woody species present, single-leaf pinyon and Utah juniper are not commonly scarred by fire (Baker and Shinneman 2004); the latter is also difficult to crossdate accurately (Landis and Bailey 2005). For each tree, we measured the height, diameter at breast height (DBH), location (Universal Transverse Mercator coordinates), slope, aspect, lean direction and degree, scar azimuth and scar height (Table 1).

In order to cross date our fire scar samples using dendrochronological techniques, we developed a master tree-ring chronology (Fritts 1976, Veblen et al. 2000, Brown 2006) for the Ella Mountain Summit area (Fig. 8). To do so 47 increment cores were collected from 26 healthy ponderosa pines. This sampling focused on trees with signs of old age to achieve maximum temporal coverage. Young and medium aged trees were also cored to aid the crossdating process (S. Strachan, personal communication).

Laboratory Methods

Increment cores for the master chronology were mounted using standard techniques (Stokes and Smiley 1968). Using a belt sander, we sanded the cores with progressively finer grit sandpaper (up to 600 grit) until cell walls were visible under a zoom binocular microscope with 10-50x magnification. The cores were visually cross dated (Fritts 1976, Stokes and Smiley 1968) to allow accurate assignment of dates to individual rings by identifying locally absent and micro rings (Dieterich and Swetnam 1984). All dating was checked by a second dendrochronologist. Cores that could not be visually cross dated were not used to construct the chronology. Following cross dating, we measured all ring widths using a Velmex measuring system with .001 measurement precision. Statistical quality control was performed using COFECHA (Holmes 1983). Using this chronology we identified marker years and patterns in ring width which we used to accurately cross date the fire scar wedge samples. Summary statistics for circular variables, i.e. data measured in the form of angles (Fisher 2000), were computed using the software package R (R Development Core Team 2008).

Fire scar wedge samples were mounted on plywood and surfaced first using coarse grit sandpaper on a belt sander to flatten the surface. Then increasingly fine sandpaper grits (up to 600 grit) were used until the wood cell walls were visible under 10-30x magnification. We visually crossdated the wedge samples under a binocular microscope using our master chronology to account for micro or missing rings (McBride 1983). Once a sample was cross dated we assigned fire dates to the fire scars (Madany *et al.* 1982; Table 3, Table 4, Fig 7). All dating was checked by a second dendrochronologist. If a sample could not be cross dated it was removed from analysis. Ring widths of cross dated samples were measured and quality controlled as was done for the increment cores.

We analyzed our fire dates using the software FHX2 (Grissino-Mayer 2001). With FHX2 we computed the Individual Mean Fire Interval (IMFI), Mean Fire Return Interval (MFRI), and the Weibull Median Fire Interval (WMFI). The IMFI is based on the average of fire intervals for each single tree; therefore it is not affected by any filter applied to the data, and often it yields a conservative estimate of fire intervals (Taylor 2000). The WMFI is based on the Weibull distribution, which is flexible and can be adapted to non-normally distributed data (Grissino-Mayer 1999). Other statistics calculated include fire frequency, Weibull fire frequency, maximum and minimum fire intervals, and standard deviation. We calculated our statistics based on fires recorded by at least two trees (Brown 2006) as well as by combining this two-scar minimum with the requirement of having at least 10% of the samples recording the fire (Baker and Ehle 2001, Van Horne and Fulé 2006). These minimum filters ensure all events in the record are fires and not another type of injury. The two scar minimum filter also removes from the analysis single tree fires, which may be of little ecological significance. The additional 10% filter can mitigate the decrease in MFRI usually found with increasing sample size and area (Grissino-Mayer 1995, Baker and Ehle 2001).

Two time periods were considered: the first period contained the entire fire record from 1675 until 2007. This period of analysis was used for all stands (Stand A through F) as well as a more focused area (Stands B, C, D, and E). The other period analyzed was from 1785 to 2007, which is the period of time with more than 20 recorder trees. This analysis, from 1785 to 2007, was also performed for all stands and for the focus area. Using the period from 1785 to 2007 helps remove potential distortion in MFRI caused by low sample depth early in the record (Grissino-Mayer 1995), and makes comparison with other fire history studies more meaningful. Because of limited sample sizes at each stand, we also calculated fire statistics and dates without any restriction filters.

Ring boundary fires need to be assigned to a single year to conduct the statistical analyses. In some cases the ring boundary scars have been assigned to the second year, as in Dieterich and Swetnam, 1984. However, in that study no data was used to justify the decision. We used national lightning strike (Vaisala Global Atmospheric Inc. 2007) and fire start data (Fire Science Library 1998, Hall 2006), which were cropped and examined specifically for the Clover Mountains area using ArcMap (ArcMap 2008). We found that fire and lightning strikes were most prevalent during the late summer and early fall months (Fig. 9). From this we concluded that fires were more likely to occur after the growing season in a calendar year than to occur before the start of growth in the subsequent calendar year. The lightning and fire start data show that fires may also occur in late March, April, and May, but the probability of fire is much higher later in the season (Fig. 9). Therefore, ring boundary scars were assigned to the first of the two years. Instrumental climate records from climate station data and PRISM were used to compare precipitation in the year prior to and coincident with major fire events. We used monthly absolute difference and percent difference from mean monthly values for the comparison.

We created maps for all fire events that scarred two or more trees in a single year (ArcMap 2008). These maps were used to examine spatial distribution and patterns of fire throughout the study area. We graphically examined fire scar locations along with the Southwest Regional GAP data (Lowry *et al.* 2005) and Fire Regime Condition Class (FRCC; Hann 2004) data for the area to determine if there was a relationship between fire, landcover, and FRCC. FRCC is based on mapping natural variability based solely on Potential Natural Vegetation Types (PNVT) derived from a soil survey (Provencher *et al.* 2008). Three conditions classes are used to represent vegetation departure from reference conditions. Condition class one represents areas that are within reference conditions. Condition class two represents areas outside reference conditions but not at the level where dangerous alterations of fire regime may take place. Condition class three represents significant departure from reference conditions that are likely to cause alterations of fire regime. It has been shown that at times the soil survey data are too coarse and can lead to misclassification of vegetation, which may then lead to alterations in the FRCC (Provencher *et al.* 2008). An additional component in FRCC for the LANDFIRE models (Rollins *et al.* 2007) is estimation of fire frequency and severity using the LANDSUM model (Keane *et al* 2006). The LANDSUM model uses estimates of past disturbance to simulate the fire regime (Rollins *et al* 2007), however in the Clover Mountains, or the Great Basin in general, accurate estimates of historic disturbance regimes are lacking. The LANDSUM model was chosen because it was flexible and required less input parameters than other models, however it was recognized that LANDSUM does not always generate the most accurate simulations (Rollins *et al.* 2007). To examine if fire regimes have changed since the onset of Euroamerican settlement we computed fire statistics for the period prior to settlement as well as the post-settlement period. In the Clover Mountains area Euroamerican settlement began around 1900 (Hulse 1998). We tested whether fire intervals were significantly different for a 100-year period before and after 1900 using the Mann-Whitney-Wilcoxon Rank Sum test, which does not rely on the Gaussian distribution and compares the medians of two sets of data. It is useful for fire intervals because they are rarely normally distributed (Grissino-Mayer 1999).

Finally, results from this fire history were compared to those for Mt. Irish, approximately 90km to the west. We compared fire statistics from all stands at the Clover Mountains to all stands at Mt. Irish. We also compared fire statistics by stand at both the Clovers and Mt. Irish. In an attempt to compare areas of roughly similar size, and also because of the census-type sampling conducted there, stands B, C, and D at the Clover Mountains were compared to Mount Irish. The primary tools of comparison were the

MFRI and WMFI, and temporal trends in fire occurrence. We tested for similarity in fire interval distribution between the two study sites using the Mann-Whitney-Wilcoxon (MWW) test. Finally, using the historical record of Federal Fire Start data from 1980 to 2006 for Nevada, we assessed the number of fires within a 225 km^2 area around Mt. Irish and the Clover Mountains, and compared that data to our fire scar record.

Results

A total of 150 wedge samples from 148 ponderosa pines were studied (Table 2), and fire history analysis for stands A through F used 139 of them (Table 3). Stands B through E contained 120 wedge samples. The samples yielded 302 crossdated fire scars (Table 4), of which 56% were ring boundary scars. The first fire date was in 1675 and the first measured ring in 1500. We used our master chronology to date the wedges; the master chronology covers a period of 538 years, from 1470 to 2007, with a mean series intercorrelation of .823 and a mean sensitivity of .437. Eleven samples were undateable or lacked useable fire scars. A total of 110 measured fire scar samples contained 20417 rings with a series intercorrelation of 0.742, a mean sensitivity of 0.410, and a mean correlation of 0.713 with the master tree chronology (Table 5). The sample ring widths are shown in Figure 10. Graphical representations of fire dates are shown in Figures 11, 12, and 13.

Fire Statistics and Analysis

For the entire study area, from 1675 to 2007, and using a 2 scar filter there were a total of 30 fire dates (Table 6, Table 8). These fire dates had a mean fire return interval (MFRI) of 9.34 years, a Weibull median fire interval (WMFI) of 5.91 years, and a fire frequency of .11 fires/year. Applying the 10% restriction filter yielded a MFRI of 15.94

years, a WMFI of 11.82 years and a fire frequency of 0.06 fires/year. The individual mean fire interval (IMFI) was 50.13 years.

The period from 1785 to the present was selected to analyze fire history because 20 or more recorder trees were present. This mimics the methodology used in the Mt. Irish study (Jamieson 2008), and allows for a more direct comparison with that study. For stands A through F, using the 2 scar filter we found 24 fire events (Table 7, Table 8) with a MFRI of 7.00 years, a WMFI of 4.50 years and a fire frequency of 0.14 fires/year. Adding the 10% filter yielded 12 fires with a MFRI of 14.64 years, a WMFI of 10.19 years, and a fire frequency of 0.07 fires/year. The IMFI was 47.05 years.

Fire occurs in consecutive years in eight instances: in 1788-1789, 1820-1821, 1836-1837, 1837-1838, 1856-1857, 1860-1861, 1861-1862, and 1945-1946 (Table 9). Major fire events, scarring greater than 25% of recorder trees, were recorded in 1877 and 1946. The largest fire event was the 1946 event, which scarred 55% of recorder trees for a total of 72 trees (Table 8). The 1877 fire scarred 50% of recorder trees.

From 1675 to 2007, trees in stands B through E recorded 26 fire events (Table 10, Table 11) using the 2 scar filter, with a MFRI of 9.24 years, a WMFI of 5.5 years and a fire frequency of .11 fires/year. The addition of the 10% filter yielded 17 fires with a MFRI of 14.44 years, a WMFI of 8.96 years and a fire frequency of 0.07 fires/year. The IMFI was 50.5 years. In the same area, from 1785 to 2007 we recorded 23 fires with the 2 scar filter. The MFRI was 7.32, the WMFI was 4.81 and the fire frequency was .14. Including the 10% filter yielded 14 fires with a MFRI of 12.38, a WMFI of 7.61 and fire frequency of 0.08. The IMFI was 47.34 years.

Temporal Changes in Fire

For all stands, 14 fires were recorded from 1801 to 1900 with a MFRI of 4.57 years. Following the onset of settlement, from 1901 to 2000, 5 fires were recorded with a MFRI of 9 years. MWW test results do not indicate the difference in fire intervals between the two periods is significant (p value = .30). For stands B through E, in the pre-settlement period 14 fires were recorded with a MFRI of 4.92 years. Following settlement, 5 fires were recorded with a MFRI of 9 years. MWW test results do not indicate the difference in fire intervals between the periods is significant (p value=.41).

The last fire event in the entire fire scar record was the 1946 fire, which scarred 72 trees. Since then, there have been no fire events that were recorded on more than one tree. This time period of 62 years represents the longest fire free period in our 1675-2007 fire scar record.

Spatial Analysis of Fire

Examination of the fire maps and fire dates by stand (Fig. 14, Fig. 15) shows fifteen fire dates recorded in multiple stands. Stands B, C, and D share three large (>10% scarred) fires in 1877, 1945 and 1946, despite being spatially isolated currently. Stand E has experienced two large fires, 1838 and 1862, which are synchronous with the other stands. Stand F is the most spatially isolated and its fire years are the least synchronous with the other stands. Based on fire occurrence stands A, B, C, and D comprise one division, stand E forms another and, stand F represents the last division. Stands B, C, D, and E experienced all the large fires recorded across the landscape; hence they provide a good representation of widespread fire activity over the landscape.

Individual stands showed variation in recorded fire frequency and fire dates as well (Fig. 15). The stands vary in slope, aspect and elevation (Table 1). We used the 2 scar filter to compute the MFRI for each stand (Table 6). Stand A recorded only the 1946 fire in more one than tree. Thus we could not compute any fire statistics for this stand using the 2 scar filter. The 1946 fire scarred 10 out of 13 recorder trees in stand A. Stand A had an IMFI of 46.75 years. Stand B recorded 10 fire events with a MFRI of 17.44 years and an IMFI of 49.06 years. In stand B, fires occurred from 1789 until 1946, with the 1877 and 1946 fires being the largest events. Stand C recorded 5 fires from 1820 to 1946. Stand C shared the 1877, 1945 and 1946 fire events with Stand B. Stand C had a MFRI of 31.5 years and an IMFI of 58.82 years. Stand D recorded 7 fire events with a MFRI of 26.3 years and an IMFI of 40.48 years. Stand D also recorded 1877, 1945 and 1946 fires. Stand E had 9 fire events with a MFRI of 18.5 years and an IMFI of 40.63 years. Stand E did not record the 1877, 1946 or 1946 dates, but did have fires in 1788 and 1820 that matched stand D and C, respectively. 1862 was the most prominent fire date in Stand E. Stand F did not record any fires that met the 2 scar minimum filter, however its IMFI was 37.67 years and had fire scars that match other stands. Care must be taken when comparing composite fire statistics between stands as sample sizes varied greatly, ranging from 6 trees in stand F to 38 trees in stand E.

Climate Conditions and Major Fires

The 1946 fire was the only one that scarred more than 25% of recorder trees and occurred within the period of instrumental climate records. The Caliente and Modena climate stations were used along with PRISM for this analysis; the Elgin station did not have records going back that far in time. The analysis of precipitation data for 1945 and 1946 showed drier than average conditions in early 1946, with January, February, April, May and June all recording precipitation between 2 and 100% below average. June was especially dry with no recorded precipitation (Table 12). June and August of 1945 showed precipitation that was 150 to 300% above the mean for those months (Table 12).

Comparison to Mount Irish

Stands A through F at the Clover Mountains (Table 6) had a higher MFRI than Mt. Irish, 7 years to 4 years, but the IMFI of 47.05 years was similar to the IMFI at Mount Irish of 49.22 years (Table 13). Fire interval distributions differed significantly (Mann-Whitney-Wilcoxon test, $P < 0.05$ two-tailed). Visual comparison of FHX2 outputs, along with fire maps and number or percentage of trees scarred, show that larger fires are more common in the Clover Mountains (Table 6) than at Mount Irish (Table 13). Considering all stands at the Clover Mountains, 12 of 24 fire events which scarred >10% of recorders. At Mount Irish, only 6 of 73 events scarred >10%. We see fire dates synchronous between the sites in 1788, 1820, 1836, and 1860 (Table 8, Table 14). Neither site experienced a fire gap, from about 1822 to 1845, that has been observed in other regions of the American West (Brown *et al.* 2008). At Mount Irish we see fire stopped occurring after 1860, but this is not observed at the Clover Mountains until after 1946 (Table 8, Fig. 11). The Clover Mountains experienced less frequent fires from 1860 to 1946 (MFRI 10.75 years) than in previous decades. This more subtle change (Fig. 11) predates Euroamerican settlement at the Clover Mountains. At Mount Irish the change in fire regime at 1860 was coincident with heavy Euroamerican settlement, including the establishment of the mining town Logan City. The Federal Fire start data showed 42 fires burned in a 225 km^2 area around the Clover Mountains study area compared to only 2 for the same time period and area around Mt. Irish. Comparison of fire statistics for stands B, C, and D (Table 15) to Mt. Irish (Table 13) show that the Clover Mountains have a higher

MFRI of 13.59 years to 4 years for Mt. Irish, a higher of WMFI 8.37 years to 3.00 years and a similar IMFI of 50.50 years to 49.22 years. The sample size for stands for B, C, and D is 95 samples which less than the 175 sample size at Mt. Irish.

Mean fire return intervals for the stands at Mt. Irish ranged from 8.85 in the north/east stand to 34.75 years in the central valley (Table 16). At the Clover Mountains stands MFRI ranges from 17.44 to 31.5 (Table 7). The WMFI ranged from 5.98 years in the north/east to 20.26 in the central valley (Table 16). At the Clover Mountains stands the WMFI ranges from 13.05 to 19.98 (Table 7). The north/east stand at Mount Irish had a sample size of 77 which is greater than any of the other stands at both Mt. Irish and the Clover Mountains and may explain why it has shorter return intervals than any of the other stands.

Comparison to other Fire History Studies

Seven Clover Mountains fire dates (29% of the total), 1785, 1813, 1817, 1820, 1845, 1857, 1861 and 1862, match dates from studies in Utah (Brown *et al.* 2008), the Black Hills (Brown and Sieg 1996, Brown 2006), and Arizona (Heinlein *et al.* 2005, Fulé *et al.* 2003). A fire free period from 1822 to 1845 was observed in Utah (Brown *et al.* 2008) but not at Clovers where fires were recorded in 1836, 1837, and 1838. Studies in the southwestern US have found drastic reductions in fire frequencies subsequent to Euroamerican settlement typically from 1870 to 1900 (Savage and Swetnam 1990, Swetnam and Baisan 1996, Fulé *et al.* 1997, Fulé *et al.* 2003). We did not observe an abrupt change in fire frequencies during this time period, and instead we uncovered an abrupt drop after World War II, which is unlike other studies in the west. Our MFRI of 7 years is within the range of 2 to 8 years that has generally been observed for southwestern ponderosa pine study areas (Moore *et al.* 1999).

Some studies calculated fire statistics for individual stands; in those cases we used our stand fire statistics for comparison. Stands in the Grand Canyon had MFRI ranging from 3.2 to 6.9 years, and WMFI ranging from 3.0 to 6.5 years (Fulé *et al.* 2003), both of which are lower than the range of MFRI and WMFI (Table 7) found at the Clover Mountains. In the Black Hills based only on 57 fire scarred trees, presettlement MFRI was 16 years for all stands, but MFRI in individual stands ranged from 20 to 23 years (Brown and Sieg 1996). In the southern San Juan Mountains of Colorado stand MFRI ranged from 7 to 30 years, with WMFI ranging from 6 to 28 years (Grissino-Mayer *et al.* 2004). These ranges of fire intervals include data from stands at higher elevations (2500-2800m) in mixed-conifer ecosystems. Our stand MFRI of 17.4 to 31.5 years and stand WMFI of 13.05 to 19.98 is higher than in the San Juan Mountains. Sample sizes at each stand ranged from 8 to 28, compared to the Clover Mountains range of 6 to 38. Stands in the San Juan Mountains were farther apart spatially with as many as 80 km between some stands (Grissino-Mayer *et al.* 2004).

Discussion

The Clover Mountains is at the edge of the Great Basin, the Mojave Desert and the southwest and seems to get monsoonal influences based on climate data. The vegetation is dominated by a mix of species found in the Great Basin and the American southwest, such a single-leaf pinyon, pointleaf manzanita and Gambel oak. Different species provide different fuel characteristics and respond to fire differently, making generalization amongst all of them difficult. A common dilemma facing managers is a desire to use fire in multiple forest types but only having data derived from one cover type, such as ponderosa pine. In the Great Basin, ponderosa pine is used for fire histories, but pinyon-juniper woodlands are more common throughout the region, as shown by a map of regional scale tree distribution (Figure 16). This can be challenging for managers because fire regimes in ponderosa stands may not be indicative of fire regimes in adjacent pinyon-juniper areas (Baker and Shinneman 2004, Huffman *et al.* 2008).

Fire Regimes

The results from our study area contrast with the results from Mount Irish. Visual examination of the fire graphic outputs (Fig. 11, Fig. 17) shows the Clover Mountains with more large fire events than Mount Irish. At the Clover Mountains small fires occurred, scarring only 2 or 3 trees, but larger fire events, scarring greater than 10% of recorder trees make up about half of the fire events in the Clovers. From the presence of gambel oak (Floyd *et al.* 2000) and manzanita (Carmichael *et al.* 1978), which often establish in gaps created by fire, it may be inferred that some of these fires burn with higher severities. Complex topography is typical of sites that have a mixed severity fire regime (Schoennagel *et al.* 2004, Sherriff and Veblen 2006), with low severity fires of various sizes dominating the fire regime. This is different from Mount Irish, which was dominated by patchy, low severity surface fire regime with little evidence for mixed or high severity fire and few widespread surface fires (Jamieson 2008).

Analysis of fire at the stand level showed synchronicity of fire dates amongst isolated stands. This was especially apparent with the fires in 1877 and 1946 amongst stands A, B, C, and D. MFRI in the stands ranged from 11 years to 31.5 year for the period from 1785 to 2007. Because of such a disparity in stand sample sizes and the known affect sample and study area size have on MFRI (Baker and Ehle 2001), the IMFI may be the most useful tool for comparison. The IMFI is less affected by sample size, and the stands are generally similar in IMFI, ranging from 38 to 58 years with sample size not having a common relationship to IMFI (Table 6). Excluding the north/east stand at Mt. Irish stand fire statistics between the Clover Mountains and Mt. Irish are similar in MFRI, ranging from 17.44 to 31.5 at the Clovers and from 17.5 to 34.75 at Mt. Irish. The north/east stand had a MFRI of 8.85 years but had a sample size of 77 samples whereas none of the other stands at Mt. Irish or the Clover Mountains had more than 38 samples. These individual stand statistics support the finding that fires are more widespread at the Clover Mountains and more frequent on the landscape at Mt. Irish. The stands at the Clover Mountains are, in many cases, recording fires burned in multiple stands whereas at Mt. Irish the fires were not generally as widespread and it is more likely that fires recorded in each stand only burned in that stand. Therefore, when we expand our analysis from the stands up to the study area we find many more fires on landscape as a whole at Mt. Irish than at the Clover Mountains where the stands have recorded many of the fires found across the landscape. This highlights a danger of using too fine a scale when examining fire, which is that we can potentially miss a key component in fire regime, fire size. At the Clover Mountains we find many fires that burn beyond the boundaries of our individual stands and into other stands. At the individual stand level of analysis we cannot see the synchronous occurrence of fire throughout the study site, which appears to be a key characteristic of historic fire at the Clover Mountains.

The fires in 1845, 1861, 1877, 1945 and 1946 burned in multiple, currently isolated stands. It is possible these fire events were single contiguous events when they burned.

More recent fire events may have killed intermediate trees and isolated the stands, causing the current landscape. The 1946 fire appears to be the prime candidate for a stand replacing fire that fragmented the stands. Evidence in support of this hypothesis is that the 1946 fire is the last fire event to be recorded by multiple isolated stands. Fires that burned during or before 1946 could spread throughout the landscape, but after the 1946 fire stand A, B, C, and D may have become separate islands which share several fire dates (1845, 1860, 1861, 1877, and 1945). Standing snags and downed logs are often relics of high severity fires (Passovoy and Fulé 2006), both of which are present in the ponderosa stands and surrounding manzanita shrubfields. Lack of reestablishment of ponderosa in the shrubfields may be evidence that the fire event was both high intensity and high severity. Ponderosa pine seed is not serotinous and can be destroyed by high intensity fire events (Lentile *et al.* 2005, Schoennagel *et al.* 2008) that significantly alter soil characteristics (Ryan 2002). It has been proposed that extreme alteration of site conditions by high severity fire may make tree establishment in the foreseeable future unlikely because of changes in vegetation, soil and fire regime (Savage and Mast 2005).

Climate, Lightning, and Fire

Moisture is a potential factor driving fire differences between Mt. Irish and Clover Mountains. PRISM data indicates 50% higher annual precipitation in the Clovers than at Mt. Irish although elevation is generally 300-500m greater at Mt. Irish. Higher precipitation at the Clovers would allow for more fuel production and buildup. With suitably dry conditions fires could spread further than at Mount Irish because of higher loads and fuel continuity. It is not uncommon to see increasing fire size with increasing moisture, while also observing decreased fire frequency. Such a trend has been observed in the U.S. Rocky Mountains with increasing elevation (Veblen *et al.* 2000, Sherriff and Veblen 2006).

It is interesting to note that the Clover Mountains have higher lightning strike density (22-44 km^2) than Mount Irish (<15 km^2; Dilts *et al.* 2009). Yet, we see longer mean fire return intervals in the Clover Mountains and a similar IMFI at the two sites. The increased lightning strike frequency may be caused by the Southwest Monsoon, which provides both moisture and a source of ignitions in the southwest (Evett *et* al 2007). Cursory examination of lightning/fire relationships throughout the American West does not show a consistent relationship. Fire regimes in the subalpine zone of the Rocky Mountains feature infrequent, widespread, stand replacing fires despite the fact that they have frequent ignitions (Veblen *et al.* 2000, Baker 2003, Sibold *et al.* 2006). In the southwest, plentiful ignitions (Hall 2007) are coupled with a low-intensity fire dominated regime (Savage and Swetnam 1990, Fulé *et al.* 2003). It is then necessary to examine site specific factors such as topography, species composition, fuel loads, fuel structure, and fuel moisture if we want to determine the effect ignition sources may have on fire regime. Interestingly, government records of fire starts from 1980 to 2006 for Nevada show a higher occurrence of fires in the Clover Mountains than Mt. Irish. A 225km^2 area around each study site contained 42 fires in the Clovers and only 2 at Mount Irish. However, our MFRI does not bear this out and shows that fires are more common at Mt. Irish. Fire size and observation technology could be influencing modern detection of fires as the Clover Mountains historically had larger fires than Mt. Irish based on our fire scar reconstructions. The Clover Mountains currently have a manned fire tower nearby to observe fires, which should aid in detecting fires. Another potential cause for this discrepancy could come be fires in pinyon-juniper patches that are not often recorded by ponderosa fire scars, and would not influence our fire scar record. Examination of the federal fire data for Lincoln County from 1980-2006 indicates that many of the fires in the Clover Mountains burned at lower elevations which are dominated by pinyon-juniper. Although fire location data were gridded and therefore the fire locations are not exact, it is clear that the majority of fires are not burning near the study area (Fig. 18). Ponderosa pines occur only at higher elevations in the Clover Mountains so it is not likely these fires burned in ponderosa pine habitat. This highlights the difficulty of reconstructing fire regimes for certain forest types based on fire regimes in neighboring forests (Baker and Shinneman 2004, Huffman *et al.* 2008). Studies have shown that fire regimes can vary significantly over short distances if different forest types with varying fuel loads and characteristics are involved (Stephens 2001). Fire scars will not be useful for comparing fire regimes in pinyon-juniper to ponderosa because neither species scars reliably (Baker and Shinneman 2004, Huffman *et al.* 2008). Future analysis of fuels loads will help determine if ponderosa and pinyon-juniper stands are capable of supporting similar fire regimes.

The climate data from 1945 and 1946 show that dry conditions prevailed in the first half of 1946 and that June and August were unusually wet. The wet summer conditions in 1945 may have caused a build up of surface fuels. The lack of precipitation during the winter months may have caused a thinner snowpack that could have retreated earlier which combined with continued dry conditions through the spring would cause fuels to dry out and become more flammable. In the case of 1945 and 1946 the combination of accumulation of surface fuels and dry conditions would be ideal for fire spread once ignited. Unfortunately, we only have this one major fire event to examine in comparison to climate but this one example shows a relationship between wet conditions in the previous summer, with dry conditions in the winter and spring of the fire year.

Human Effects on Fire Regime

In the American southwest substantial increases in fire intervals are linked with Euroamerican settlement (Savage and Swetnam 1990, Brown and Sieg 2005). In most areas of the American southwest alteration of fire regime began in the mid-late 19th century coincident with heavy grazing and Euroamerican settlement (Swetnam and Baisan 1996). The ranches nearest to our study area are in the Clover Valley about 30 km to the north. Our study area would not have been suitable for grazing because of the steep terrain and lack of forage; therefore grazing cannot be a cause for the cessation of fires from 1946 to 2008. The mid 20th century, following the 1946 fire, marked the onset of alterations of the historic fire regime at the study site. The lack of forage and mining prospects in the Clover Mountains may have contributed to later settlement, in the Caliente and Clover Mountains region compared to Mt. Irish. Attempts to suppress fires in eastern Nevada started in the mid 1900's (Ely Bureau of Land Management 2000) and included the construction of a fire tower on Ella Mtn. in 1964. Low cut stumps, felled ponderosa stems, and fire line logging observed near stand E are evidence of recent fire management. Because of the evidence above, it is likely that human fire suppression/management activities are the primary cause of the lack of fires since the mid 20th century.

In some areas Native American land use practices supplied a source of ignitions in addition to lightning (Kilgore and Taylor 1979, Evett *et al.* 2007). Native Americans used fire for multiple purposes, such as driving game, and clearing underbrush to aid in gathering nuts (Vale 2002, Stewart 1908). It is possible that in some cases, these fires scarred trees, or burned out of control, leaving behind the dates we see in the fire scar record. The eradication and displacement of Native Americans by Euroamerican settlers would have caused a reduction in these native caused fires, which in some locations may be a contributing factor to the reduced fire frequencies following Euroamerican settlement. However, the role of native ignitions may not be uniform throughout the west (Vale 2002). Native ignitions may not have been important in ponderosa pine forests (Barrett *et al.* 2005), especially since practices like burning to gather pinyon nuts would not have been useful in ponderosa stands and fire spread between pinyon and ponderosa may be uncommon (Huffman *et al.* 2008).

In the case of the Clover Mountains, it is difficult to accept the hypothesis that a reduction in numbers of Native Americans caused a substantial shift in fire regime. In our fire scar record, the termination of fire occurred in the last half of the 20^{th} century. Euroamerican settlers were active in southeastern Nevada starting in the 1860's with mining in Pioche, farming activity in the Clover Valley, and the railroad city of Caliente founded in 1901 (Hulse 1998). Therefore a drop in fire occurrence should have occurred before the mid 20^{th} century if Native Americans were a significant source of ignitions of fire at this site.

Fire and Vegetation Connections

Fire scars are only an indication of fire occurrence; other pieces of evidence are needed to determine fire severity and ecological effects. Variation in forest structure can be useful for spatial examination of fire history (Veblen *et al.* 1994, Kipfmueller and

Baker 2000). Vegetation life history traits also help in determining fire extent and/or severity. Gambel oak stem age has been used as a proxy for fire occurrence because of its ability to re-sprout following fire and the assumption that it established in response to fire (Floyd *et al.* 2000). Pointleaf Manzanita has the potential to be used in a similar fashion as Gambel oak. Pointleaf manzanita carries fire well and requires scarification of its seeds in order for them to germinate (Pase and Pond 1964, Carmichael *et al.* 1964, Conrad 1987, Fulé *et al.* 2000). Because manzanita can only regenerate via fire or layering (Carmichael *et al.* 1978, Conrad 1987) its continued presence on a landscape is indicative of past fire activity at that location. However, because manzanita can spread via layering, the extent of past fires cannot be determined from manzanita alone.

Manzanita occurs throughout the study area, especially between stands B, C and D. The presence of Manzanita on these slopes probably means that they have burned at some point in the past. This conclusion is reinforced by the presence of ponderosa snags and logs in the shrubfields. Stands B, C, and D bordering the shrubfields contain fire scars. Several fire dates in these stands, such as 1845, 1860, 1861, 1877 and 1946 burned throughout multiple stands, yet the stands are no longer connected. It is possible these stands may have been connected in the past when the scars were recorded and were recording single widespread fires. By collecting tree establishment data via increment cores from trees within or near the cleared areas one could test if the 1946 fire separated the stands. Quantification of growth releases in our stands may also prove useful for determining fire severity (Py *et. al* 2006).

It possible that past fires were carried primarily by grasses and/or shrubs such as manzanita. This ground vegetation would have served as fuel to carry fires between stands. In this scenario fire spread would not have been dependent on presence of trees but rather the presence of grasses/shrubs. The trees merely serve as recorders of fires carried by the grass/shrub understory. The mortality evidenced by the downed ponderosa stems could have been caused by girdling of the cambium or root damage (McHugh and Kolb 2003), if tree densities were insufficient to support ground fire. A further possibility is that the 1946 fire significantly altered ground cover to the point that it no longer carried fire effectively.

Regardless of the cause, the establishment of pure shrubfields of manzanita indicates that future tree establishment in the shrubfields is unlikely because of potential for intense fires that will make tree establishment difficult (Savage and Mast 2005). If reestablishment of trees is desired suppression of fires within the shrubfields may be an effective long term strategy because conifers generally outcompete manzanita in the absence of fire (Carmichael *et al.* 1978).

A map of Fire Regime Condition Class (FRCC) from the LANDFIRE site (Figure 19; LANDFIRE 2007) shows that fire regime condition classes one, two and three are present at the Clover Mountains. The comparison of the FRCC map to the GAP landcover map (Figure 20) shows that many of the areas (especially near stands A, B and C) classified as Condition Class 3 are dominated by shrubs and oak. Areas along Pennsylvania Canyon Road and drainages are also classified as Condition Class 3; these areas are also dominated by shrubs and oak. Generally, it seems the FRCC classifies dense shrub/oak dominated areas as deviating from the HRV. However, classifying these shrub/oak dominated areas as outside the historic range of variability only makes sense if we understand the HRV. This area has never had fire history studies or stand structure studies done. This lack of previous research in the region may undermine FRCC modeling for the Clover Mountains because of a lack of knowledge of reference conditions. It is possible that some areas classified as condition class 3 occur in natural response to past fire events.

The Southwest regional GAP data (Figure 20; Lowry Jr. *et al.* 2005) does not show any ponderosa present in the Clover Mountains, most likely because ponderosa pine could not be distinguished from other cover types at this study area. GAP did detect the presence of oak and shrubs in the vegetation cover in the study area.

The lack of understanding of stand and disturbance history and dynamics may make attempts at modeling disturbance and vegetation departure difficult. This difficulty may be amplified when the soil survey data which forms the backbone of the model can be inaccurate. A site specific FRCC estimate was able to increase the accuracy of the FRCC classification at Mt. Grant, Mineral County, Nevada (Provencher *et al.* 2008). For FRCC to be accurately modeled in Clover Mountains a site specific classification, as found in Provencher *et al.* 2008, may need to be conducted.

Comparison to Other Studies in the American West

The similarity in fire dates between the Clover Mountains and several other areas in the intermountain west suggests that the Clovers have similar climatic drivers of fire to those areas. Similar climatic drivers could lead to common patterns in fuel build up and moisture as well as common trends in lightning strikes at the broad scale. These similarities could lead to the synchronicity in fire dates we have observed. These similarities may also be an aid in fire forecasting in the future. If fires in the Clover Mountains have similar regional climatic drivers as the southwest, then we may assume that predicted periods of high fire activity in that region may portend high fire activity in the Clover Mountains as well.

Study Limitations and Methodological Concerns

Fire scar histories are not perfect reconstructions of past fire (Baker and Ehle 2001). Fire scars can only tell where a fire has burned; their absence does not prove that fire did not burn since fires do not necessarily scar all trees within their burn perimeter (Baker and Ehle 2001). Several factors determine whether a scar will be made such as the tree's age, size, bark thickness and the intensity of the fire, as well as whether the tree has been scarred already (Kilgore and Taylor 1979).

Difficulties in fire scar history reconstructions influence statistics such as MFRI (Arno and Peterson 1983, Baker and Ehle 2001). The use of restrictive filters has been proposed (Baker and Ehle 2001) as a way to reduce the effect that large sample sizes and areas have on MFRI (Arno and Peterson 1983). However in our data set the 10% restricted filter does not have any effect on earlier fire events, because the lack of recorder trees nearly assures that a fire will not be removed by the filter. With lower sample depth fewer scars will be required to pass through the filter. During more recent periods in the fire record the filter will remove fire events because of increasing sample size, even though in some cases fires that are removed scar more trees than fires that made the cut earlier in the record. This effect may distort the fire record by making it appear that fewer fires are occurring in recent times. Because of these issues using the two scar filter should be preferred for small sample sizes.

A limitation of fire scar reconstructions is the preservation of scars as evidence of fire (Swetnam 1999, Baker and Ehle 2001, Parsons *et al.* 2007). The snag and logs in the

Manzanita shrubfields indicate past presence of ponderosa. Did these now dead trees record fire, and if so would our fire history be different had they been included? Given the spatial extent and location of these shrubfields, and the estimated size of many of our fire events, it is likely that fires were missing in our record due to destruction of the recorders, the ponderosa pines. This loss of data makes it unlikely the MFRI from our fire history incorporates every fire that actually burned in the study area. This cannot be avoided, but must be acknowledged as a concern and may impose a limitation on how precisely we can reconstruct fires, especially on sites with a mixed severity fire regime. Because of the above issues with the MFRI, IMFI may prove a more useful tool for inter and intra site comparison. The IMFI is less sensitive to sample size and sample area than MFRI. However difficulties may arise with IMFI when using targeted sampling (Baker and Ehle 2001, Van Horne and Fulé 2006), which aims to collect trees with multiple fire scars. The multi-scar samples may artificially reduce the IMFI because the samples will only represent the most heavily scarred individuals, while sampling will pass over specimens with fewer scars.

Loss of recorder trees may affect results when reconstructing area burned in past fires (Jordan *et al.* 2005). If trees beyond the perimeter of our current stands recorded past fires, then their destruction removes evidence for mapping fires. The boundaries and areas of fires in the scar record may differ from the actual area burned, potentially significantly so, especially at the local scale although it may be less significant at larger spatial scales (Levin 1992). Additional uncertainty with creating exact fire maps/areas comes from the simple truth that not every tree within a burn perimeter is scarred (Baker and Ehle 2001). Because of these uncertainties, we did not compute Population Mean

Fire Interval (PMRI; Kou and Baker 2006), which has also been referred to as fire rotation (Agee 1993, Baker and Ehle 2001, Baker 2006). Mapping historical area burned will require data from growth releases (Lorimer 1985, Heyerdahl *et al.* 2001, Py *et al.* 2006), stand establishment data (Veblen *et al.* 2000, Buechling and Baker 2004, Sibold *et al.* 2006), species distribution, and life history characteristics. Regardless, none of these sources of evidence will eliminate the problem encountered in mixed severity fire regimes, which is loss of spatial data because of high severity fire. Even if the dominant fire type in the Clover Mountains is low severity, the rare high severity event will still have this effect. In areas historically dominated by high severity (Subalpine Rocky Mountains) or low severity fires (southwest and also Mt. Irish), use of area burned and associated statistics may be more useful.

Another issue to be considered related to consecutive fire years (Table 9). Our treatment of ring boundary fires assigned the fire to the first of the two years based on archival fire records and lightning strike data. It is possible that some scars occurring on a ring boundary actually occurred in the later year and should have been grouped with fire scars from that year. What this implies is that there are variations in the start of growth at the site to the point where scars occur in the late-earlywood in some specimens while still being in the dormant season in others. Possible side effects of putting ring boundary scars into the wrong year by always putting them in the first year include alteration of fire statistics such as the MFRI, WMFI, and fire frequency, and these alterations may be magnified at the stand level because of small samples sizes and number of fires. The danger of grouping fire scars is that, as said before the individual samples give us no evidence to support putting them in the first year. Grouping may also impart some bias into the assignment of fire scar dates by moving ring boundaries scars to match a perceived logical distribution. In many cases this may be correct, but one must be careful not to alter their methods to manipulate data into a desired result. If ring boundary dates are improperly assigned this could confound climate analysis of the data where movement of fire years in one direction or the other could alter or muddle resulting the climate relationship. A key question that arises from this dilemma is whether seasonal fire occurrence has changed over the course of our fire scar record? Is it possible that early spring fires were more common in the past?

This study highlights a potential limitation in the use of southwest regional GAP data for this region. The GAP data was unable to detect ponderosa pine at both the Clover Mountains and Mt. Irish (Fig. 20; Fig. 21). At both sites ponderosa pine populations large enough for fire history studies were present. At Mount Irish the GAP data classified all the vegetation as Great Basin Pinyon-Juniper Woodland including areas of pure ponderosa pine (Fig. 21). At the Clover Mountains much of the ponderosa was in areas classified as Great Basin Pinyon-Juniper, but ponderosa pine was also found under Mogollan Chaparral and Gambel Oak-Mixed Montane Shrubland cover types. These discrepancies indicate that GAP data may not be appropriate for cover type examinations involving ponderosa pine and pinyon-juniper in the Great Basin. This could lead to invalid associations between fire and forest type. GAP data has been used to aid in various FRCC mapping projects (Provencher *et al.* 2008) but it is not appropriate for use in the Clover Mountains because it does not differentiate between ponderosa pine and pinyon-juniper. The Southwest Regional GAP data was designed for use at scales greater than 1:100,000 (Lowry *et al.* 2005) and our observations show that GAP data may not be appropriate for work at smaller scales or for distinguishing conifer cover types in Lincoln County.

Conclusions

Historical fires in the Clover Mountains were typically frequent, (MFRI <10 years) and ranged from small fires scarring only a handful of trees to widespread fires scarring several dozen trees across the landscape. From 1675 until 1946 the longest fire free period was 33 years. Currently the Clover Mountains are experiencing a 63 year fire free period since the 1946 fire. This 63 year period is outside the historic range of variability and is likely the result of fire suppression activity in the area, starting the in the mid 20^{th} century. In the future the Clover Mountains may require alteration of current land management and fire suppression policies if a return to the HRV is desired.

The comparison of the Clover Mountains to Mount Irish reveals significant differences between the sites. First, the Clover Mountains have a longer MFRI, 7 years to 3.98 years. Second, the onset of Euroamerican settlement influenced the fire regime differently at the two sites. Finally, the Clover Mountains had more widespread fire events than Mt. Irish. Therefore, within 100km we find differences in fire size, frequency and temporal patterns. This variation suggests that one should not rely solely on fire history studies from other regions of the west to guide management, and highlights the need for further research within southern Nevada and the Great Basin as a whole.

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Table 1. Summary of sample location data for each ponderosa stand at the Clover Mountains. Mean of exposure and scar azimuth was computed using circular statistics.

A. Mean	Total Pines Sampled	Elevation (m)	Slope (percent)	Exposure (degrees)	Scar Azimuth (degrees)	Diameter (cm)	Height (m)	Scar Height (m)
Stand A	13	1850	31	18	226	56	14.8	2.0
Stand B	29	2117	41	313	129	60	13.3	1.9
Stand C	30	2156	45	211	33	48	12.5	1.5
Stand D	40	2220	36	117	317	53	11.3	1.3
Stand E	27	2129	37	356	176	74	16.1	2.2
Stand F	9	1984	37	17	210	65	10.9	1.1

B. Range	Elevation (m)	Slope (percent)	Diameter (cm)	Height (m)	Scar Height (m)
Stand A	1799-1871	5-63	25-96	9.5-18	0.7-4
Stand B	2043-2159	20-60	32-95	7-20	0.25-9
Stand C	2078-2219	30-60	21-80	5-20	0.2-6
Stand D	2114-2250	15-56	25-99	4.5-16.5	0.2-5
Stand E	2073-2175	18-62	25-114	10-22	0.4-5
Stand F	1950-2000	7-50	57-78	8.5-15.5	0.25-2

Table 2. List of ponderosa pines (n=148) sampled for fire scar wedges from the Clover Mountains study area.

Tree ID	Location (UTM)		Elevation (m)	Exposure (degrees)	Slope (percent)	Tree Diameter (cm)	Tree Height (m)	Lean (degrees)	Lean Direction (degrees)	Scar Azimuth (degrees)	Scar Height (m)
	Northing	Easting									
CLA001	4152821	723503	1810	270	15	96	18	32	100	100	3.5
CLA002	4152748	723452	1799	100	36	76	18	20	200	280	1.2
CLA003	4152536	723399	1836	0	45	50	14	30	350	180	1
CLA004	4152516	723469	1854	35	63	57	15	5	45	230	1.1
CLA005	4152515	723470	1854	35	63	35	12.5	0		290	0.7
CLA006	4152170	723271	1850	10	7	61	15	0		260	1.3
CLA007	4152160	723268	1855	30	10	41	13.5	0		280	4
CLA008			1860	40	15	56	16	0		120	2
CLA009	4152094	723256	1865	210	38	53	14.5	10	190	190	3
CLA010	4152080	723271	1864	30	55	54	16	0		210	1
CLA011	4152002	723275	1860	10	5	25	9.5	30	250	250	3
CLA012	4151980	723305	1868	280	15	75	15		120	80	1.4
CLA013	4151934	723312	1871	40	35	48	15.5	0		250	2.5
CLB001	4149970	723552	2109	270	50	57	10	0		50	0.6
CLB002	4149967	723568	2112	240	30	63		0		60	0.5
CLB003	4150011	723547	2112	240	52	55	10	0		80	1.7
CLB004	4149994	723599	2110	80	40	58	9	0		320	9
CLB005	4149982	723594	2105	110	42	57	9	0		290	1.3
CLC001	4149579	723598	2145	10	47	85	17	5	210	200	1.2
CLC002	4149605	723614	2152	0	60	95	16	0		180	0.8
CLC003	4149630	723650	2159	10	20	56	12	10	0	170	7
CLC004	4149647	723648	2152	0	50	38	9.5	10	170	190	1.9
CLC005	4149658	723608	2131	310	60	67	16	5	120	150	0.9
CLC006	4149656	723659	2134	0	50	39	9.5	0		220	2
CLC007	4149689	723635	2120	10	20	53	11	0		190	3.5
CLC008	4149758	723704	2131	300	43	35	9.5	0		100	1.5
CLC009	4149800	723681	2108	300	40	68	14	20	180	180	4.5
CLC010	4149809	723686	2107	315	40	86	16	35	140	140	2.5
CLC011	4149849	723781	2131	340	32	45	12.5	30	130	130	1.5
CLD001	4149429	723475	2219	240	30	32	8	0		70	2
CLD002	4149429	723467	2209	220	35	27	8	10	320	30	1.2
CLD003	4149419	723462	2206	230	35	21	5	10	300	50	0.3
CLD004	4149404	723502	2217	220	40	59	9	0		40	0.5
CLD005	4149380	723509	2203	190	50	64	15	0		20	0.25
CLD006	4149356	723489	2203	200	60	47	12	0		30	3.5
CLD007	4149356	723489	2187	200	60	42	8	0		30	3
CLD008	4149345	723472	2183	200	55	53	9.5	15	30	30	1.4
CLD009	4149446	723442	2209	190	38	57	8.5	32	0	320	3.5
CLD010	4149436	723467	2211	220	33	49	9	0		10	0.8
CLE001	4148333	723868	2235	80	40	71	15	0		260	2
CLE002	4148388	723896	2231	100	50	72	16	9	270	280	1.9
CLE003	4148316	723907	2231	90	45	84	16	0		270	0.9
CLE004	4148255	723911	2226	90	35	64	15.5	0		270	0.3

CLE005	4148119	723884	2207	130	45	55	12.5	0		310	1.2
CLE006	4148090	723860	2206	170	16	35	7	20	10	0	1.9
CLE007	4148291	723852	2250	90	37	63	14	0		280	1.4
CLE008	4148534	723979	2230	120	30	46	13.5	0		310	2
CLE009	4148539	723971	2230	90	37	50	13.5	0		350	1.5
CLE010	4148536	723992	2217	100	37	48	9	0		300	2
CLE011	4148570	723983	2236	130	30	59	13	10	270	20	1.2
CLE012	4148579	723979	2236	80	25	39	12	0		50	1.4
CLF001	4148623	724942	2135	350	35	82	17	0		115	2.5
CLF002	4148607	724985	2144	10	39	89	17	10	180	180	4
CLF003	4148544	725230	2163	5	45	78	20	0		135	2
CLF004	4148630	725293	2158	340	40	72	18	0		210	2.5
CLF005	4148667	725335	2137	10	32	68	15.5	5	180	150	3
CLF006	4148672	725374	2131	5	38	76	16	30	200	200	3.5
CLF007	4148720	725447	2101	10	18	86	19	0		260	3.5
CLF008	4148723	725450	2099	25	23	51	13	26	160	140	1
CLF009	4148655	725476	2123	20	35	85	20	0		270	4
CLF010	4148633	725536	2101	30	22	90	20	0		190	1.1
CLF011	4148503	725517	2161	10	48	101	18	30	170	170	1.6
CLF012	4148527	725480	2172	0	62	67	17	20	180	180	2
CLF013	4148543	725427	2175	10	50	96	18	10	130	180	1.4
CLF014	4148594	725357	2173	0	40	94	19	0		170	2
CLF015	4148608	724876	2134	350	25	73	10	0		230	1.3
CLG001	4148319	724765	2163	350	32	73	14.5	17	180	100	0.4
CLG002	4148388	724736	2138	5	45	72	18	0		195	1.3
CLG003	4148396	724716	2127	350	50	69	17	0		240	0.5
CLG004	4148205	724709	2121	0	45	82	17.5	0		170	0.8
CLG005	4148411	724667	2129	0	43	56	14	8	90	180	2
CLG006	4148374	724654	2132	335	30	66	11.5	0		150	1.2
CLG007	4148429	724639	2115	345	40	52	13	0		140	1.8
CLG008	4148507	724683	2090	350	42	25	10	15	150	190	3.5
CLG009	4148497	724712	2083	290	25	114	22	0		200	2
CLG010	4148523	724655	2089	350	30	35	12	0		170	5
CLG011	4148521	724644	2073	350	35	40	10	0		160	3.5
CLG012	4148592	724808	2118	250	27	108	18.5	0		120	1.4
CLI001	4145370	724419	1968	350	7	78	13	10	180	220	2
CLI002	4145251	724427	1983	0	18	65	11.5	0		180	0.6
CLI003	4145239	724442	1985	0	34	61	9	23	180	180	1.4
CLI004	4145200	724448	1999	20	35	65	9	10	0	210	0.7
CLI005	4145203	724485	1987	30	47	70	11.5	0		210	1.7
CLI006	4145172	724507	1996	55	50	63	10.5	15	270	230	1.3
CLI007	4145177	724499	2000	20	50	64	8.5	10	350	200	1
CLI008	4145163	724534	1990	20	50	57	9.5	10	200	200	0.6
CLI009	4145101	724758	1950	20	40	63	15.5	0		270	0.25
CLV024	4148449	723897	2236	100	40	25	4.5	0		309	1.6
CLV031	4148549	723962	2226	130	35	55	9	0		28	1.8
CLV034	4148557	723981	2228	170	35	59	7	0		358	1.9
CLV046	4148573	723977	2238	160	35		8.5	0		330	3
CLV048	4148570	723973	2238	160	35	50	9	0		352	1.3

CLV084	4149340	723229	2113	212	48	43	20	0		55	6
CLV085	4149332	723202	2103	222	53	46	20	0		60	0.7
CLV086	4148575	723986	2234	150	35	28	5	75	360	335	1.1
CLV087	4149330	723199	2106	228	51	36.5	10	0		20	1.2
CLV088	4149324	723202	2106	228	51	28	5	0		15	1
CLV089	4149330	723205	2118	200	46	51	15	0		355	1.5
CLV090	4149292	723189	2103	209	47	45	10	0		5	0.9
CLV091	4149287	723190	2099	210	48	64	17	0		0	1
CLV092	4149340	723074	2090	208	38	80	18	0		115	0.4
CLV093	4149322	723067	2088	183	55	70	20	55	360		
CLV094	4149850	723206	2151	192	40	32	7	0		60	2
CLV096	4149868	723205	2148	298	42	58	12	0		88	0.9
CLV098	4149903	723130	2120	286	52	40	15	0		102	0.35
CLV100	4148554	723984	2227	170	35	45	6	0		352	0.8
CLV101	4148563	723955	2231	148	35	28	6	0		358	0.4
CLV102	4148557	723951	2229	152	15	42	7.5	0		342	0.7
CLV103	4148556	723953	2234	152	15	38	8.5	0		342	0.6
CLV104	4148422	723884	2237	72	42	38	8.5	0		255	0.35
CLV105	4148406	723896	2236	84	25	81	13	0		351	0.3
CLV106	4148307	723872	2239	88	34	53	16.5	0		264	0.23
CLV107	4148302	723868	2241	84	25	47	16	0		230	0.3
CLV108	4148289	723854	2242	107	33	48	14	0		282	0.2
CLV109	4148298	723880	2244	98	45	39	14	0		314	0.7
CLV110	4148272	723878	2230	116	35	57	13	0		275	2
CLV111	4148203	723921	2218	116	29	66	14	0		7	0.33
CLV112	4148131	723950	2188	127	46	69	11	0		339	0.7
CLV113	4148101	723962	2172	124	53	66	13	0		310	1.75
CLV114	4147922	724007	2143	67	35	55		0		253	1.06
CLV115	4149355	723468	2189	215	45	46	9	0		342	0.2
CLV116	4149351	723484	2176	215	45	65	11	0		64	0.7
CLV118	4149341	723474	2183	215	45	32	9	0		178	0.5
CLV119	4149360	723483	2190	215	45	40	11	0		12	3
CLV120	4149363	723488	2193	215	45	43	9	0		58	1.1
CLV121	4149383	723406	2168	198	35	75	18	0		19	0.9
CLV122	4149377	723387	2181	172	47	52	16	0		355	3
CLV123	4149877	723613	2063	120	25	77	20	0		252	1.45
CLV124	4150224	723499	2047	300	60	42	14	0		53	1.14
CLV125	4150242	723472	2043	298	51	75	15	0		178	1.1
CLV126	4149794	723693	2110	300	30	84	20	0		77	0.6
CLV127	4149801	723702	2112	300	37	52	13	0		113	0.25
CLV128	4149730	723644	2113	290	20	49	11	0		107	2
CLV129	4149762	723606	2099	275	30	75	17	0		98	0.75
CLV130	4149704	723657	2110	250	20	67	15	0		319	1.1
CLV131	4149654	723617	2132	322	47	69	18	0		134	0.3
CLV132	4149599	723613	2140	2	60	70	14	0			1.5
CLV150	4148551	723963	2224	143	39	43	10	0		309	5
CLV151	4148536	723956	2231	102	28	50	10	0		303	3
CLV152	4148345	723890	2240	100	45	99	12	0			0.5
CLV153	4148303	723963	2204	80	56	55	10	0		260	0.8

CLV154	4148044	724084	2114	161	48	34	14	80	315	325	2.5
CLV155	4148122	724024	2156	143	45	42	10	0		304	0.3
CLV156	4148182	723951	2211	109	40	70	15	0		94	0.3
CLV300	4149131	723249	2078	358	43	45	15	0		148	0.8
CLV301	4149122	723342	2087	235	40	38	11	0		48	0.3
CLV302	4149282	723214	2150	193	46	48.5	20	0		55	3.5
CLV303	4149310	723226	2103	203	49	45	18	0		42	1.4

Table 3. Summary of the number of fire scars, fire scar samples and the status of those samples.

Fire Scar Sample Summary Dating Table	
Number of Fire Scarred Trees Sampled	148
Total Number of Fire Scar Samples Cut	150
Number of Fire Scar Samples Crossdated	139
Unable to Crossdate Sample	2
Sample lacked fire scar or fire scar tip	9
Number of Fire scar samples crossdated and Measured	97
Number of Fire scar samples crossdated but unmeasured	42
Number of Crossdated fire scars	302
Number of fire scars with Indeterminable dates	22

Table 4. List of wedge samples taken from ponderosa pine (*Pinus* ponderosa). Dates in bold are dates that were used in our fire statistics. Fire dates not in bold include all dates in a 3 year window or greater.

Tree ID	Species	Wedge Start Year	Wedge End Year	Fire Year (s)	Dating Status	Measurement Status
CLA001	PIPO	1716	2007	1782-1784, **1827**, **1856**-1857	Complete	Complete
CLA002	PIPO	1700	2007	**1780**, **1815**-1816, **1833**, **1872**	Complete	Complete
CLA003	PIPO	1906	2007	**1940**-1941	Complete	Complete
CLA004	PIPO	1900	2007	**1946**	Complete	Complete
CLA005	PIPO	1926	2007	**1946**	Complete	Complete
CLA006	PIPO	1912	2007	**1946**-1947	Complete	Complete
CLA007	PIPO	1891	2007	**1946**	Complete	Complete
CLA008	PIPO	1923	2007	**1946**	Complete	Complete
CLA009	PIPO	1929	2007	**1946**	Complete	Complete
CLA010	PIPO	1918	2007	**1946**	Complete	Complete
CLA011	PIPO	1908	2007	**1946**-1947	Complete	Complete
CLA012	PIPO	1698	2007	**1763**-1764, **1845**-1846, **1946**	Complete	Not measured
CLA013	PIPO	1909	2007	**1946**	Complete	Complete
CLB001	PIPO	1749	2007	1807-1809, **1844**-1845, **1860**-1861, **1877-**1878	Complete	Not measured
CLB002	PIPO	1536	2007	**1611**-1612, **1715**, **1764**-1765, **1877**-1878, **1946**	Complete	Not measured
CLB003	PIPO	1909	2007	**1946**	Complete	Complete
CLB004	PIPO	1758	2007	1945-1948	Complete	Complete
CLB005	PIPO	1780	2007	**1845, 1946**	Complete	Not measured
CLC001	PIPO	1633	2007	**1678**-1679, **1703**-1704, **1715**, **1838**-1839, **1845**, **1870**-1871, **1877**-1878, **1946**	Complete	Complete
CLC002	PIPO	1810	2007	**1860**-1861, **1945**-1946	Complete	Complete
CLC003	PIPO	1541	2007	**1946**	Complete	Complete
CLC004	PIPO	1747	2007	**1817, 1946**	Complete	Complete
CLC005	PIPO	1650	2007	**1838**-1839, **1877**-1878, **1946**	Complete	Not measured
CLC006	PIPO	1852	2007	**1946**	Complete	Complete
CLC007	PIPO	1744	2007	**1817**-1818, **1877**-1878	Complete	Complete
CLC008	PIPO	1791	2006	**1844**-1845, **1860**-1861, **1877**-1878, **1946**	Complete	Not measured
CLC009	PIPO	1727	2007	**1789**-1790, **1817**-1818, **1844**-1845, **1945**-1946	Complete	Not measured
CLC010	PIPO	1659	2007	**1845**, **1877**-1878, **1910**-1911, **1946**	Complete	Complete
CLC011	PIPO	1856	2007	**1877**-1878, **1946**	Complete	Complete
CLD001	PIPO	1805	2007	**1877**-1878, **1946**	Complete	Complete
CLD002	PIPO	1786	2007	**1946**	Complete	Complete
CLD003	PIPO	1786	2007	**1820**-1821, **1861**-1862	Complete	Not measured
CLD004	PIPO	1815	2007	**1860**-1861, **1877**-1878, **1946**	Complete	Complete
CLD005	PIPO				Not dated	Not measured
CLD006	PIPO	1890	2007	**1946**	Complete	Not measured
CLD007	PIPO	1676	2007	**1946**	Complete	Not measured
CLD008	PIPO	1645	2007	**1946**	Complete	Complete
CLD009	PIPO	1790	2007	**1821**, **1946**-1947, **1971**-1972	Complete	Complete

CLD010	PIPO	1783	2007	**1820**-1821, **1861**, **1877**-1878, **1946**	Complete	Not measured
CLE001	PIPO	1660	2007	**1724**-1725, **1751**, **1776**-1777, **1857**-1858, **1877**-1878, **1922**, **1946**	Complete	Complete
CLE002	PIPO	1587	2007	**1788**-1789, **1861**-1862, **1877**-1878, **1946**	Complete	Complete
CLE003	PIPO	1678	2007	**1788**, **1823**-1824, **1877**-1878	Complete	Not measured
CLE004	PIPO	1806	2007	**1922, 1946**	Complete	Complete
CLE005	PIPO	1826	2007	**1877**-1878, **1922**, **1946**	Complete	Complete
CLE006	PIPO	1905	2007	**1946**	Complete	Complete
CLE007	PIPO	1833	2007	**1857**-1858, **1877**-1878, **1922**, **1946**	Complete	Complete
CLE008	PIPO	1890	2007	**1946**	Complete	Complete
CLE009	PIPO	1919	2007	**1946**	Complete	Complete
CLE010	PIPO	1925	2007	**1946**	Complete	Complete
CLE011	PIPO	1810	2007	**1857**-1858, **1946**	Complete	Complete
CLE012	PIPO	1915	2007	**1946**, 1973-1976	Complete	Complete
CLF001	PIPO	1800	1950	**1856**-1857	Complete	Complete
CLF002	PIPO	1745	2007	**1875**-1876	Complete	Complete
CLF003	PIPO	1624	2007	**1752**, **1773**-1774, **1813**-1814, **1836**-1837, **1862**, **1869**-1870	Complete	Complete
CLF004	PIPO	1599	2007	**1822**-1823, **1836**, **1862**	Complete	Not measured
CLF005	PIPO	1600	2007	**1752**-1753, **1785**-1786, 1862-1864	Complete	Complete
CLF006	PIPO	1688	2007	**1820**-1821, 1862-1865	Complete	Complete
CLF007	PIPO	1689	2007	1714-1716, **1813**-1814, 1862-1864	Complete	Complete
CLF008	PIPO	1560	2007	**1613**-1614, 1714-1716, **1752**-1753, **1862**	Complete	Complete
CLF009	PIPO	1616	2007	**1654**-1655, **1669**, **1813**-1814	Complete	Complete
CLF010	PIPO				No scar	Not measured
CLF011	PIPO	1595	2007	**1626**, **1723**-1724, **1798**-1799	Complete	Complete
CLF012	PIPO	1672	2007	**1862**-1863	Complete	Complete
CLF013	PIPO	1500	2007	**1715**, **1752**-1753, **1798**-1799, **1813**, **1862**, **1967**-1968	Complete	Complete
CLF014	PIPO	1657	2007	**1686**-1687, **1785**-1786, **1813**-1814, **1838**-1839, **1862**-1863	Complete	Complete
CLF015	PIPO	1680	2007	**1785**-1786	Complete	Complete
CLG001	PIPO	1682	2007	1862-1865	Complete	Not measured
CLG002	PIPO	1655	2007	**1666**-1667, **1697**-1698, **1707**-1708, **1733**, **1751**-1752, **1788**-1789, **1837**-1838, **1862**	Complete	Not measured
CLG003	PIPO	1751	2007	**1788**-1789, **1837**-1838, **1862**-1863	Complete	Complete
CLG004	PIPO	1632	2007	**1788**-1789, **1837**-1838, **1979**-1980	Complete	Not measured
CLG005	PIPO	1597	2007	**1653**-1654, **1698**, **1751**-1752, **1820**-1821, **1836**-1837	Complete	Complete
CLG006	PIPO	1880	2007	**1907**-1908	Complete	Complete
CLG007	PIPO				No scar	Not measured
CLG008	PIPO	1896	2007	**1933**-1934	Complete	Complete
CLG009	PIPO	1773	2007	1861-1865, 1881-1884	Complete	Complete
CLG010	PIPO	1886	2007	**1933**-1934	Complete	Not measured
CLG011	PIPO	1885	2007	**1932**-1933	Complete	Complete
CLG012	PIPO	1578	2007	**1617**-1618, **1681**-1682, **1778**-1779, **1861**-1862, **1936**-1937	Complete	Complete
CLI001	PIPO	1639	2007	**1675**-1676, **1698**-1699, **1724**-1725, 1757-1759	Complete	Not measured
CLI002	PIPO	1590	2007	**1665**, **1712**-1713, **1801**-1802	Complete	Complete
CLI003	PIPO				No scar	Not measured
CLI004	PIPO	1627	2007	**1792**-1793, **1865**, **1867**-1868, **1905**-1906	Complete	Complete
CLI005	PIPO				Not dated	Not measured

CLI006	PIPO	1650	2007	**1851**	Complete	Complete
CLI007	PIPO	1538	2007	1757-1759, **1956**-1957	Complete	Complete
CLI008	PIPO				No scar	Not measured
CLI009	PIPO	1623	2007	**1675**-1676, 1821-1824	Complete	Not measured
CLV024	PIPO	1810	1950	**1857**-1858, **1877**-1878, **1945**-1946	Complete	Complete
CLV031	PIPO	1893	2008	**1946**	Complete	Complete
CLV034	PIPO	1924	2008	**1946**	Complete	Complete
CLV046	PIPO	1913	2008	**1946**	Complete	Complete
CLV048	PIPO	1933	2008	**1946**	Complete	Complete
CLV084	PIPO	1823	2008	**1877**-1878, **1946**, **1950**-1951	Complete	Complete
CLV085	PIPO	1885	2008	**1946**	Complete	Not measured
CLV086	PIPO	1927	2008	**1946**	Complete	Not measured
CLV087	PIPO	1845	2008	**1945**-1946	Complete	Not measured
CLV088	PIPO	1818	2008	**1877**-1878, **1946**-1947	Complete	Complete
CLV089	PIPO	1816	2008	**1877**-1878, **1946**	Complete	Complete
CLV090	PIPO	1834	2007	**1877**-1878, **1946**	Complete	Complete
CLV091	PIPO	1764	2008	**1945**-1946	Complete	Complete
CLV092	PIPO	1804	2008	**1898**, **1908**, **1945**-1946	Complete	Complete
CLV093	PIPO	1915	2008	**1946**	Complete	Complete
CLV094	PIPO	1870	2008	**1903**-1904, **1946**	Complete	Not measured
CLV096	PIPO	1771	2008	1812-1814 , 1945-1947	Complete	Complete
CLV098	PIPO	1763	2007	1807-1810 , **1877**-1878, **1945**-1946	Complete	Complete
CLV100	PIPO	1928	2008	**1946**	Complete	Complete
CLV101	PIPO	1920	2008	**1946**	Complete	Complete
CLV102	PIPO	1920	2008	**1946**	Complete	Complete
CLV103	PIPO	1924	2008	**1946**	Complete	Complete
CLV104	PIPO	1907	2007	**1946**	Complete	Complete
CLV105	PIPO	1749	2008	**1861**-1862, **1945**-1946	Complete	Complete
CLV106	PIPO	1898	2008	**1922, 1946**	Complete	Complete
CLV107	PIPO	1832	2008	**1877**-1878	Complete	Complete
CLV108	PIPO	1845	2008	**1877**-1878, **1922**, **1946**	Complete	Complete
CLV109	PIPO	1839	2008	**1877**-1878, **1922**-1923, **1946**	Complete	Not measured
CLV110	PIPO				No scar	Not measured
CLV111	PIPO	1789	2008	**1821**-1822, **1877**-1878	Complete	Not measured
CLV112	PIPO	1865	2008	**1922**	Complete	Complete
CLV113	PIPO	1888	2008	**1942**-1943	Complete	Complete
CLV114	PIPO				No scar	Not measured
CLV115	PIPO	1740	2008	**1751**, **1795**-1796, **1946**	Complete	Complete
CLV116	PIPO	1900	2008	1963-1966	Complete	Not measured
CLV118	PIPO	1778	2008	**1877**-1878, **1946**	Complete	Not measured
CLV119	PIPO				No Scar	Not measured
CLV120	PIPO	1890	2007	**1945**-1946	Complete	Not measured
CLV121	PIPO	1884	2007	**1945**-1946	Complete	Complete
CLV122	PIPO	1922	2008	**1946**	Complete	Complete
CLV123	PIPO	1799	2007	**1945**-1946	Complete	Complete
CLV124	PIPO	1745	2007	1817-1819	Complete	Not measured
CLV125	PIPO	1790	2007	1845-1847, 1877-1879, **1945**-1946	Complete	Complete

CLV126	PIPO	1848	2008	**1910**-1911, **1945**-1946	Complete	Complete
CLV127	PIPO	1932	2008	**1945**-1946	Complete	Complete
CLV128	PIPO	1906	1950	**1945**-1946	Complete	Not measured
CLV129	PIPO	1673	2008	**1946**	Complete	Complete
CLV130	PIPO	1860	2008	**1877**-1878, **1945**-1946	Complete	Complete
CLV131	PIPO	1729	2008	**1790**, **1877**-1878, 1946	Complete	Complete
CLV132	PIPO	1678	1991	**1789**-1790, **1817**-1818, **1838**-1839, **1860**-1861, **1877**-1878, **1946**	Complete	Complete
CLV150	PIPO	1905	2008	**1946**	Complete	Complete
CLV151	PIPO	1920	2008	**1946**	Complete	Complete
CLV152	PIPO	1686	2008	**1922**, **1945**-1946	Complete	Complete
CLV153	PIPO	1805	2008	**1877**-1878	Complete	Not measured
CLV154	PIPO	1877	2008	**1945**-1946	Complete	Complete
CLV155	PIPO	1845	2008	**1913**-1914	Complete	Complete
CLV156	PIPO	1707	2008	**1877**-1878, **1922**	Complete	Complete
CLV300	PIPO	1763	2008	**1877**-1878, **1945**-1946	Complete	Complete
CLV301	PIPO	1775	2008	**1877**-1878, **1946**	Complete	Complete
CLV302	PIPO	1819	2007	**1877**-1878, **1946**	Complete	Not measured
CLV303	PIPO	1840	2008	**1877**-1878, **1946**	Complete	Not measured

Table 5. Results of COFECHA analysis of our master chronology (top) and our fire scar sample measurements (bottom).

Summary of COFECHA analysis of master chronology measurement and dating	
Number of Series Dated	47
Master Series Length (yrs)	538
First Year	1470
Last Year	2007
Total Rings in all Series	14744
Total Rings analyzed	14741
Avg. Ring Width (mm)	0.72
Series Intercorrelation	0.823
Avg. Mean Sensitivity	0.437
Mean Series Length (yrs)	313.7

Summary of COFECHA analysis of fire scar wedge sample dating	
Number of Series Dated	110
Master Series Length (yrs)	458
First Year	1500
Last Year	2007
Total Rings in all Series	20417
Total Rings analyzed	20371
Avg. Ring Width (mm)	0.89
Series Intercorrelation	0.742
Avg. Mean Sensitivity	0.410
Mean Series Length (yrs)	185.6
Average Mean Correlation with Master Chronology	0.713

Table 6. Fire statistics for our entire fire record (1675-2007). Fire statistics for each stand were tabulated using fires that burned only in that specific stand. Stand A and Stand F did not have enough fires to calculate statistics.
Note that the stand fire statistics are largely unchanged by the addition of the 10% minimum recorder filter. This is because of small sample sizes and corresponding low thresholds needed to exceed 10% scarred.

A. Fire Statistics for the whole Fire Study Area and by Stand. Requiring a minimum of 2 scars recording a fire. Covers period from 1675-2007.							
	Whole Study Area	Stand A	Stand B	Stand C	Stand D	Stand E	Stand F
Number of Samples Used	139	13	29	28	38	25	6
Number of Fires	30	1	11	5	7	11	1
Mean Fire Return Interval (yrs)	9.34	NA	23.1	31.5	26.33	18.2	NA
Individual Mean Fire Interval (yrs)	50.13	50.67	50.97	58.17	40.87	46.46	41.83
Fire Frequency (fires/yr)	0.11	NA	0.04	0.03	0.04	0.05	NA
Weibull Median Fire Interval (yrs)	5.91	NA	15.83	19.98	16.86	11.15	NA
Weibull Fire Frequency (fires/yr)	0.17	NA	0.06	0.05	0.06	0.09	NA
Minimum and Maximum Fire Intervals (yrs)	1--33	NA	1--74	1--68	1--69	1--71	NA
Standard Deviation (yrs)	9.73	NA	21.68	29.4	26.18	21.3	NA

B. Fire Statistics for the whole Fire Study Area and by Stand. Requiring a minimum of 2 scars and 10% recorder trees recording a fire. Covers period from 1675-2007.							
	Whole Study Area	Stand A	Stand B	Stand C	Stand D	Stand E	Stand F
Number of Samples Used	139	13	29	28	38	25	6
Number of Fires	18	1	11	5	7	10	1
Mean Fire Return Interval (yrs)	15.94	NA	23.1	31.5	26.33	12.3	NA
Individual Mean Fire Interval (yrs)	50.13	50.67	50.97	58.17	40.87	46.46	41.83
Fire Frequency (fires/yr)	0.06	NA	0.04	0.03	0.04	0.08	NA
Weibull Median Fire Interval (yrs)	11.82	NA	15.83	19.98	16.86	8.81	NA
Weibull Fire Frequency (fires/yr)	0.08	NA	0.06	0.05	0.06	0.11	NA
Minimum and Maximum Fire Intervals (yrs)	1--45	NA	1--74	1--68	1--69	1--31	NA
Standard Deviation (yrs)	12.87	NA	21.68	29.4	26.18	11.1	NA

Table 7. Fire statistics for our primary fire analysis period (1785-2007) when there were at least 20 recorder trees. Fire statistics for each stand were tabulated using fires that burned only in that specific stand. Stand A and Stand F did not have enough fires to calculate statistics.
Note that the stand fire statistics are largely unchanged by the addition of the 10% minimum recorder filter. This is because of small sample sizes and corresponding low thresholds needed to exceed 10% scarred.

A. Fire Statistics for the whole Fire Study Area and by Stand. Requiring a minimum of 2 scars recording a fire for the period 1785-2007.							
	Whole Study Area	Stand A	Stand B	Stand C	Stand D	Stand E	Stand F
Number of Samples Used	139	13	29	28	38	25	6
Number of Fires	24	1	10	5	7	9	NA
Mean Fire Return Interval (yrs)	7	NA	17.44	31.5	26.33	18.5	NA
Individual Mean Fire Interval (yrs)	47.05	46.75	49.06	58.82	40.48	40.63	37.67
Fire Frequency (fires/yr)	0.14	NA	0.06	0.03	0.04	0.05	NA
Weibull Median Fire Interval (yrs)	4.50	NA	13.05	19.98	16.86	11.97	NA
Weibull Fire Frequency (fires/yr)	0.22	NA	0.08	0.05	0.06	0.08	NA
Minimum and Maximum Fire Intervals (yrs)	1--33	NA	1--35	1--68	1--69	1--71	NA
Standard Deviation (yrs)	7.79	NA	13	29.4	26.18	22.58	NA

B. Fire Statistics for the whole Fire Study Area and by Stand. Requiring a minimum of 2 scars and 10% recorder trees recording a fire for the period 1785-2007.							
	Whole Study Area	Stand A	Stand B	Stand C	Stand D	Stand E	Stand F
Number of Samples Used	139	13	29	28	38	25	6
Number of Fires	12	1	10	5	7	8	NA
Mean Fire Return Interval (yrs)	14.64	NA	17.44	31.5	26.33	11	NA
Individual Mean Fire Interval (yrs)	47.05	46.75	49.06	58.82	40.48	40.63	37.67
Fire Frequency (fires/yr)	0.07	NA	0.06	0.03	0.04	0.09	NA
Weibull Median Fire Interval (yrs)	10.19	NA	13.05	19.98	16.86	9.01	NA
Weibull Fire Frequency (fires/yr)	0.1	NA	0.08	0.05	0.06	0.11	NA
Minimum and Maximum Fire Intervals (yrs)	1--45	NA	1--35	1--68	1--69	1--25	NA
Standard Deviation (yrs)	13.76	NA	13	29.4	26.18	8.35	NA

Table 8. Fire years identified from our fire scar record. All fire dates included in the table required a minimum of 2 fire scars from separate trees confirming the date. Fires in 1877 and 1946 scarred the most trees and the highest percent of recorder trees.

Fire Year	Number of Trees Scarred	Percent of Recorder Trees Scarred
1675	2	20
1698	2	17
1715	3	23
1724	2	14
1751	4	27
1752	4	24
1785	3	15
1788	5	21
1789	2	8
1798	2	7
1813	5	17
1817	4	13
1820	4	12
1821	2	6
1836	3	8
1837	3	8
1838	4	10
1844	3	7
1845	4	9
1856	2	4
1857	4	8
1860	5	10
1861	5	10
1862	8	15
1877	36	50
1910	2	3
1922	10	12
1933	2	2
1945	19	20
1946	72	55

Table 9 Consecutive years with fire recorded at the study area. We see fire occurring in three consecutive years in two instances; from 1836 to 1838 and from 1860 to 1862. See figure 11 for fire maps to compare locations of scars.

Year	Number of Trees Scarred	Percent Scarred
1751	4	27
1752	4	24
1788	5	21
1789	2	8
1820	4	12
1821	2	6
1836	3	8
1837	3	8
1838	4	10
1844	3	7
1845	4	9
1856	2	4
1857	4	8
1860	5	10
1861	5	10
1862	8	15
1945	19	20
1946	72	55

Table 10. Fire statistics for the Stands B-E, which were generally similar to those for the whole study area, given how few fires were recorded in stands A and F.

A. Statistics Calculated with 2 Scar Filter and with 2 Scar 10% Filters. Covers Period From 1675-2007.		
	Minimum 2 Trees and 10% Scarred	Minimum 2 Trees Scarred
Number of Samples Used	120	120
Number of Fires	17	26
Mean Fire Return Interval (yrs)	14.44	9.24
Individual Mean Fire Interval (yrs)	50.5	50.5
Fire Frequency (fires/yr)	0.07	0.11
Weibull Median Fire Interval (yrs)	8.96	5.5
Weibull Fire Frequency (fires/yr)	0.11	0.18
Minimum and Maximum Fire Intervals (yrs)	1--45	1--36
Standard Deviation (yrs)	14.35	10.68

B. Statistics Calculated with 2 Scar Filter and with 2 Scar 10% Filters. Covers Period From 1785-2007.		
	Minimum 2 Trees and 10% Scarred	Minimum 2 Trees Scarred
Number of Samples Used	120	120
Number of Fires	14	23
Mean Fire Return Interval (yrs)	12.38	7.32
Individual Mean Fire Interval (yrs)	47.34	47.34
Fire Frequency (fires/yr)	0.08	0.14
Weibull Median Fire Interval (yrs)	7.61	4.81
Weibull Fire Frequency (fires/yr)	0.13	0.21
Minimum and Maximum Fire Intervals (yrs)	1--45	1--33
Standard Deviation (yrs)	13.36	7.89

Table 11. Fire years within Stands B-E for the entire fire record, 1715-2007, with all fires recorded by a minimum of 2 scars.

Fire Year	Number of Trees Scarred	Percent of Recorder Trees Scarred
1715	3	30
1751	4	33
1752	4	29
1785	3	20
1788	5	26
1789	2	10
1798	2	9
1813	5	22
1817	5	19
1820	4	14
1821	2	6
1836	3	9
1837	3	9
1838	4	12
1844	3	9
1845	4	11
1857	4	10
1860	5	11
1861	5	11
1862	12	26
1877	37	55
1910	2	3
1922	10	13
1933	2	3
1945	20	22
1946	62	53

Table 12. Monthly precipitation for 1945 and 1946 from climate stations in Caliente, Modena and the PRISM data.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PRISM Mean Precip (mm)	45.0	54.0	46.0	30.0	21.0	10.0	27.0	40.0	28.0	34.0	34.0	39.0
PRISM precip (mm)												
1945	**30.5**	**48.6**	**85.9**	**25.0**	**4.1**	**26.8**	**33.0**	**116.4**	**2.9**	**69.6**	**9.9**	**55.5**
1945 percent diff. from mean	*-32.2*	*-9.9*	*86.7*	*-16.7*	*-80.3*	*167.9*	*22.1*	*191.1*	*-89.8*	*104.7*	*-70.8*	*42.4*
1945 absolute diff. from mean	*-14.5*	*-5.4*	*39.9*	*-5.0*	*-16.9*	*16.8*	*6.0*	*76.4*	*-25.2*	*35.6*	*-24.1*	*16.5*
1946	**16.5**	**6.2**	**58.2**	**25.4**	**15.6**	**0.0**	**32.6**	**26.4**	**8.5**	**163.6**	**117.0**	**72.7**
1946 percent diff. from mean	*-63.2*	*-88.5*	*26.6*	*-15.4*	*-26.0*	*-99.9*	*20.7*	*-33.9*	*-69.6*	*381.2*	*244.1*	*86.4*
1946 absolute diff. from mean	*-28.5*	*-47.8*	*12.2*	*-4.6*	*-5.5*	*-10.0*	*5.6*	*-13.6*	*-19.5*	*129.6*	*83.0*	*33.7*
Caliente Mean Precip (mm)	21.6	22.4	26.2	18.3	14.5	9.1	19.6	24.4	17.0	21.3	18.5	17.3
Caliente Precip (mm)												
1945	**16.3**	**12.0**	**30.8**	**12.2**	**2.3**	**24.9**	**33.8**	**106.4**	**0.0**	**32.3**	**5.3**	**18.8**
1945 percent diff. from mean	*-24.6*	*-46.5*	*17.7*	*-33.2*	*-84.2*	*172.8*	*73.1*	*336.3*	*-100.0*	*51.5*	*-71.2*	*9.0*
1945 absolute diff. from mean	*-5.3*	*-10.4*	*4.6*	*-6.1*	*-12.2*	*15.8*	*14.3*	*82.0*	*-17.0*	*11.0*	*-13.2*	*1.6*
1946	**8.9**	**3.6**	**48.6**	**9.7**	**11.2**	**0.0**	**22.9**	**6.9**	**1.8**	**109.2**	**60.1**	**31.8**
1946 percent diff. from mean	*-58.7*	*-84.1*	*85.8*	*-47.1*	*-22.7*	*-100.0*	*17.1*	*-71.8*	*-89.5*	*411.7*	*223.9*	*84.2*
1946 absolute diff. from mean	*-12.7*	*-18.8*	*22.4*	*-8.6*	*-3.3*	*-9.1*	*3.3*	*-17.5*	*-15.2*	*87.8*	*41.5*	*14.5*
Modena Mean Precip (mm)	20.3	22.4	25.7	20.1	17.8	9.9	26.9	34.8	22.6	25.9	17.5	16.8
Modena Precip (mm)												
1945	**23.4**	**13.2**	**45.8**	**13.2**	**1.3**	**36.6**	**12.2**	**86.3**	**0.5**	**40.0**	**1.5**	**18.8**
1945 percent diff. from mean	*15.2*	*-40.8*	*78.6*	*-34.0*	*-92.8*	*270.0*	*-54.6*	*147.9*	*-97.7*	*54.2*	*-91.3*	*12.3*
1945 absolute diff. from mean	*3.1*	*-9.1*	*20.2*	*-6.8*	*-16.5*	*26.7*	*-14.7*	*51.5*	*-22.1*	*14.0*	*-16.0*	*2.1*
1946	**1.5**	**4.3**	**24.9**	**19.6**	**7.9**	**0.0**	**37.9**	**43.3**	**14.3**	**150.4**	**58.5**	**27.2**
1946 percent diff. from mean	*-92.5*	*-80.6*	*-2.8*	*-2.3*	*-55.6*	*-100.0*	*40.8*	*24.3*	*-37.0*	*480.6*	*234.0*	*62.4*
1946 absolute diff. from mean	*-18.8*	*-18.0*	*-0.7*	*-0.5*	*-9.9*	*-9.9*	*11.0*	*8.5*	*-8.4*	*124.5*	*41.0*	*10.5*

Table 13. Fire statistics for the Mount Irish study area. Notice that the record going to 2006 includes only 2 more fire events than the record that stops in 1860.

A. Mount Irish Fire Statistics for Period From 1550-2006. Fire Dates Required a Minimum of Two Scars Confirming Date	
Number of Samples	175
Number of Fires	75
Mean Fire Return Interval (yrs)	4.64
Individual Mean Fire Interval (yrs)	52.51
Fire Frequency (fires/yr)	0.22
Weibull Median Fire Interval (yrs)	3.19
Weibull Fire Frequency (fires/yr)	0.31
Minimum and Maximum Intervals (yrs)	1--33
Standard Deviation (yrs)	5.65

B. Mount Irish Fire Statistics for Period From 1550-1860. Which Represents the Period within the HRV for Mt. Irish. Fire Dates Required a Minimum of Two Scars Confirming Date	
Number of Samples	175
Number of Fires	73
Mean Fire Return Interval (yrs)	3.99
Individual Mean Fire Interval (yrs)	49.22
Fire Frequency (fires/yr)	0.25
Weibull Median Fire Interval (yrs)	3
Weibull Fire Frequency (fires/yr)	0.33
Minimum and Maximum Intervals (yrs)	1--19
Standard Deviation (yrs)	4.03

Table 14. Fire years for Mount Irish from 1550 to 2006. Compared to the Clover Mountains we see less fire dates after 1860, especially in the 20th century. The Clover Mountains also have more fire events with greater than 10% percent scarred.

Year	Total Scars	Percent Scarred
1573	3	17
1592	2	10
1604	2	8
1618	2	8
1619	2	7
1621	2	7
1623	3	9
1624	2	6
1630	4	12
1634	2	6
1649	2	5
1650	2	5
1662	3	7
1673	5	11
1676	4	9
1685	2	4
1688	2	4
1689	2	4
1704	2	4
1713	6	11
1714	4	7
1715	2	3
1716	4	6
1722	4	6
1728	2	3
1731	2	3
1733	4	5
1738	6	8
1739	2	3
1740	2	3
1742	4	5
1743	3	4
1745	4	5
1747	2	2
1751	3	3
1759	4	4
1765	6	6
1767	3	3

Year	Total Scars	Percent Scarred
1770	6	6
1775	3	3
1777	3	3
1778	3	3
1780	9	8
1781	3	3
1788	9	8
1789	4	4
1791	4	4
1792	4	4
1794	4	3
1795	3	3
1798	3	3
1802	4	3
1809	2	2
1810	2	2
1818	5	4
1819	3	3
1820	8	7
1821	2	2
1824	10	8
1825	6	5
1827	4	3
1833	2	2
1835	2	2
1836	20	15
1837	6	4
1838	2	1
1841	2	1
1847	2	1
1851	4	3
1854	2	1
1855	2	1
1859	7	4
1860	6	4
1883	2	1
1916	2	1

Table 15. Fire statistics for Stands B, C, and D at the Clover Mountains calculated using the 1785-2007 period.

	Minimum 2 Trees and 10% Scarred	Minimum 2 Trees Scarred
Number of Samples Used	95	95
Number of Fires	16	17
Mean Fire Return Interval (yrs)	14.44	13.59
Individual Mean Fire Interval (yrs)	50.07	50.07
Fire Frequency (fires/yr)	0.07	0.07
Weibull Median Fire Interval (yrs)	8.26	8.37
Weibull Fire Frequency (fires/yr)	0.12	0.12
Minimum and Maximum Fire Intervals (yrs)	1--45	1--37
Standard Deviation (yrs)	15.09	13.28

Table 16. Fire statistics for each ponderosa stand/fireshed at Mount Irish.

	Ponderosa Narrows	North/East	South/East	Central Valley
Number of Samples	27	77	28	36
Number of Fires	67	144	52	61
Mean Fire Return Interval (yrs)	17.5	8.85	21.38	34.75
Fire Frequency (fires/yr)	0.06	0.11	0.05	0.03
Weibull Median Fire Interval (yrs)	10.94	5.98	19.46	20.26
Minimum and Maximum Intervals (yrs)	1--51	1--43	5--47	1--149

Table 17. Fire statistics for each Clover Mountains stand when using no restriction filters for fire dates. When compared to table 5 we see a decrease in MFRI, indicating either small one tree fires that are unrecorded or fires that failed to scar multiple trees. Note that the IMFI does not change because it is calculated from an average of each trees fire record.

Fire Statistics by Stand for whole Fire Study Area for the entire fire record, 1675-2007. A single tree was required to record a fire						
	Stand A	Stand B	Stand C	Stand D	Stand E	Stand F
Number of Samples Used	13	29	28	38	25	6
Number of Fires	10	18	13	15	39	12
Mean Fire Return Interval (yrs)	20.33	19.71	18.33	17.86	9.63	26.45
Individual Mean Fire Interval (yrs)	50.67	50.97	58.17	40.87	46.46	41.83
Fire Frequency (fires/yr)	0.05	0.05	0.05	0.06	0.1	0.04
Weibull Median Fire Interval (yrs)	16.49	13.93	12.32	14.21	7.28	21.28
Weibull Fire Frequency (fires/yr)	0.06	0.07	0.08	0.07	0.14	0.05
Minimum and Maximum Fire Intervals (yrs)	6--68	1--67	1--44	1--36	1--32	2--68
Standard Deviation (yrs)	19.86	18.05	15.59	12.79	8.51	21.73

Table 18. Fire years for each stand going as far back as scars were recorded by the samples. Stand E records more fire dates than the other sites. Unconfirmed fire dates are not included.

Fire Dates by Stand for the whole Clover Mountains study area, covering the period from 1500 to 2007. A single tree required to record a fire						
	Stand A	Stand B	Stand C	Stand D	Stand E	Stand F
Fire Dates	1763	1611	1751	1724	1613	1665
	1780	1678	1795	1751	1617	1675
	1815	1703	1820	1776	1626	1698
	1827	1715	1821	1788	1653	1712
	1833	1764	1860	1821	1654	1724
	1845	1789	1861	1823	1666	1792
	1856	1790	1877	1857	1669	1801
	1872	1817	1898	1861	1681	1851
	1940	1838	1908	1877	1686	1865
	1946	1844	1945	1913	1697	1867
		1845	1946	1922	1698	1905
		1860		1942	1707	1956
		1870		1945	1715	
		1877		1946	1723	
		1903		1950	1733	
		1910			1751	
		1945			1752	
		1946			1773	
					1778	
					1785	
					1788	
					1798	
					1813	
					1820	
					1822	
					1836	
					1837	
					1838	
					1856	
					1861	
					1862	
					1869	
					1875	
					1907	
					1932	
					1933	
					1936	
					1967	
					1979	

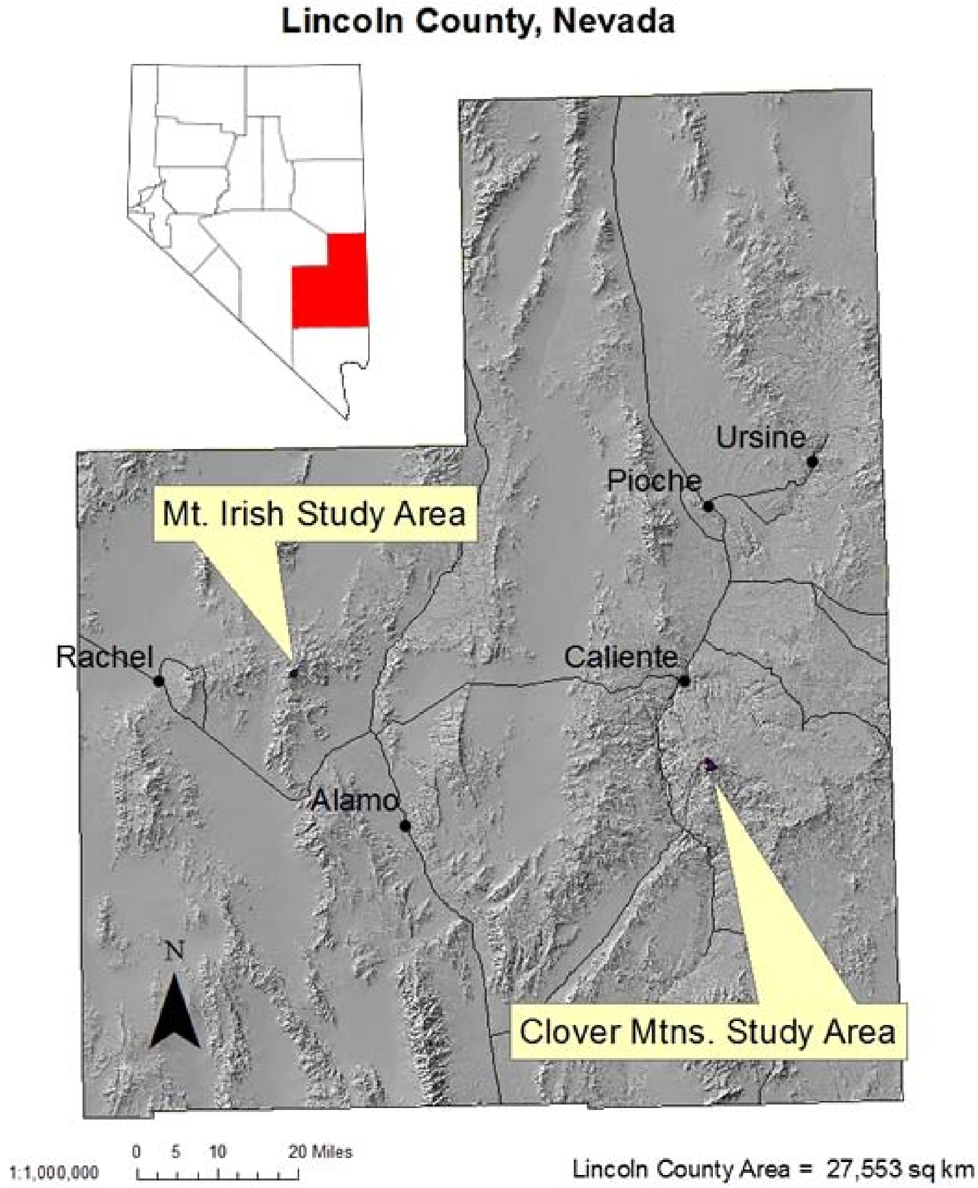


Figure 1. Map of Lincoln County Nevada showing locations of both the Clover Mountains and Mt. Irish study sites.

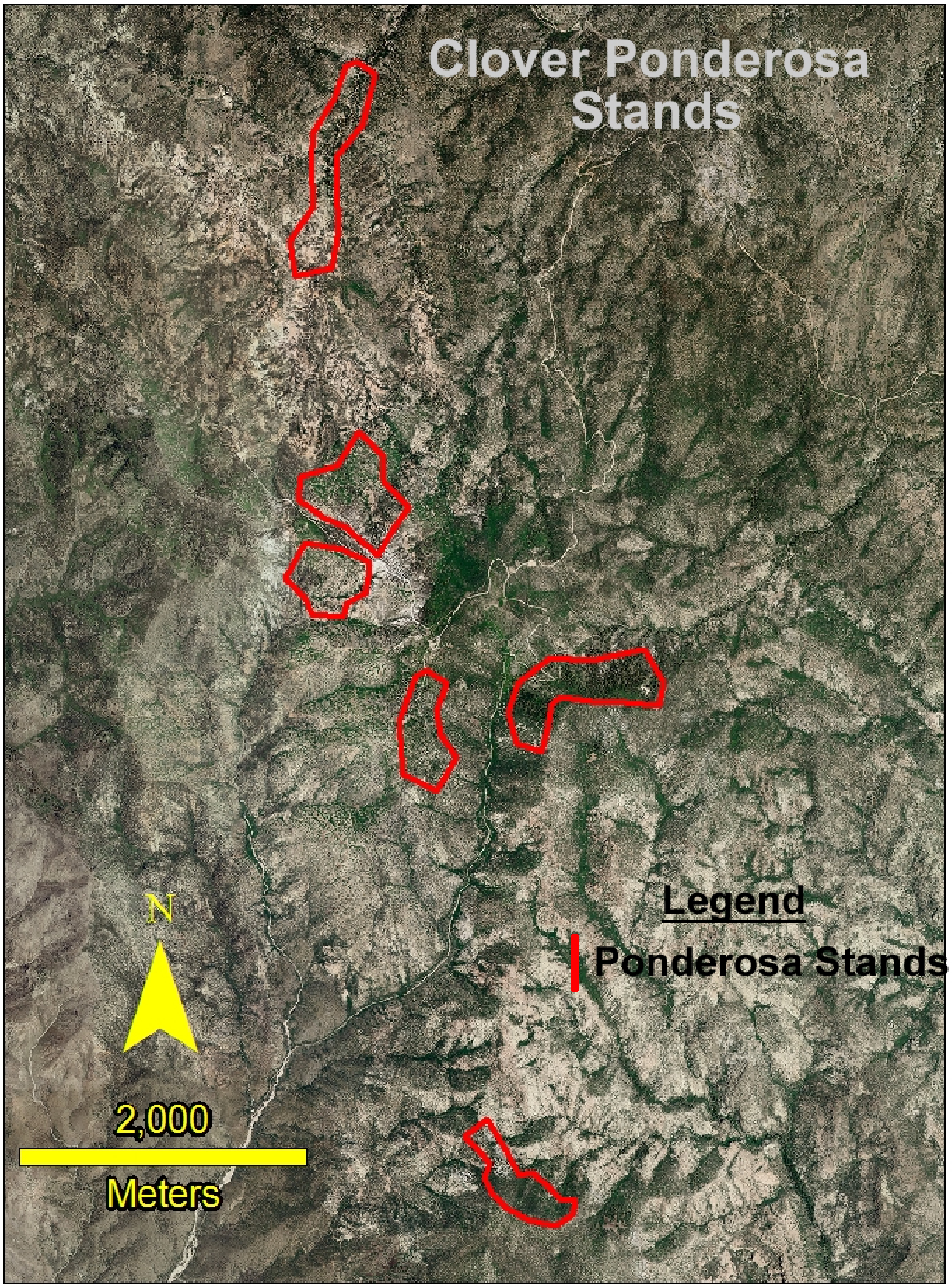


Figure 2. Map of Clover Mountains study area viewed with NAIP imagery. Sampled ponderosa stands are outlined in red.

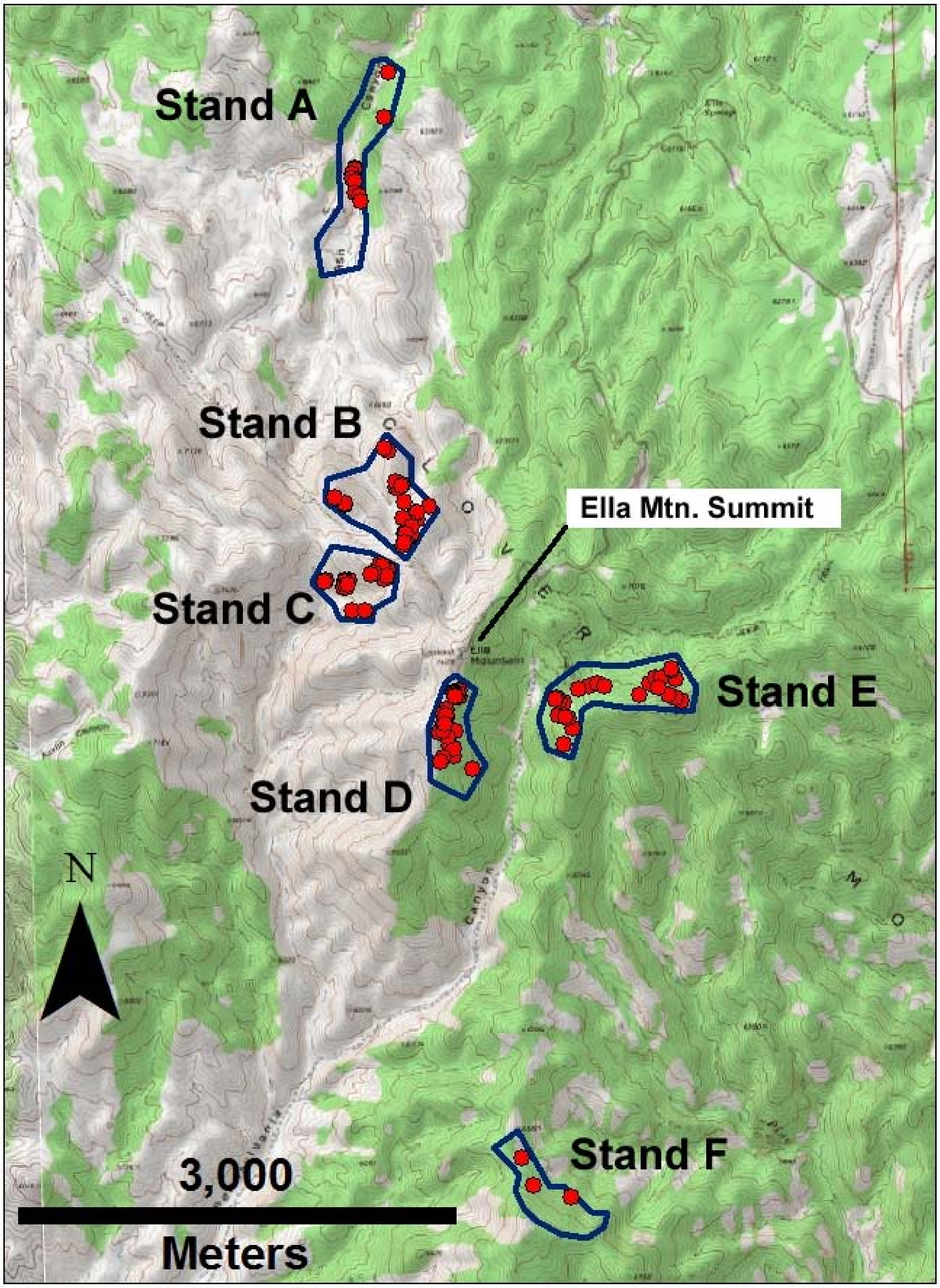


Figure 3. Map of Clover Mountains stand locations. Stands are outlined in blue. Fire scar sample locations are signified by red dots.

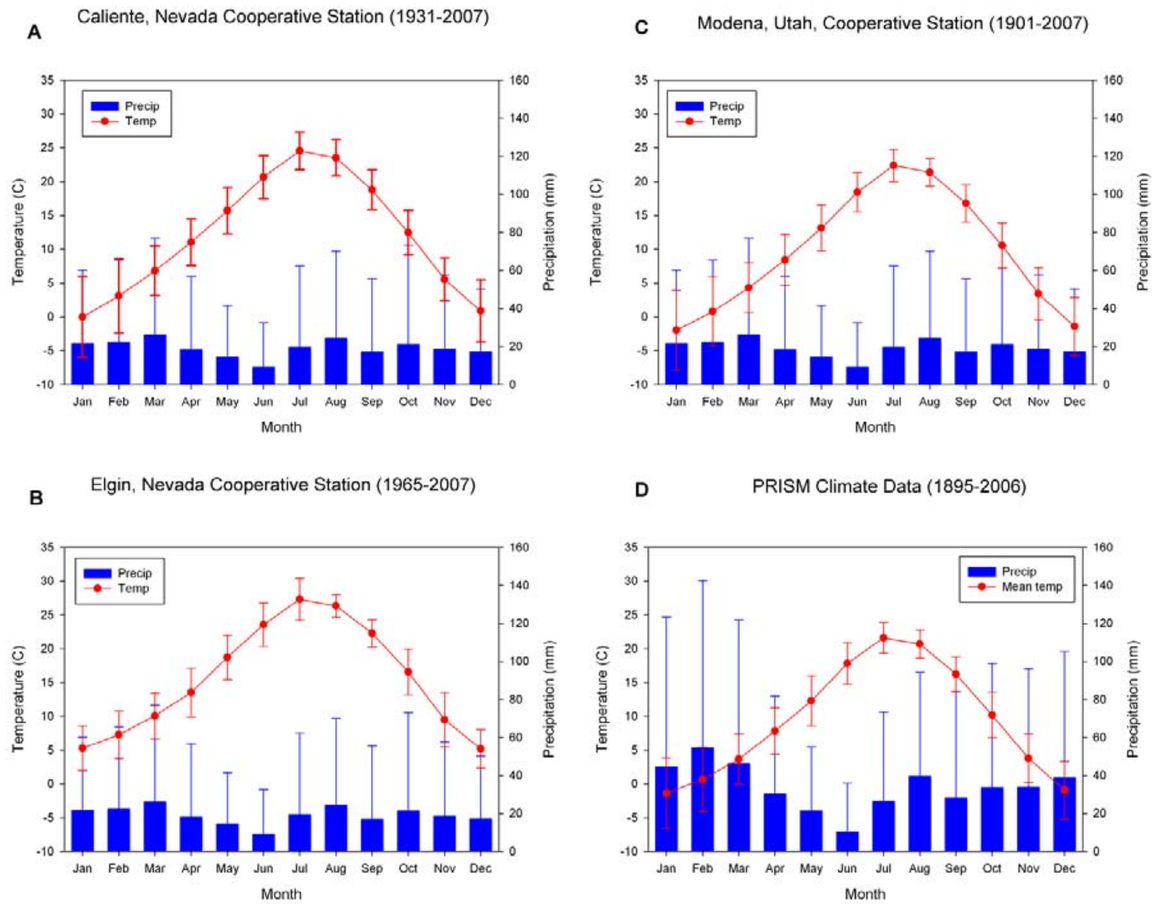


Figure 4. Mean monthly temperature and total precipitation values from climate stations in Caliente, NV (A), Elgin, NV (B), and Modena, UT (C) together with those from PRISM data (D) for the four grid cells containing the Clover Mountains study area. Locations are shown in Figure 5.

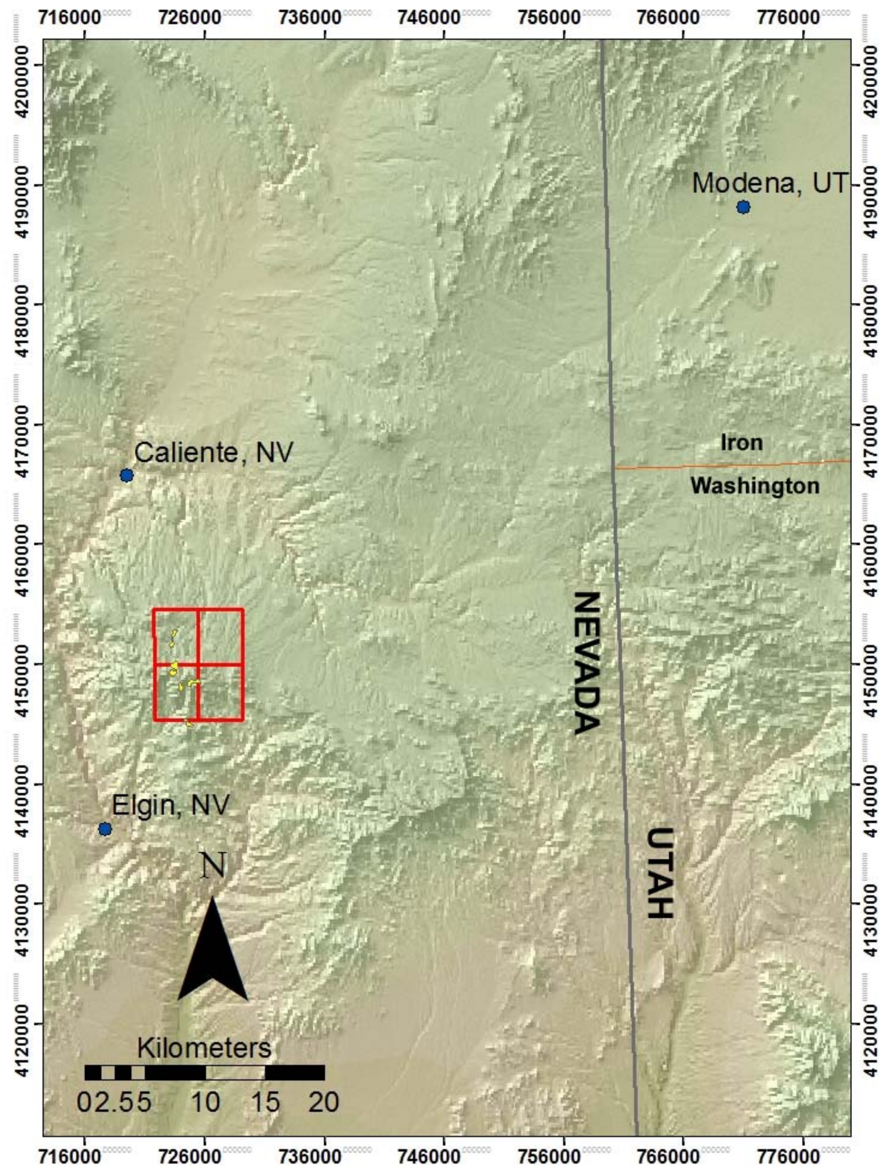


Figure 5. Map of Climate station and PRISM cell locations. Climate station locations are represented by blue dots, with station names. PRISM cells are represented by the red outlines. The UTM coordinates grid (Zone 11S) is shown along the map borders.

Figure 6. Picture of a typical fire scar (‘catface’) from the Clover Mountains. The specimen has multiple fire scars (arrows).

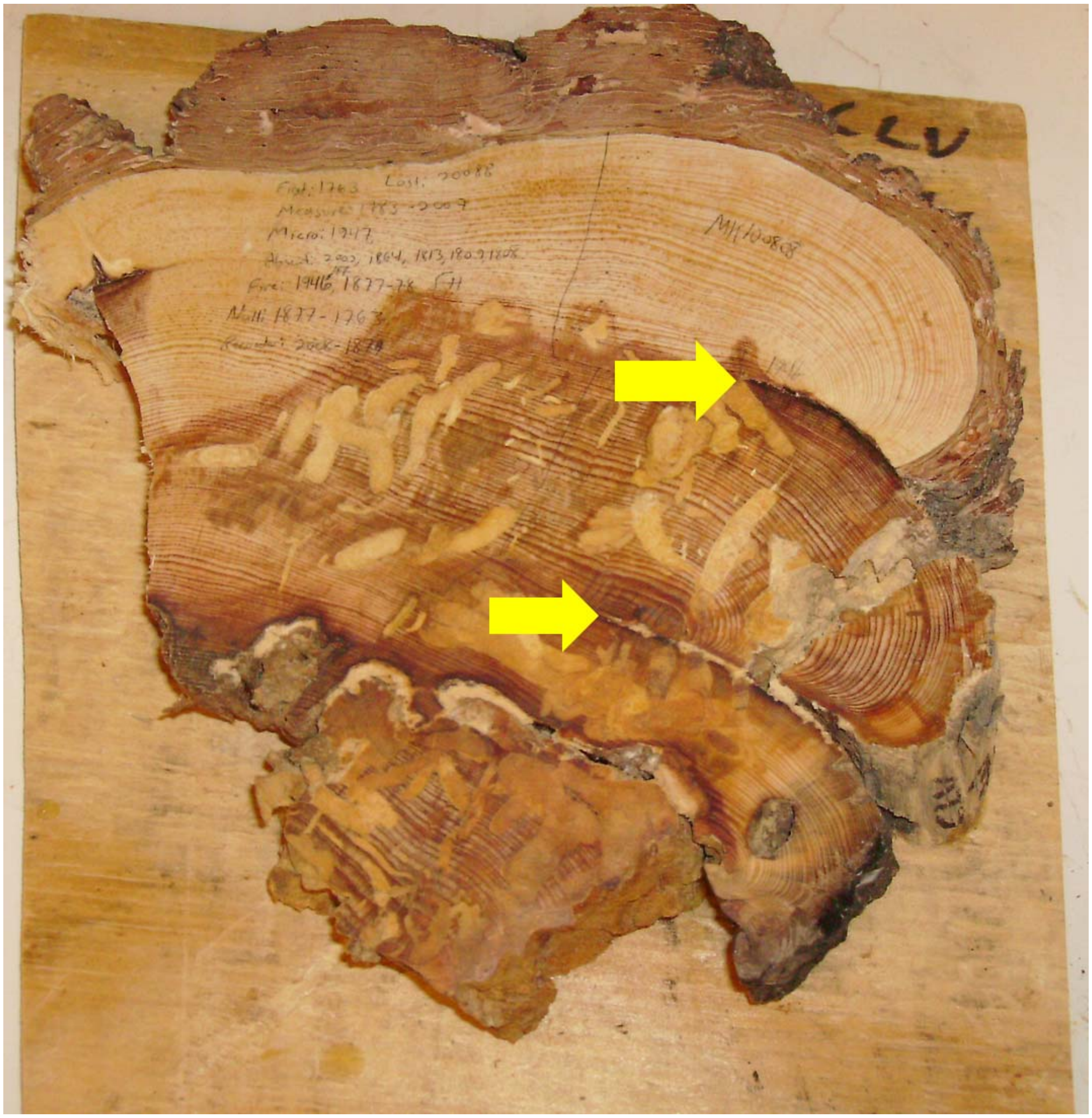


Figure 7. A typical fire scar wedge sample from the Clover Mountains. Two fire scars (arrows) are clearly visible.

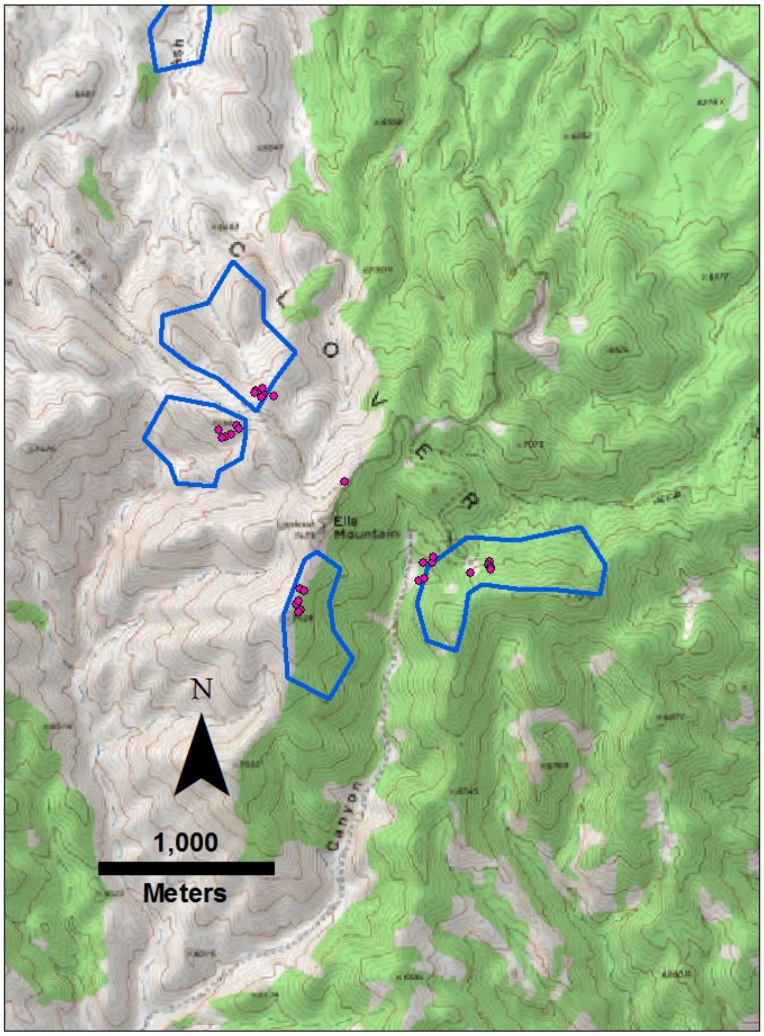


Figure 8. Map showing the locations of trees sampled (n=26) for master chronology. The magenta dots represent the location of the sampled trees. All samples for this chronology were taken from ponderosa pine.

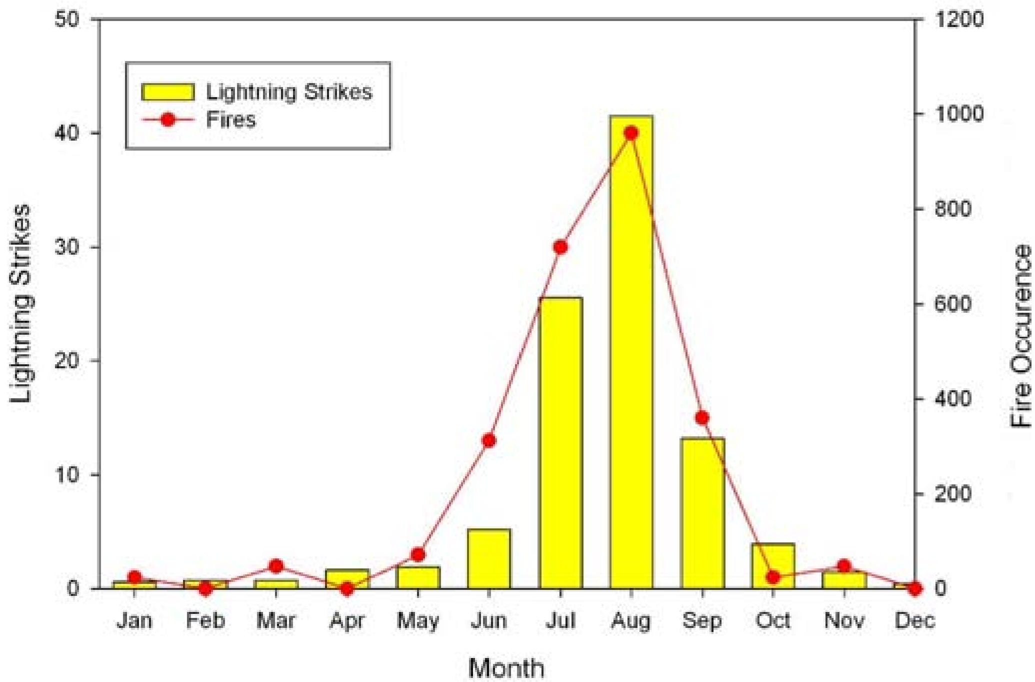


Figure 9. Monthly lightning strikes (2328 total) (Vaisala Inc., 2007) and fire starts (107 total) from a 75km² area around the Clover Mountains. Lightning strike data spans the period from 1990 until 2007. Fire start data is from 1980 until 2004. Peak lightning (995) and fire occurrences (40) are in August.

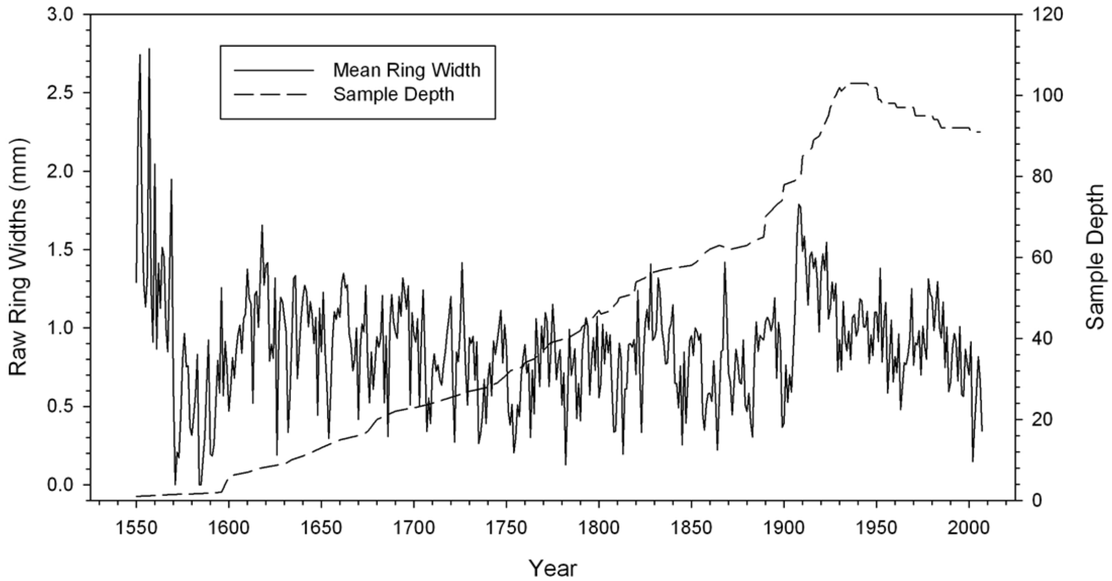


Figure 10. Line graph showing mean annual ring widths for the Clover Mountains fire scar wedge samples. The overall mean of the time series (1550-2007) is 0.89 mm. Number of samples is indicated by the dashed line.

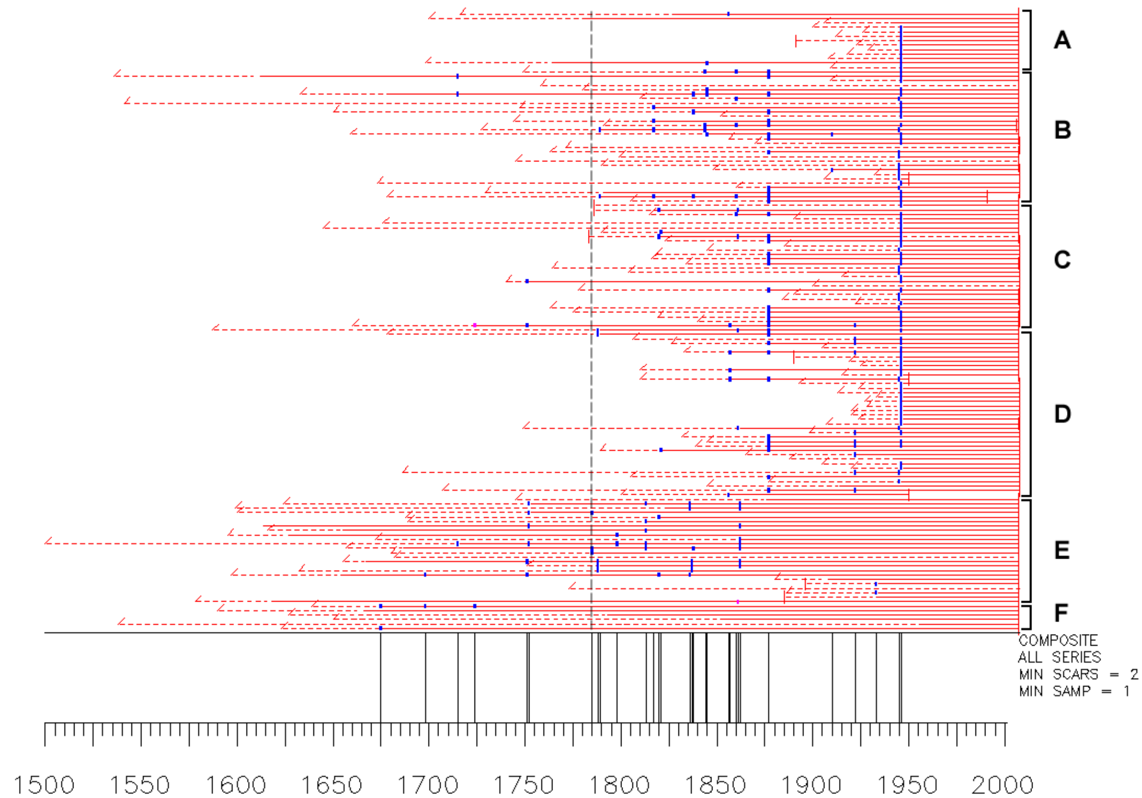


Figure 11. Summary of Clover Mountains fire dates for the entire fire study area. Each individual sample is represented by a horizontal red line on the Y-axis. Fire dates are indicated by vertical blue lines, and the composite shows fire dates that were only assigned when at least two trees had a scar in that year. Samples are grouped by stand, with each stand being shown by a capital letter on the Y-axis. The first fire occurs in 1675, the last occurs in 1946; at least 20 were present since 1785 (dashed vertical line).

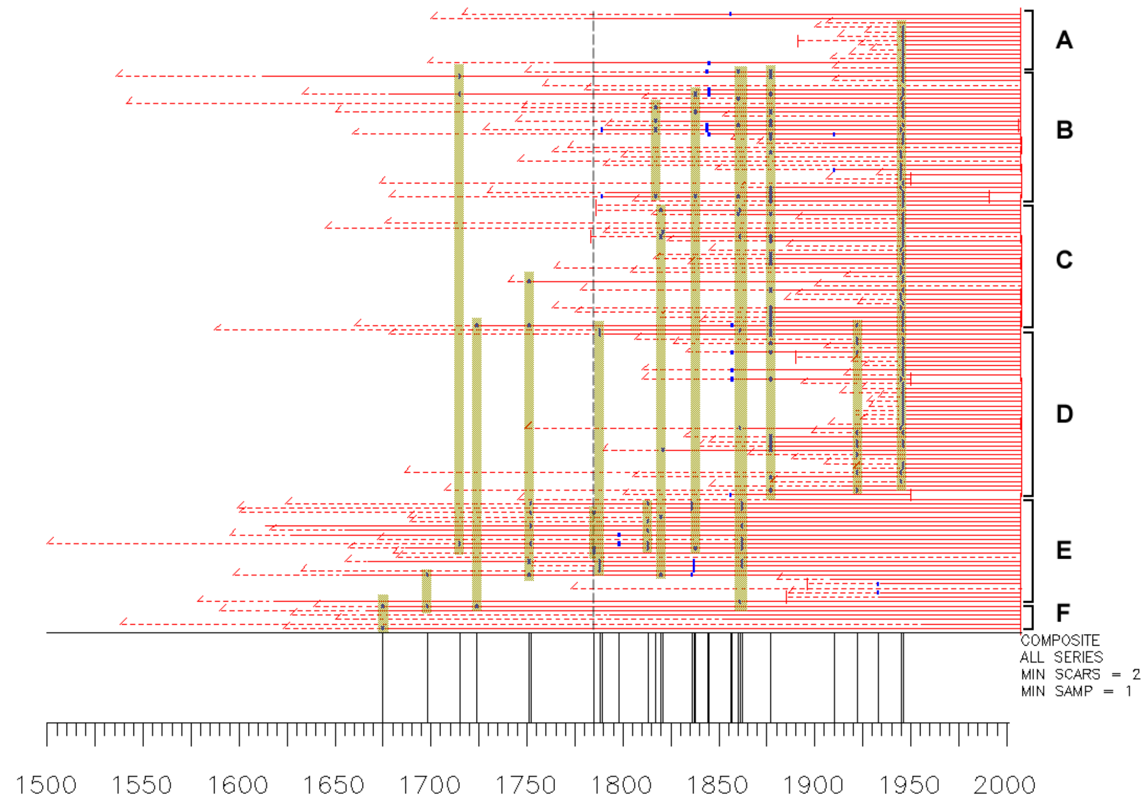


Figure 12. Summary of fire dates for the entire fire study area (see figure 9 for symbol explanation). Fire events that scarred greater than 10% of recorder trees are highlighted by the translucent vertical brown bars.

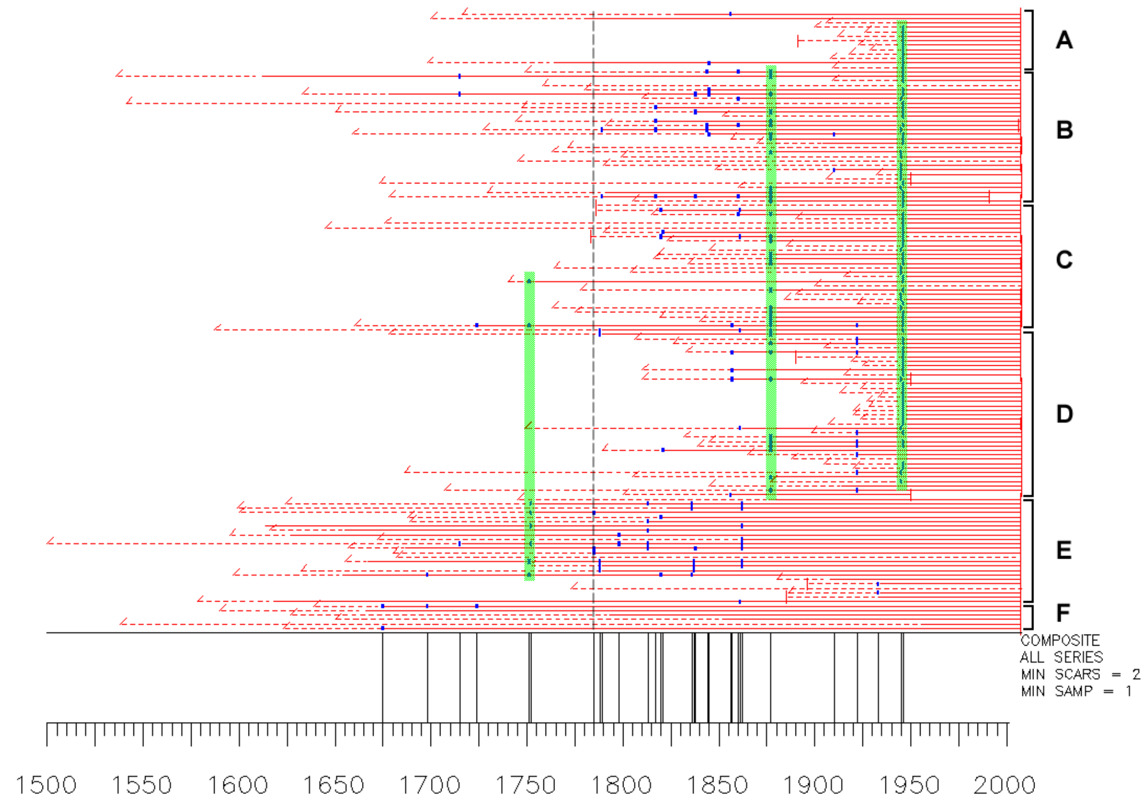
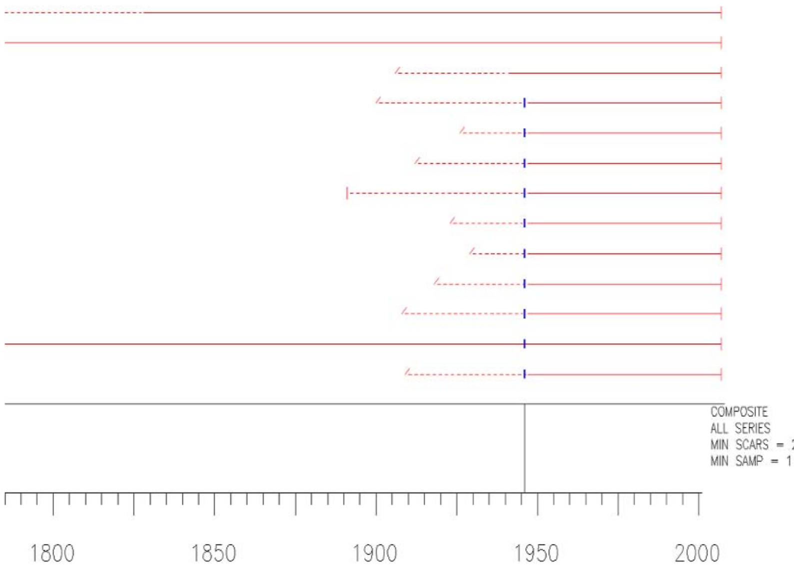


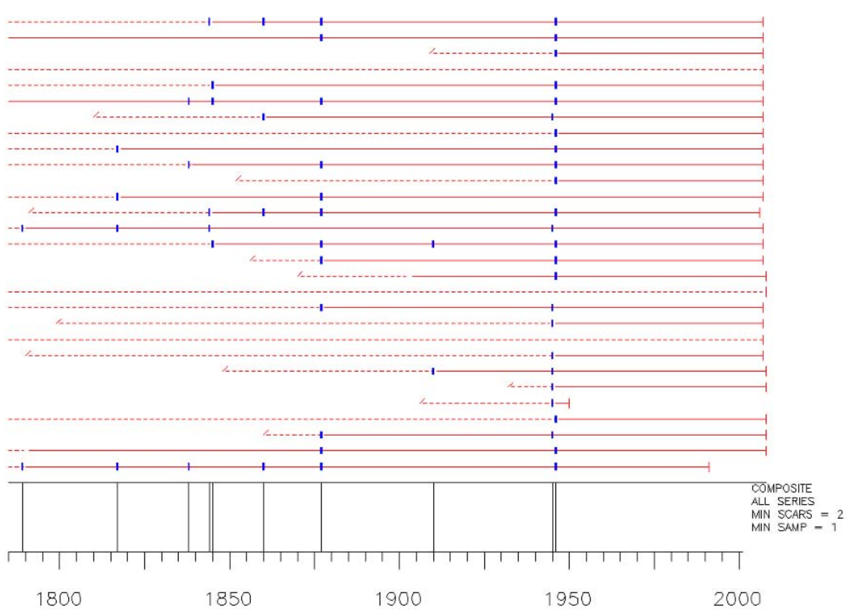
Figure 13. Summary of fire dates for the entire fire study area (see figure 9 for symbol explanation). Fire events that scarred greater than 25% of recorder trees are highlighted by the translucent vertical green bars. Worth noting is that 1877 and 1946 fire events burn extensively in stands A, B, C, and D but do not scar any specimens in E or F.

Figure 14.

Summary of fire events for each stand, during 1785-2007. Fire events are included if recorded by more than 2 trees in that stand. Vertical blue lines represent fire dates, while horizontal red lines represent each sample.

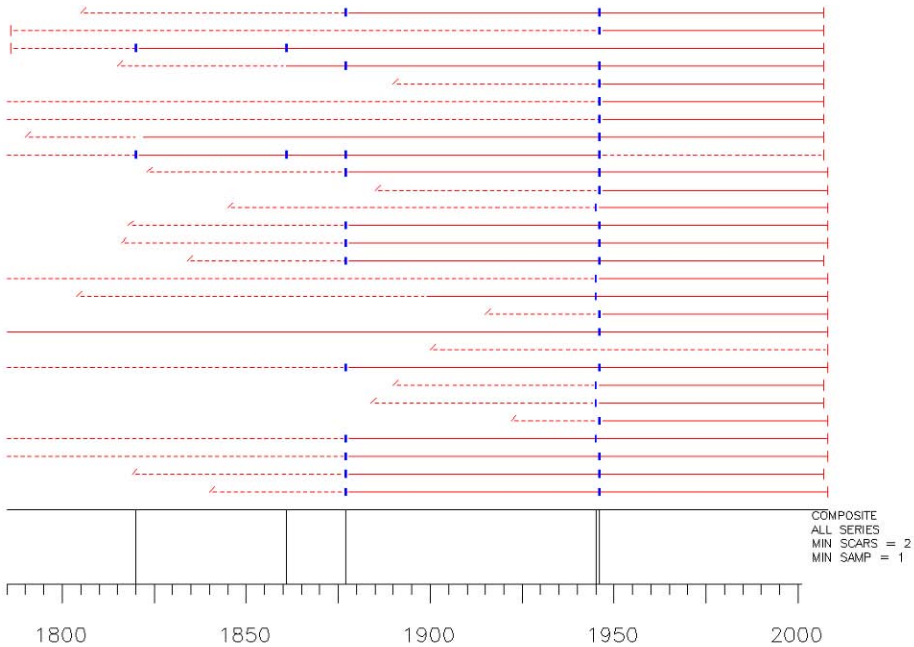


Stand A. 1946 is the only event in this stand that scarred more than 2 trees.

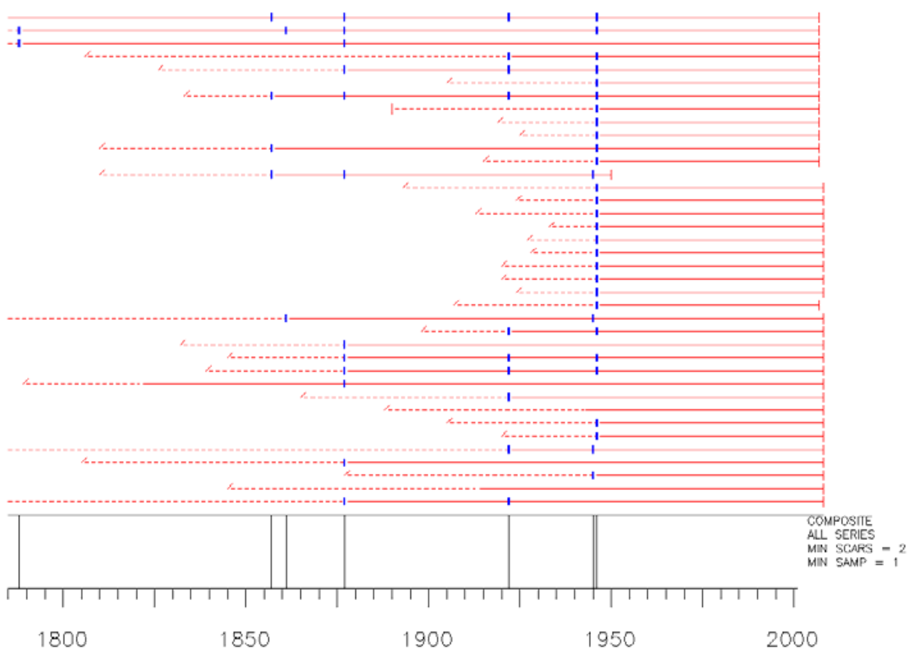


Stand B. Fires dates recorded in this stand range from 1789 to 1946.

Figure 14 continued

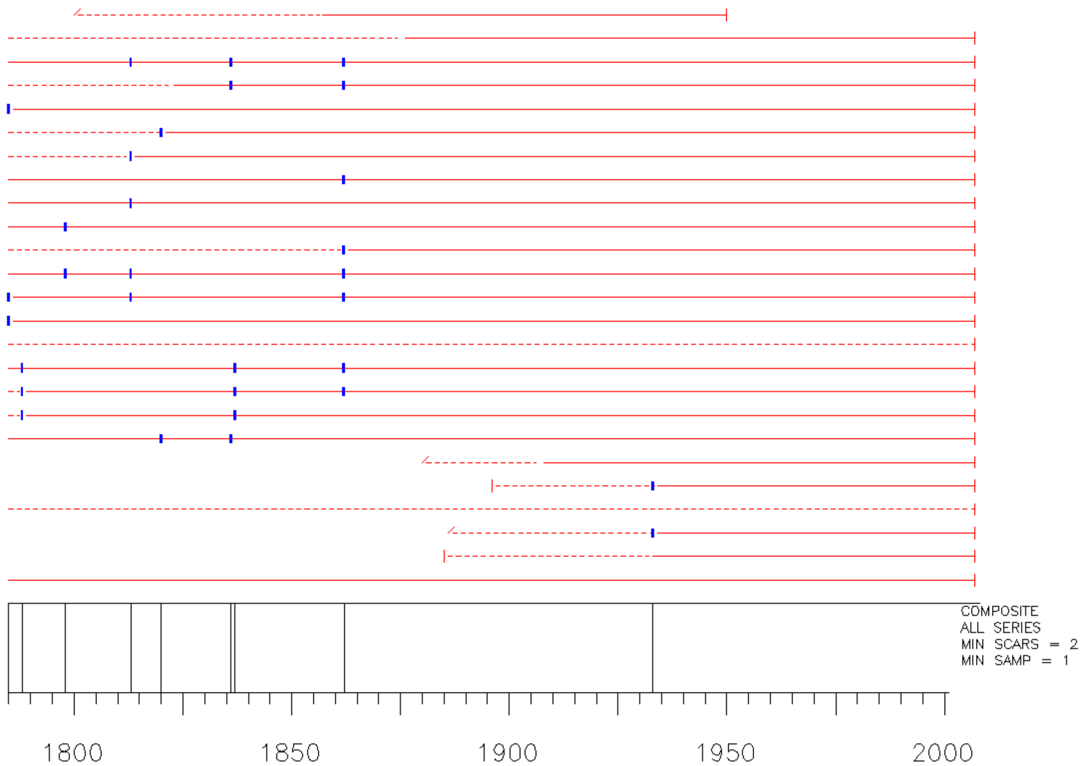


Stand C. Fire dates range from 1820 to 1946.



Stand D. Fires dates range from 1788 to 1946.

Figure 14 continued.



Stand E. Fire dates range from 1785 to 1933.

Stand F. Did not record any fire events.

A. 1675 - 1752

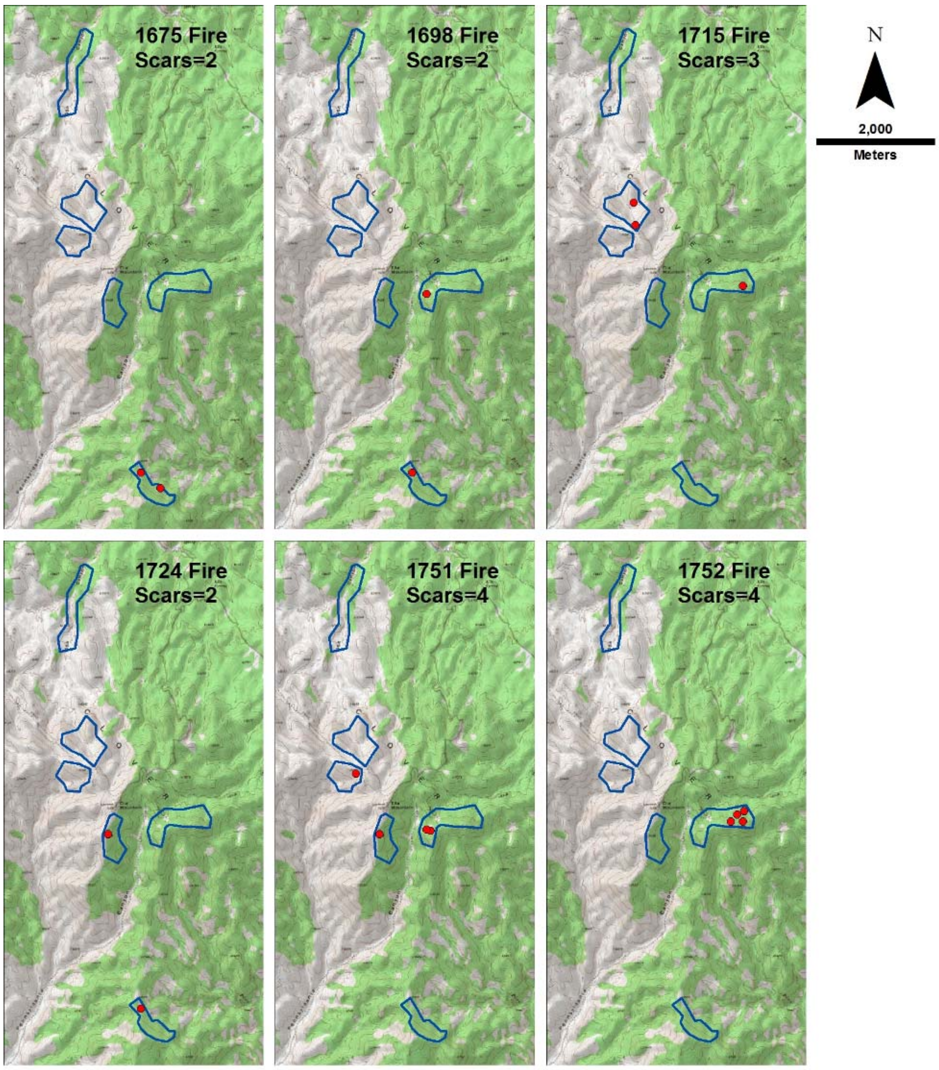


Figure 15. Maps of fire events in chronological sequence showing 6 fires per page, with number of trees scarred. Fire scar locations are shown in red, stand outlines are shown in blue.

Figure 15 continued.

B. 1785 - 1817

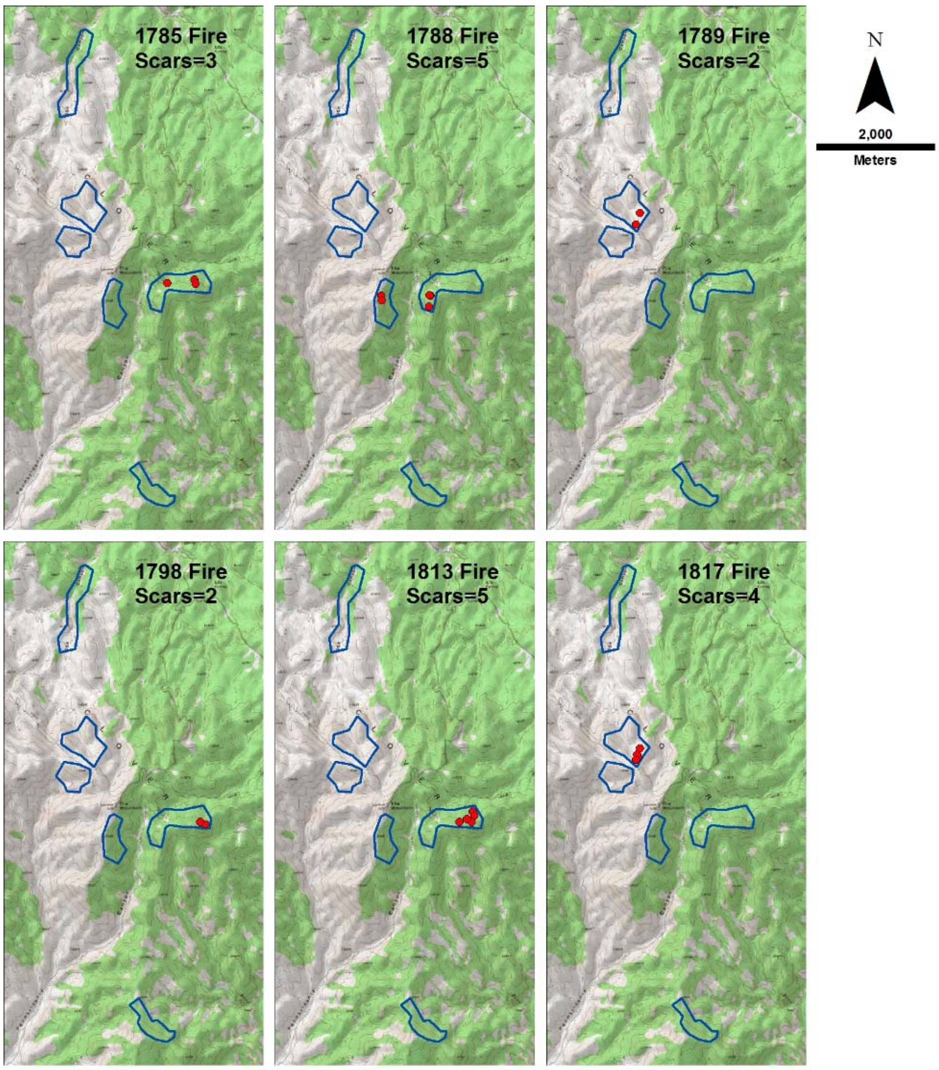


Figure 15 continued.

C. 1820 - 1844

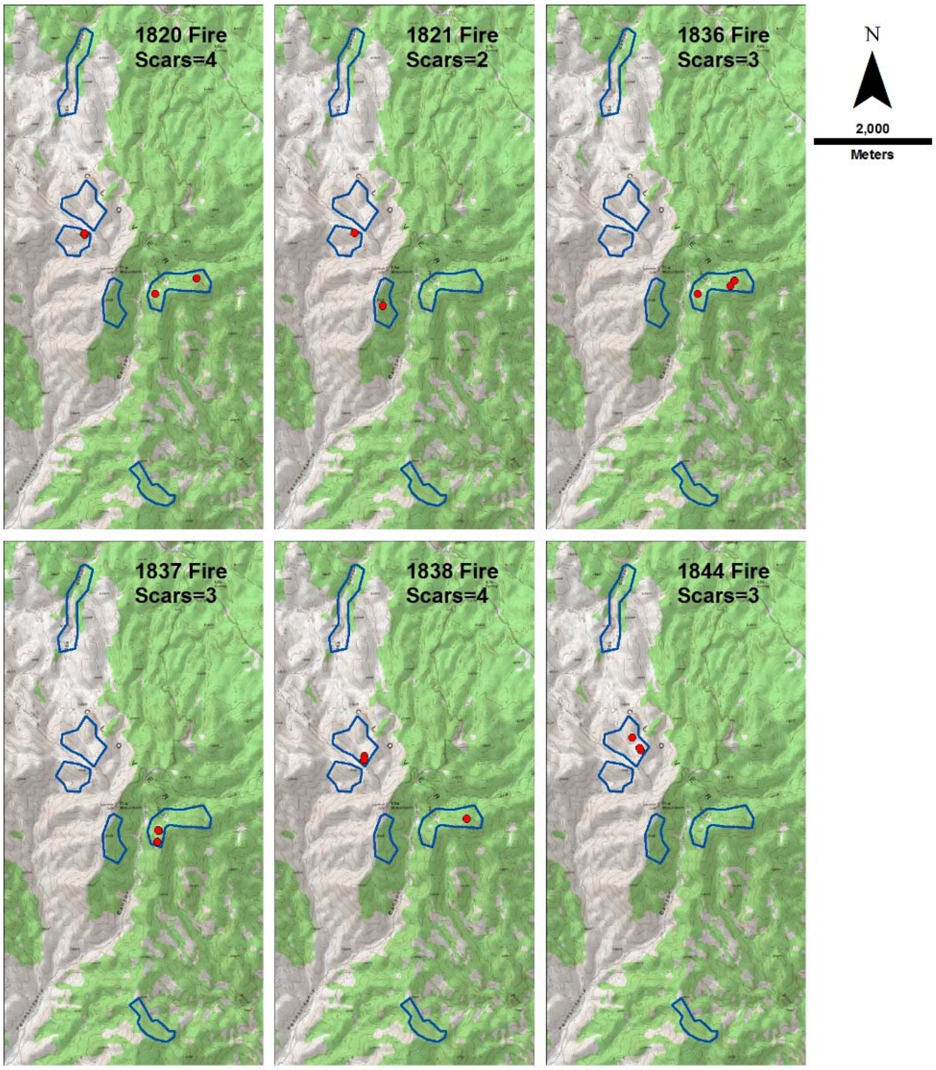


Figure 15 continued.

D. 1845 - 1862

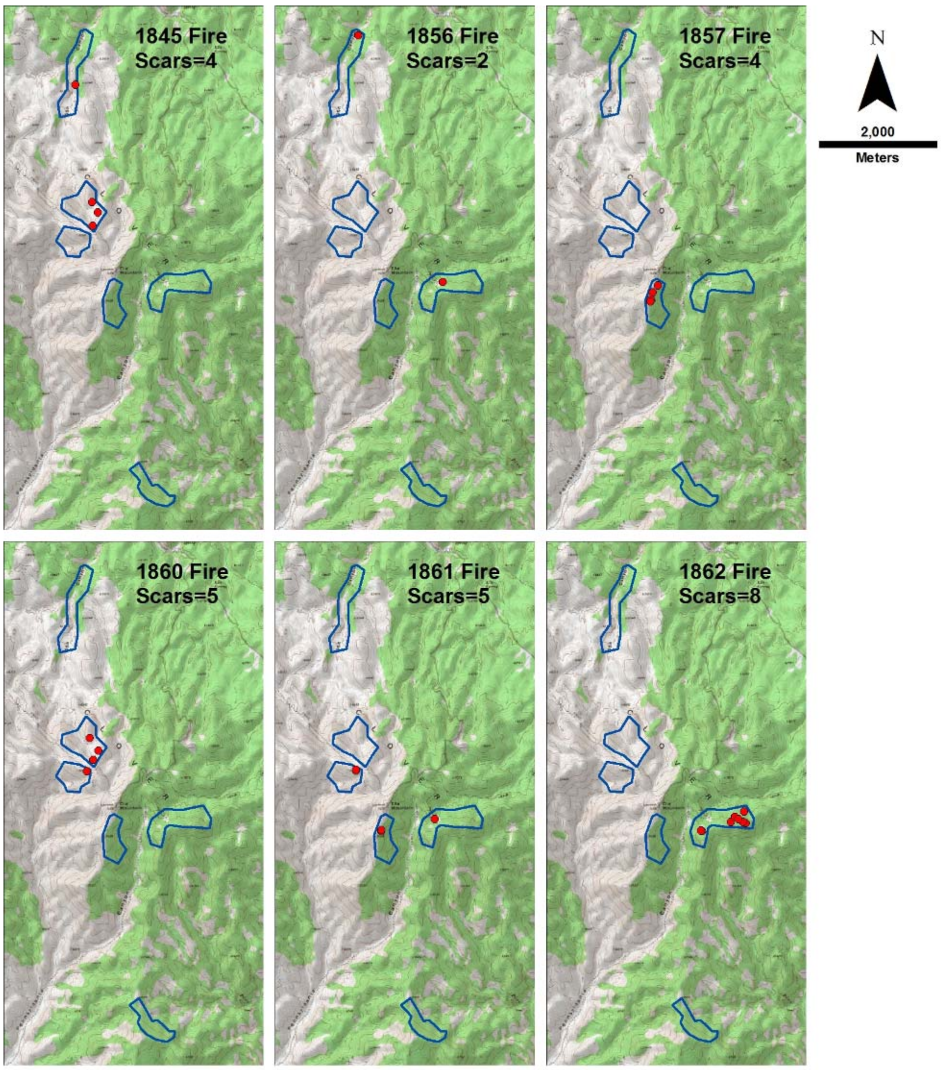
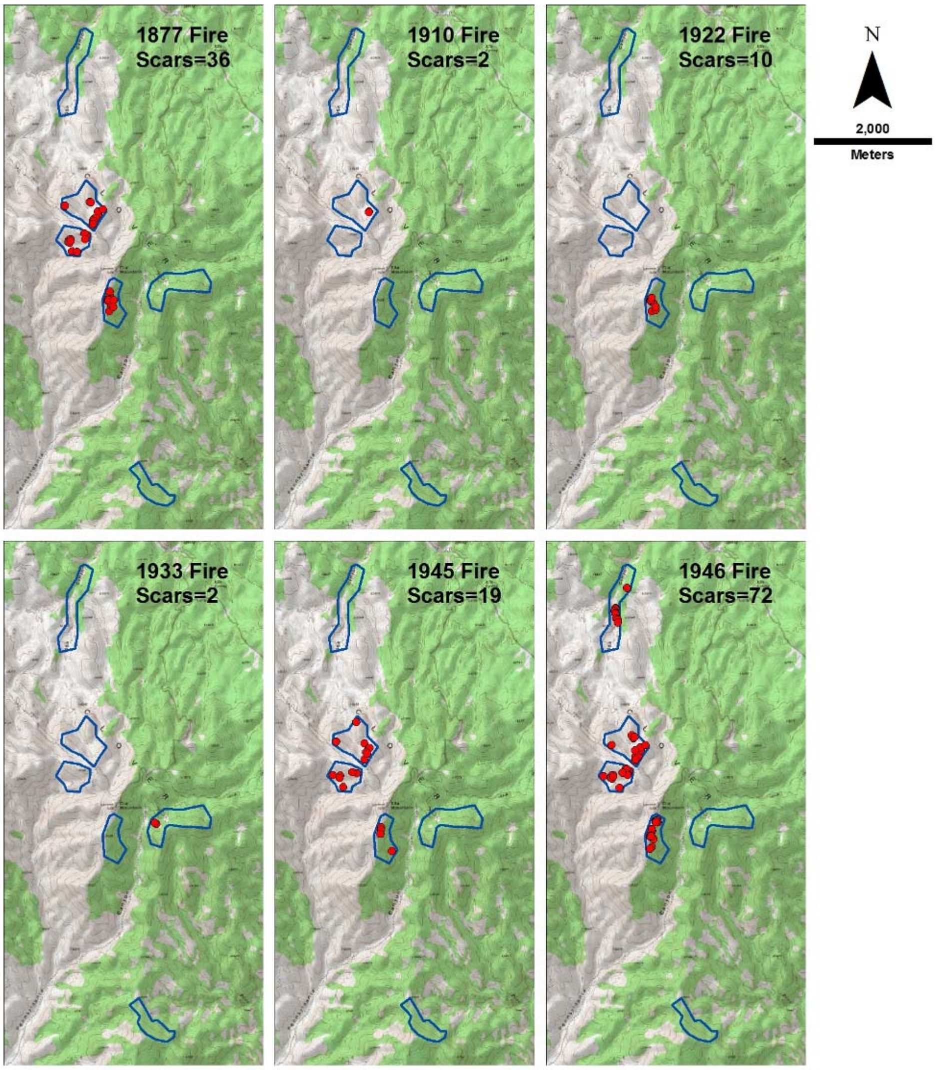


Figure 15 continued.

E. 1877 - 1946



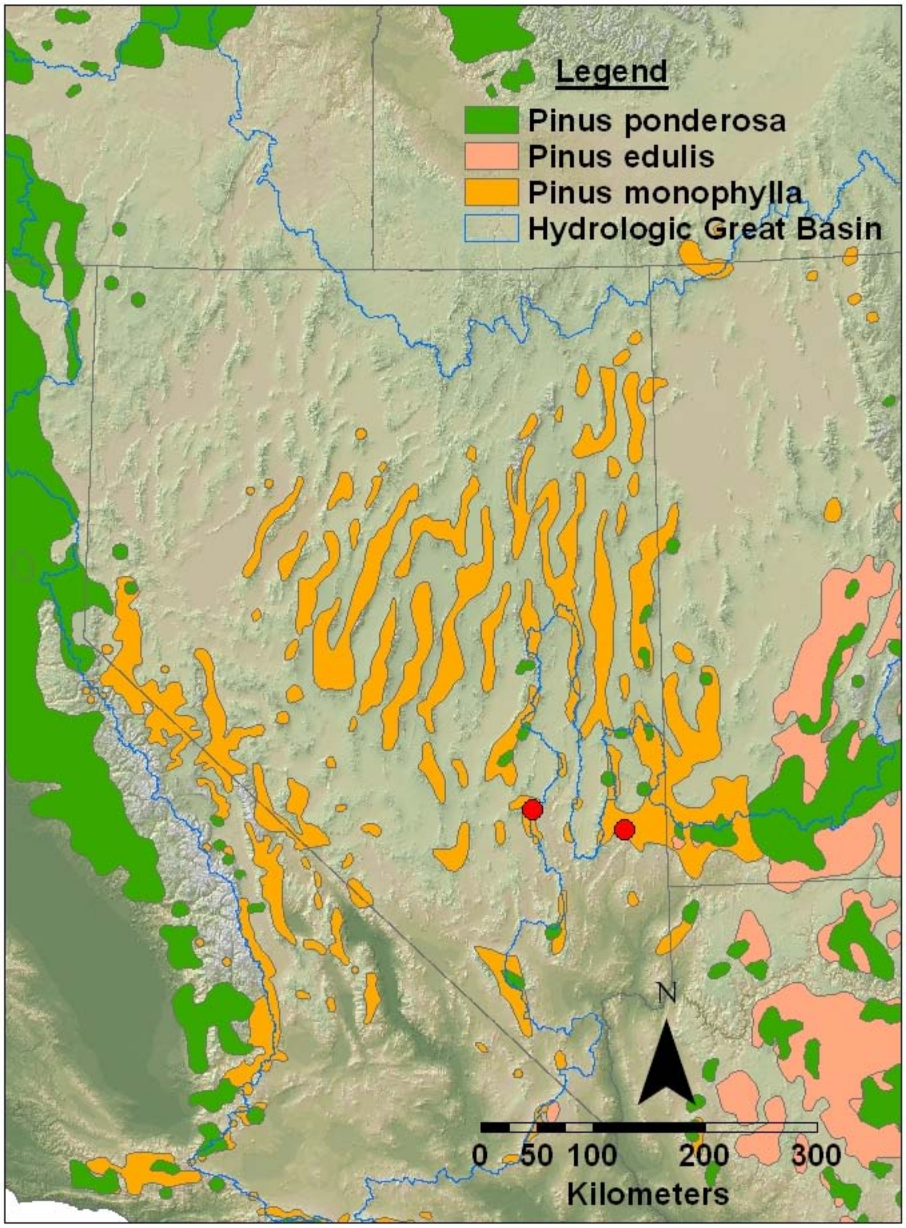


Figure 16. Regional scale distribution of Ponderosa, Single-leaf pinyon and Two-leaf pinyon pine stands.

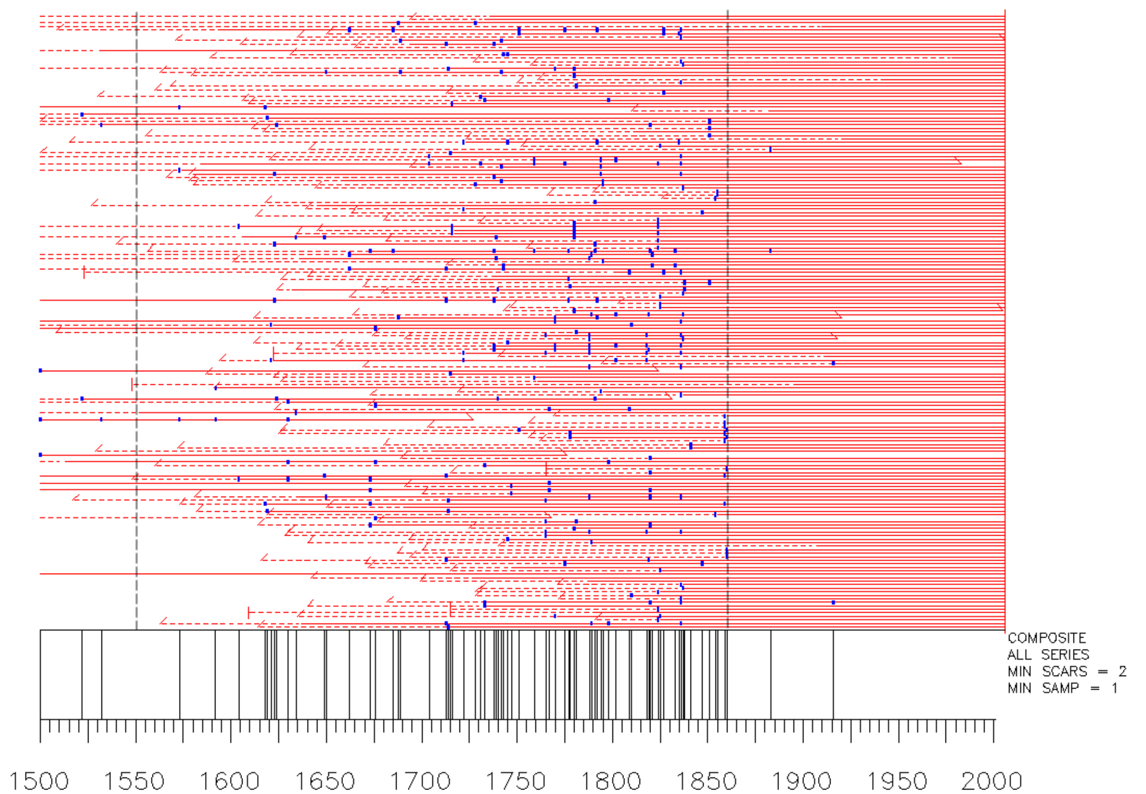


Figure 17. Summary of Mt. Irish fire dates. Horizontal red lines represent individual samples. Vertical blue lines represent fire dates, and the composite shows fire dates that were assigned only when at least two trees had scars in that year. The left vertical dashed indicates the start of the fire analysis period at Mount Irish in 1550, when 20 recorder trees were present. The right vertical dashed line indicates the time when Mount Irish left its historic range of variability with the substantial reduction in fire.
Note that there are more fires overall at Mount Irish than the Clover Mountains; however the individual fires generally scar fewer trees.

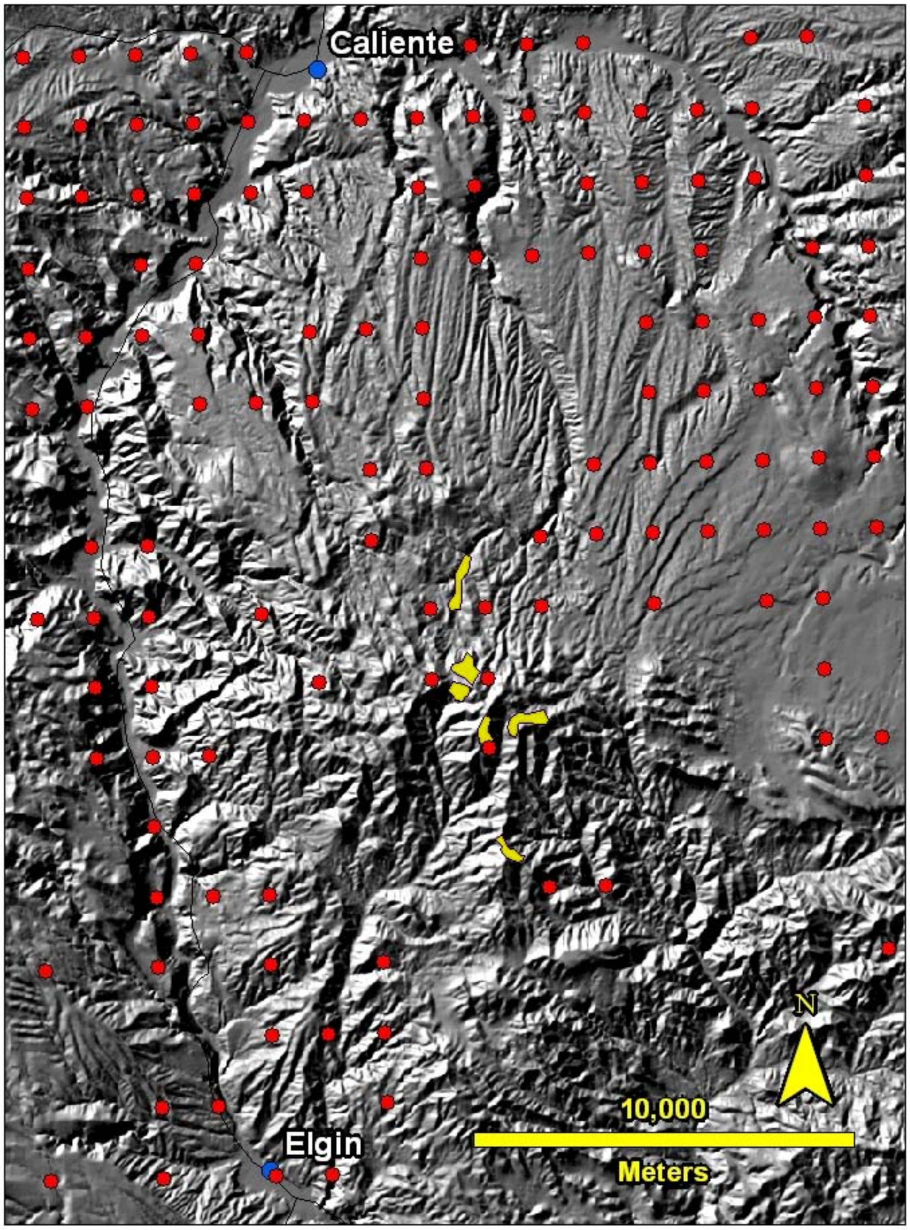


Figure 18. Fire starts from 1980 to 2004 in the Clover Mountains. The fire locations are represented by red dots. The location of the Clover Mountains study area ponderosa stands are shown in yellow. Fire locations were placed on a 1450m grid and the red dots may not represent the exact location of the fire.

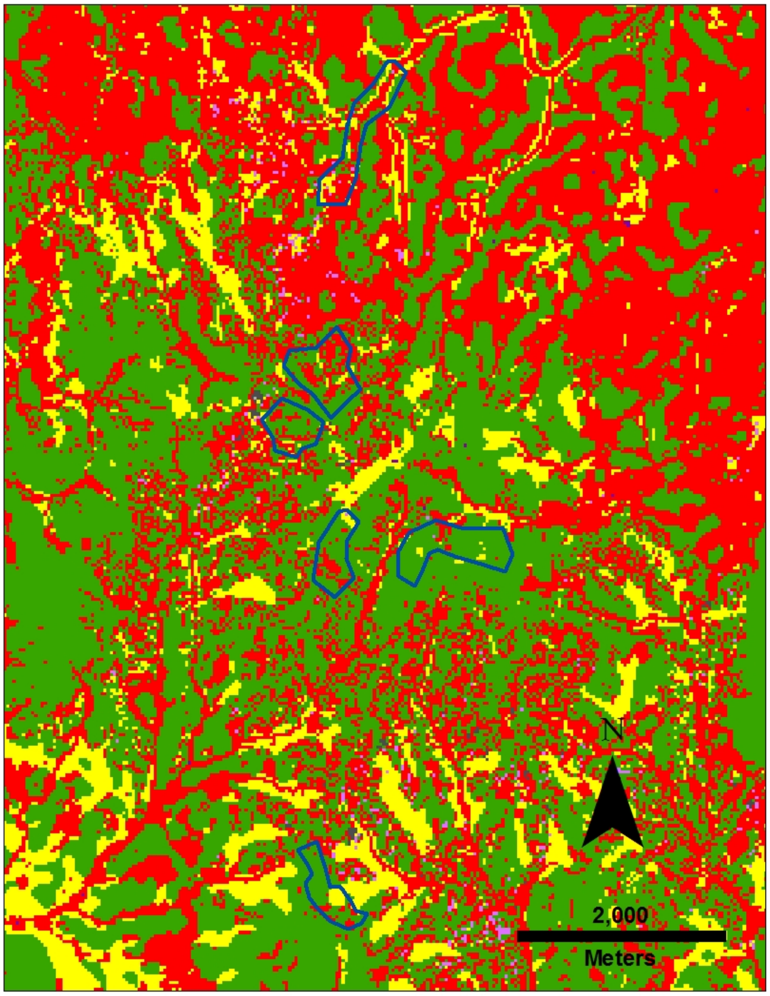


Figure 19. Fire Regime Condition Class (FRCC) map from the LANDFIRE project for the area around the Clover Mountains study area. Green represents areas in condition class 1, with low vegetation alteration from fire. Yellow represents condition class 2, with moderate vegetation alteration from fire. Red represents condition class 3, which indicates high vegetation alteration from fire. Pink represents agricultural areas.

Clover Mountains GAP Imagery

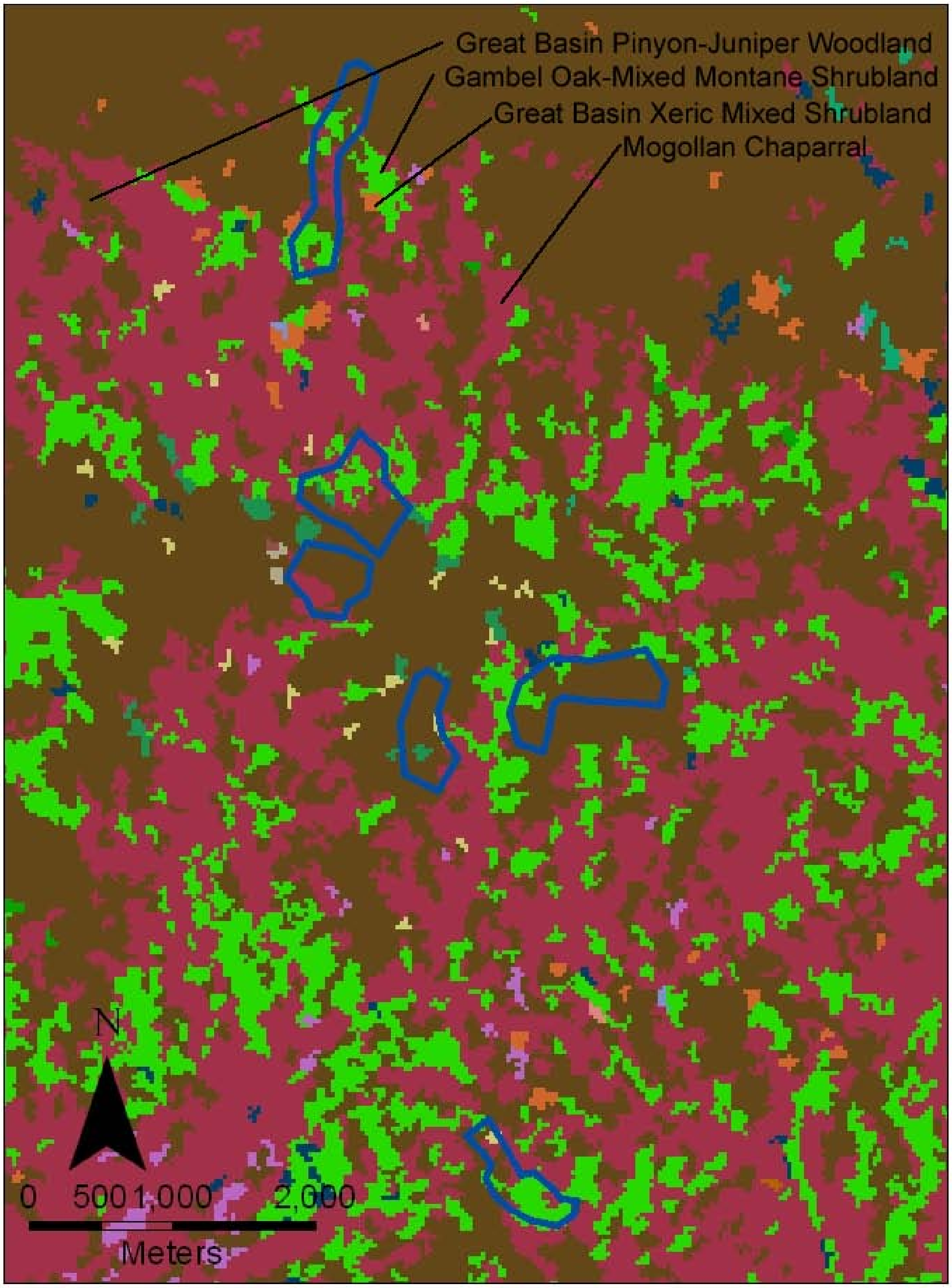


Figure 20. Southwest regional GAP data for the area around the Clover Mountains study area. Predominant cover types are Great Basin Pinyon-Juniper Woodland, Mogollan Chaparral and Gambel Oak-Mixed Montane Shrubland. Interestingly none of the area is classified as Ponderosa Pine.

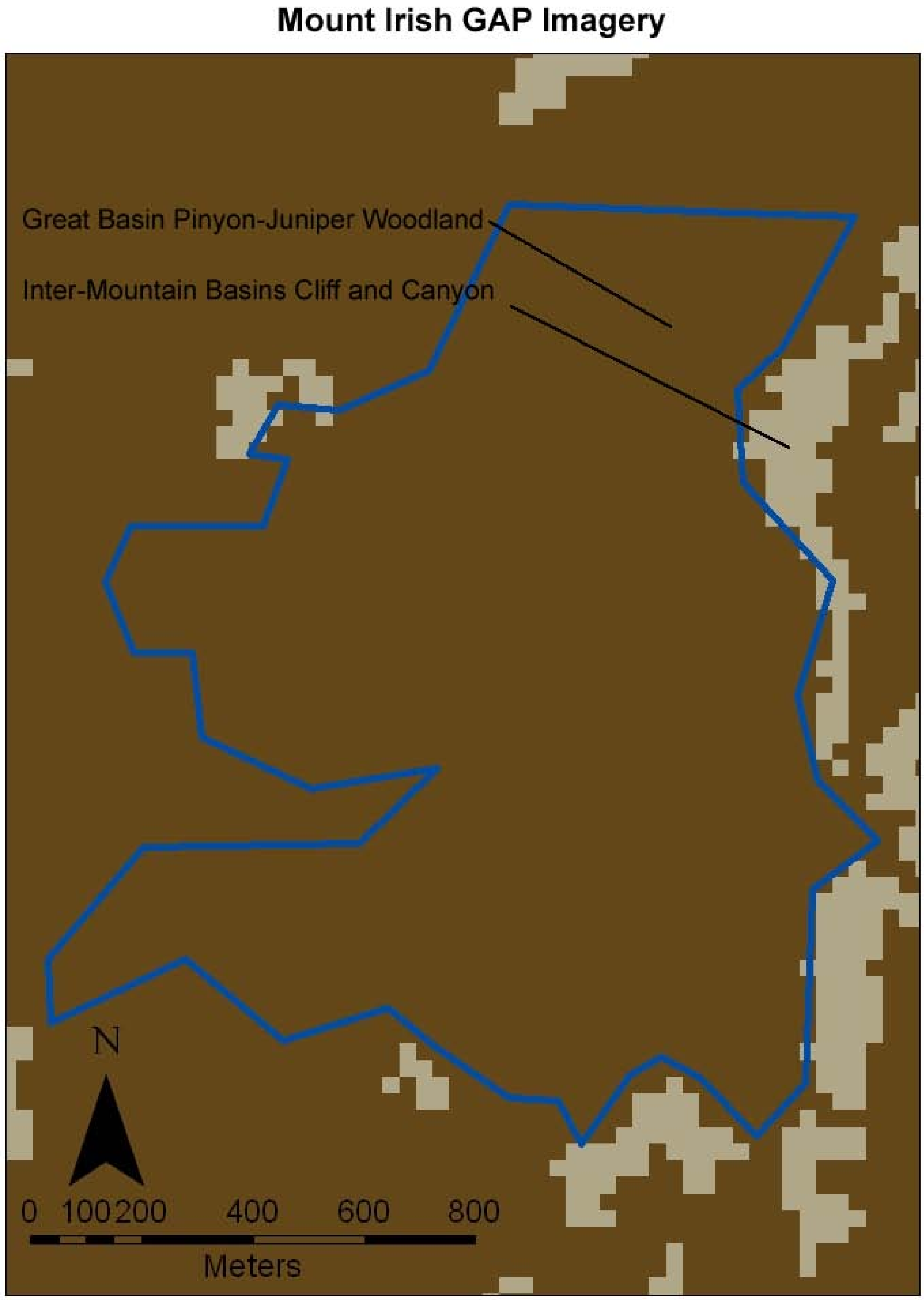


Figure 21. Southwest regional GAP data for the area around the Mt. Irish study area. Cover types include Great Basin Pinyon-Juniper Woodland and Inter-Mountain Basins Cliff and Canyon. No landcover is classified as ponderosa pine.

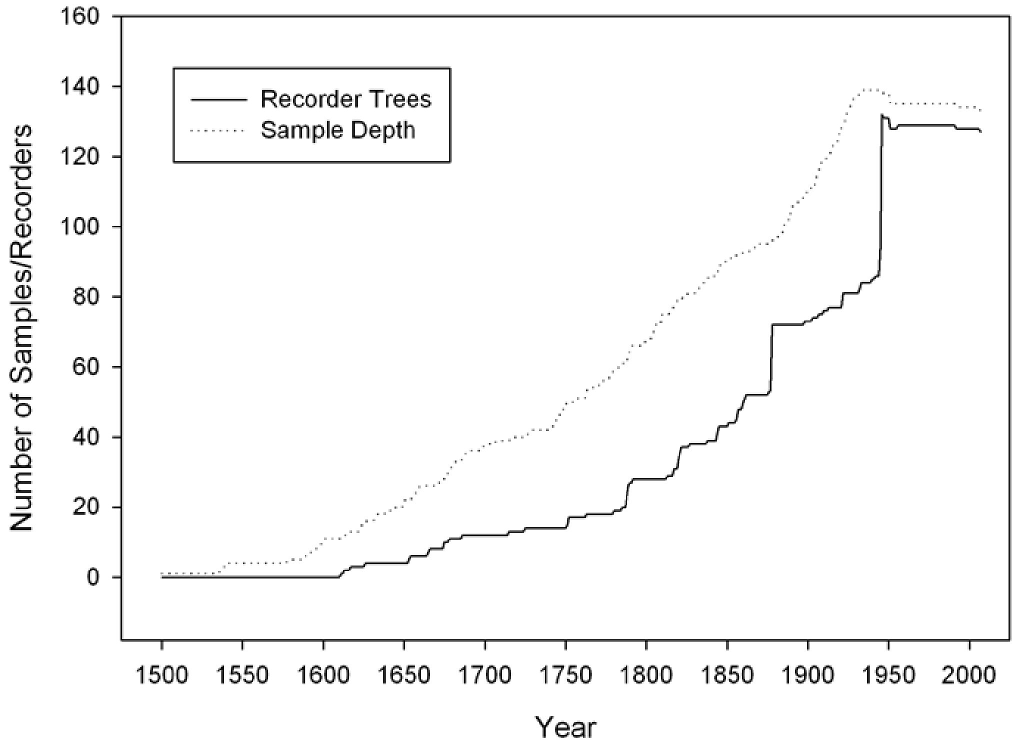


Figure 22. Number of trees alive and of trees recording fire (i.e. scarred) present at any given time from 1500 until 2006. 20 or more recorder trees were present from 1785 to 2006.

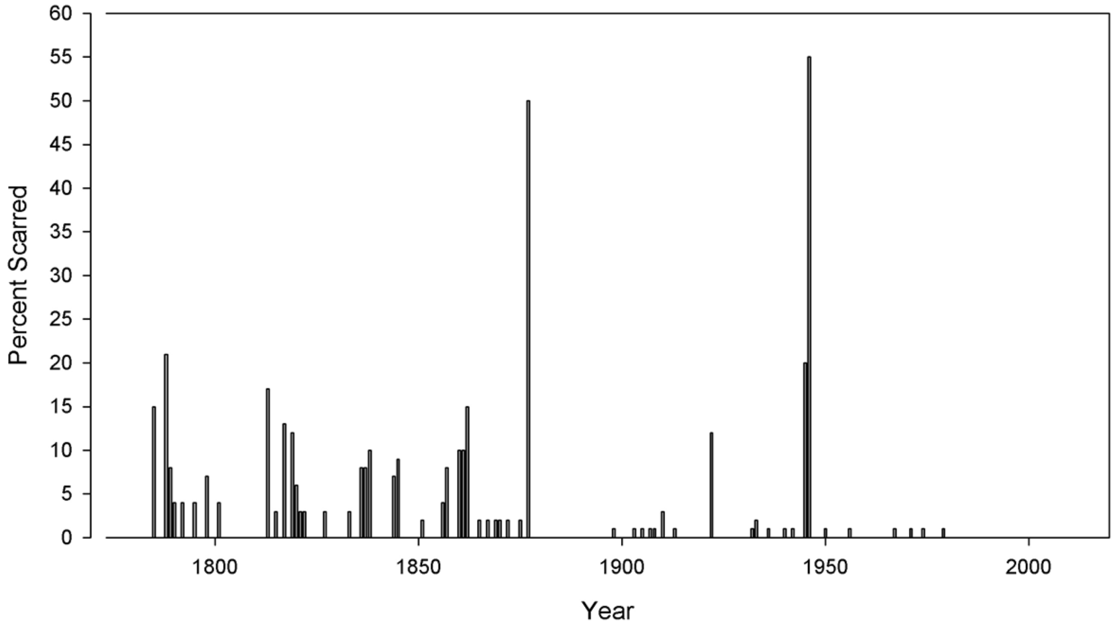


Figure 23. Histogram of percent recorder trees scarred per year from 1785 to 2007. The highest values occur in 1877 and 1946.

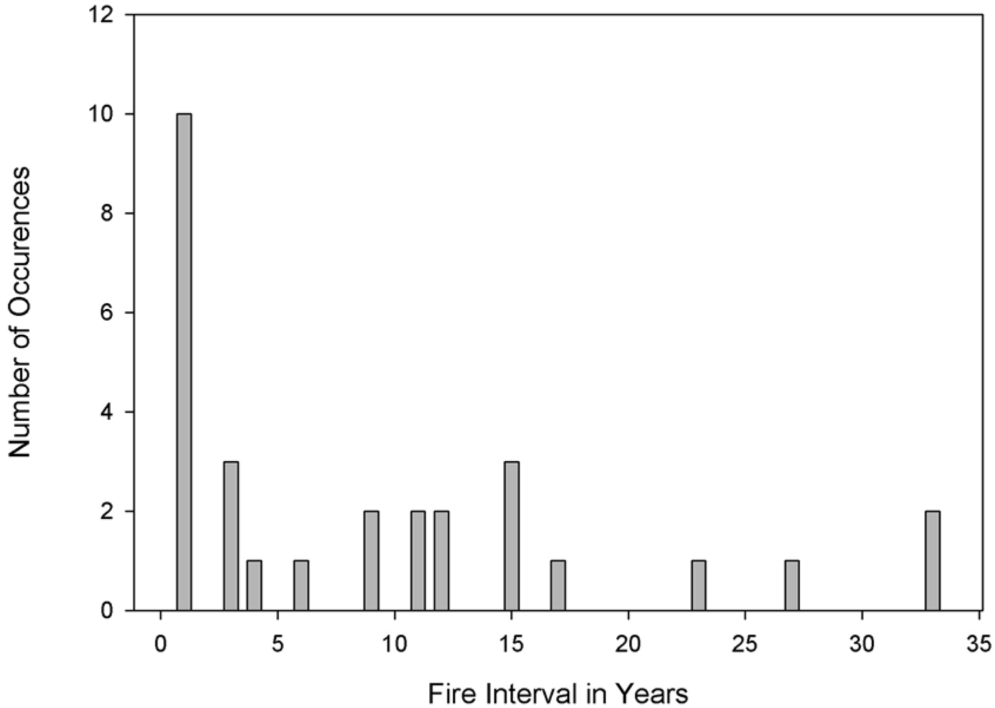


Figure 24. Histogram of fire intervals for the whole study area. All fire intervals required a minimum of 2 scars recording each interval. The most common value is one year, with ten occurrences. Values ranges from 1 to 33 years.

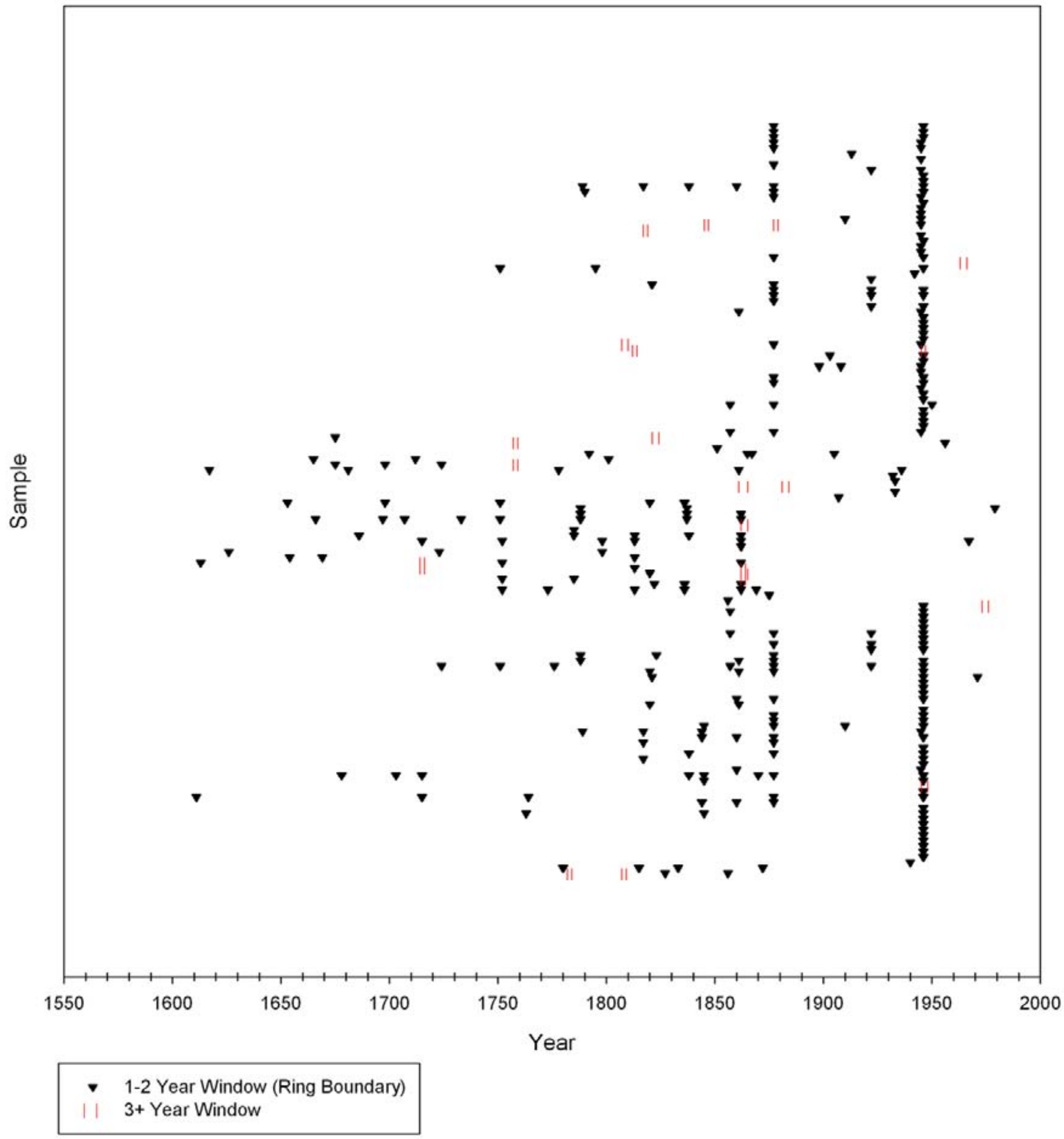


Figure 25. Composite graph of all wedge samples from the Clover Mountains (n=139), from 1550 to 2000. Black triangles represent fires that were dates to a single year or two years. Vertical red lines represent fires that could not be dated to less than a 3 year window. Distance between the red lines indicates the size of the dating window.

A.

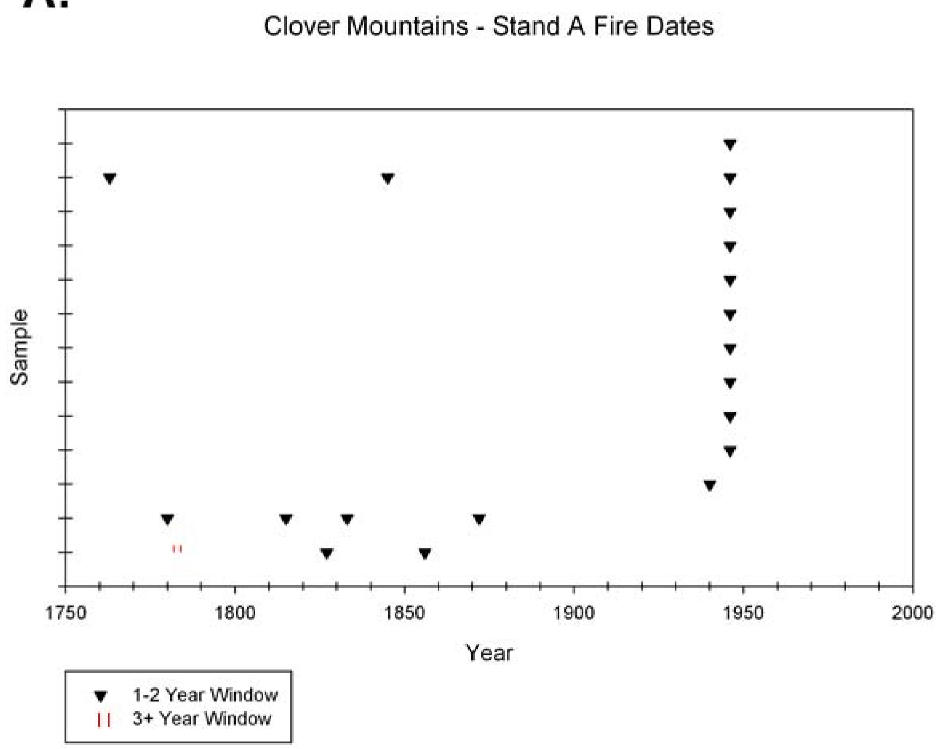
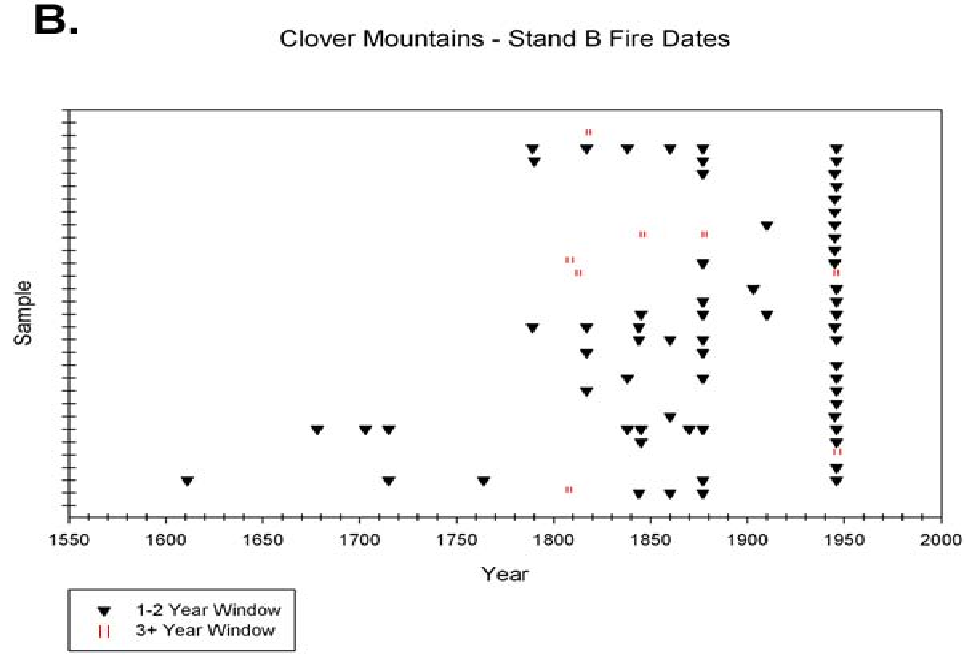


Figure 26. Composite graphs for each stand in the Clover Mountains study area. Composites show individual sample fire dates for each stand. Black triangles indicate fires that were dated to within a 2 year window. The red parallel lines indicate fires that could not be dated better than a 3 year window. Spacing of the red lines is proportional to the length of the dating window.

Figure 26 continued.

B.



C.

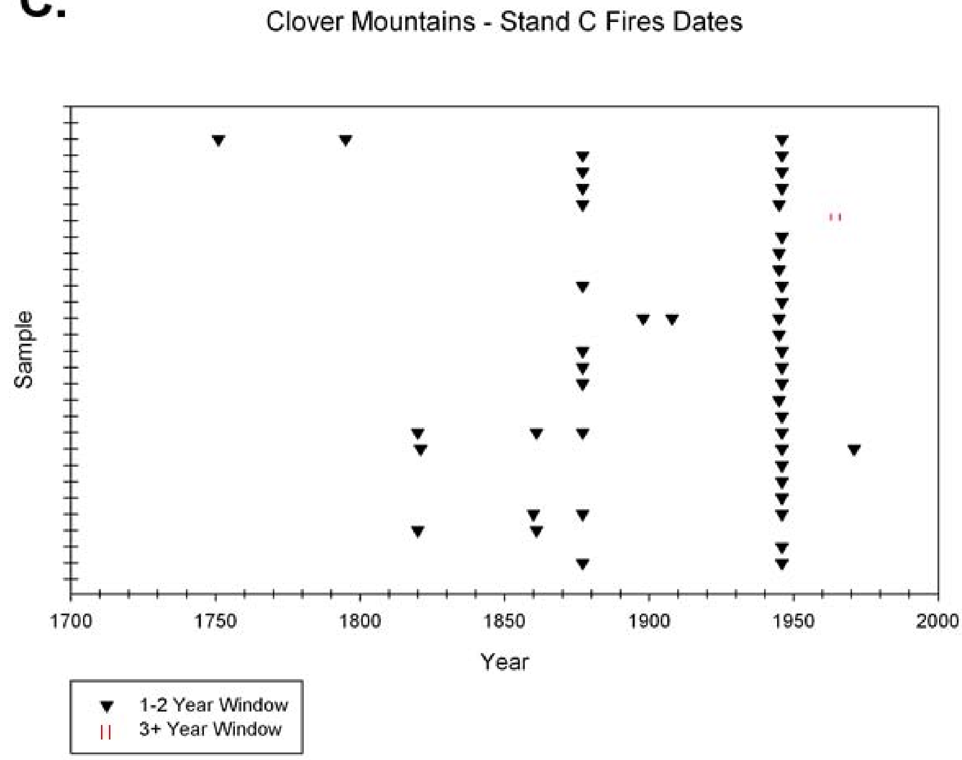
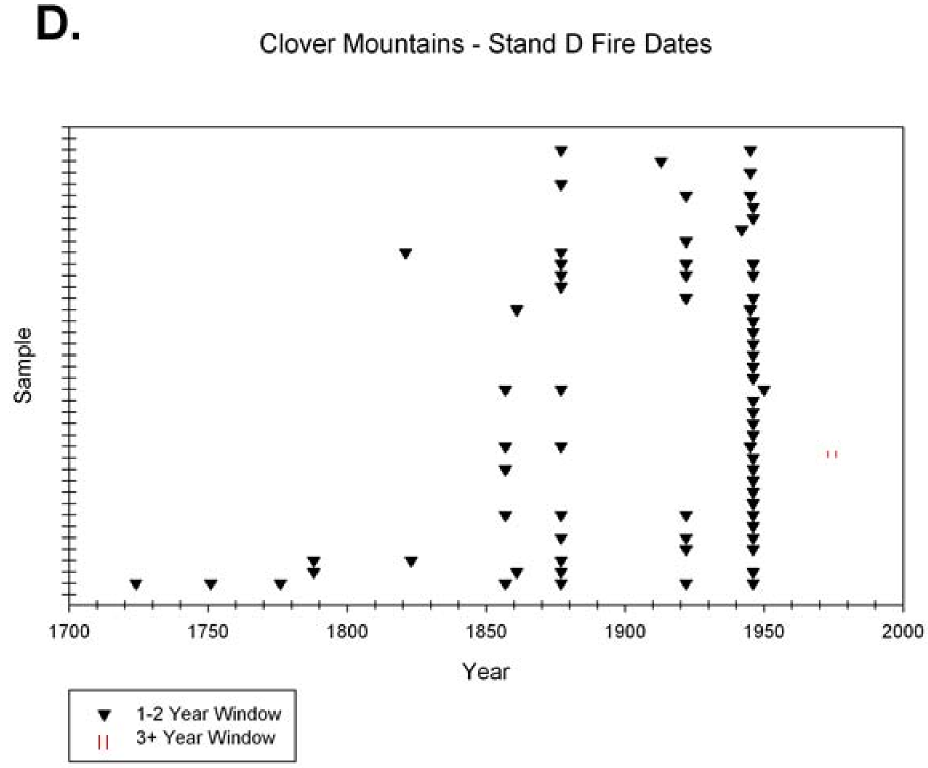


Figure 26 continued.

D.



E.

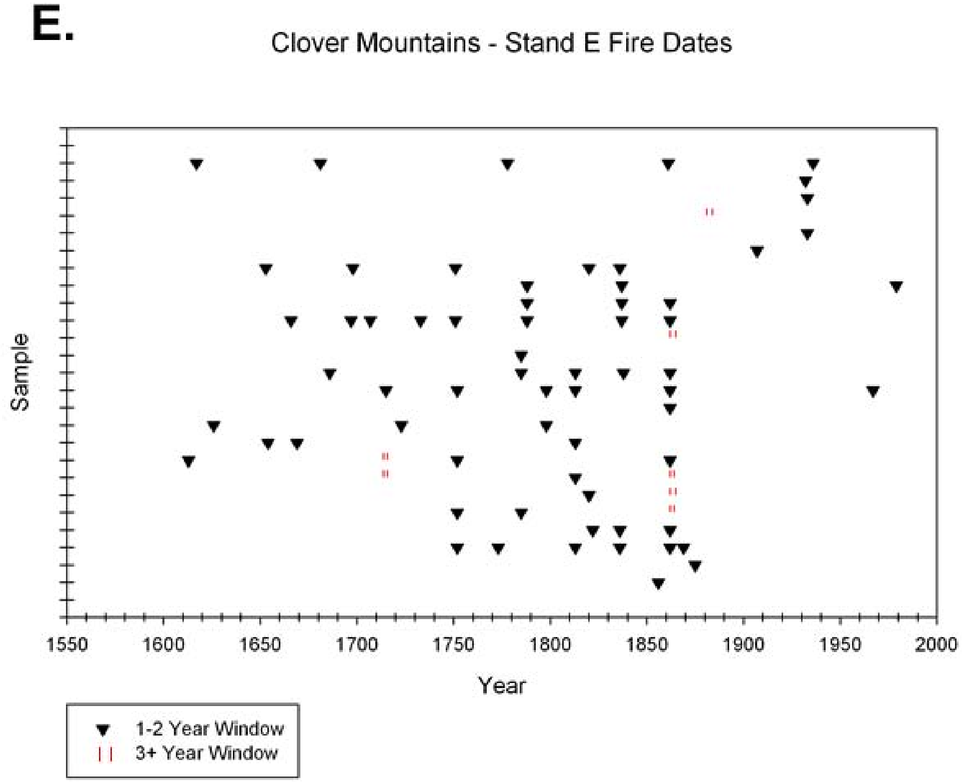
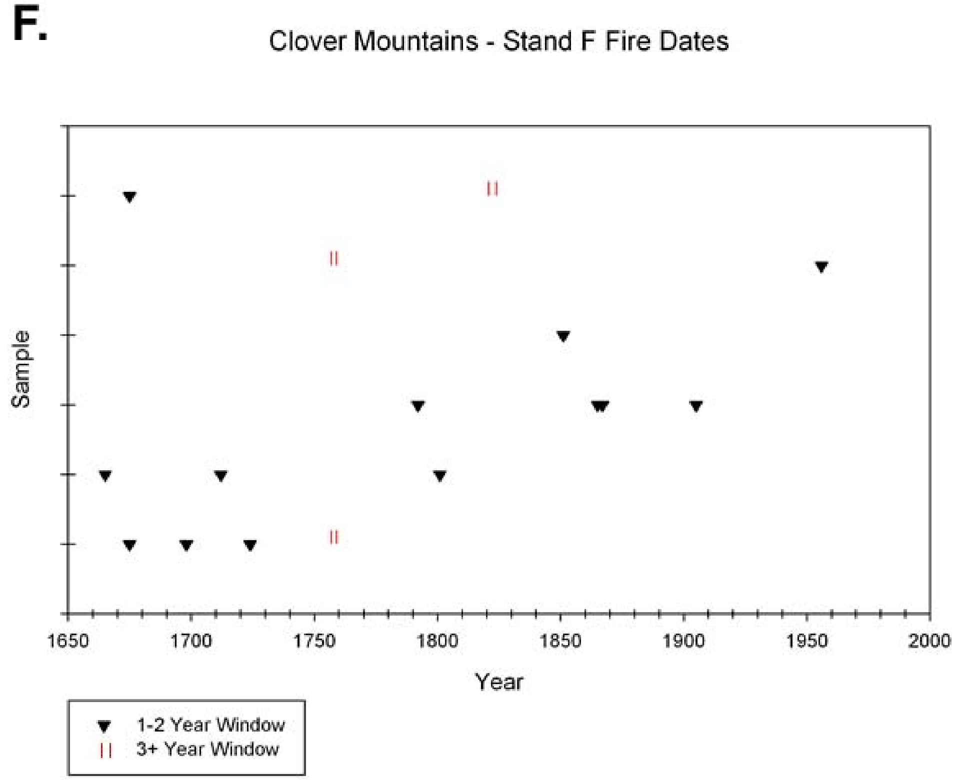


Figure 26 continued.

F.



A.

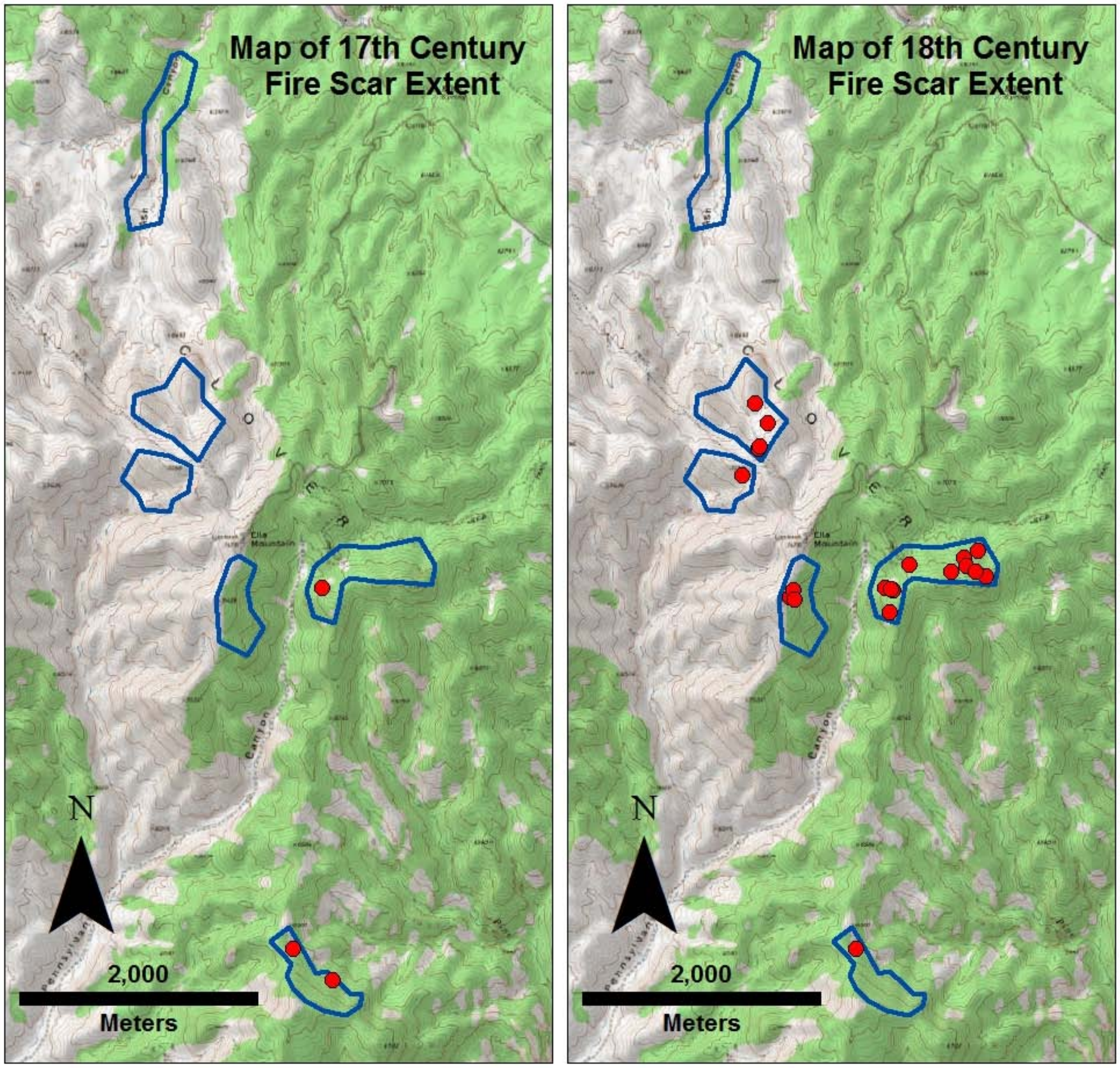
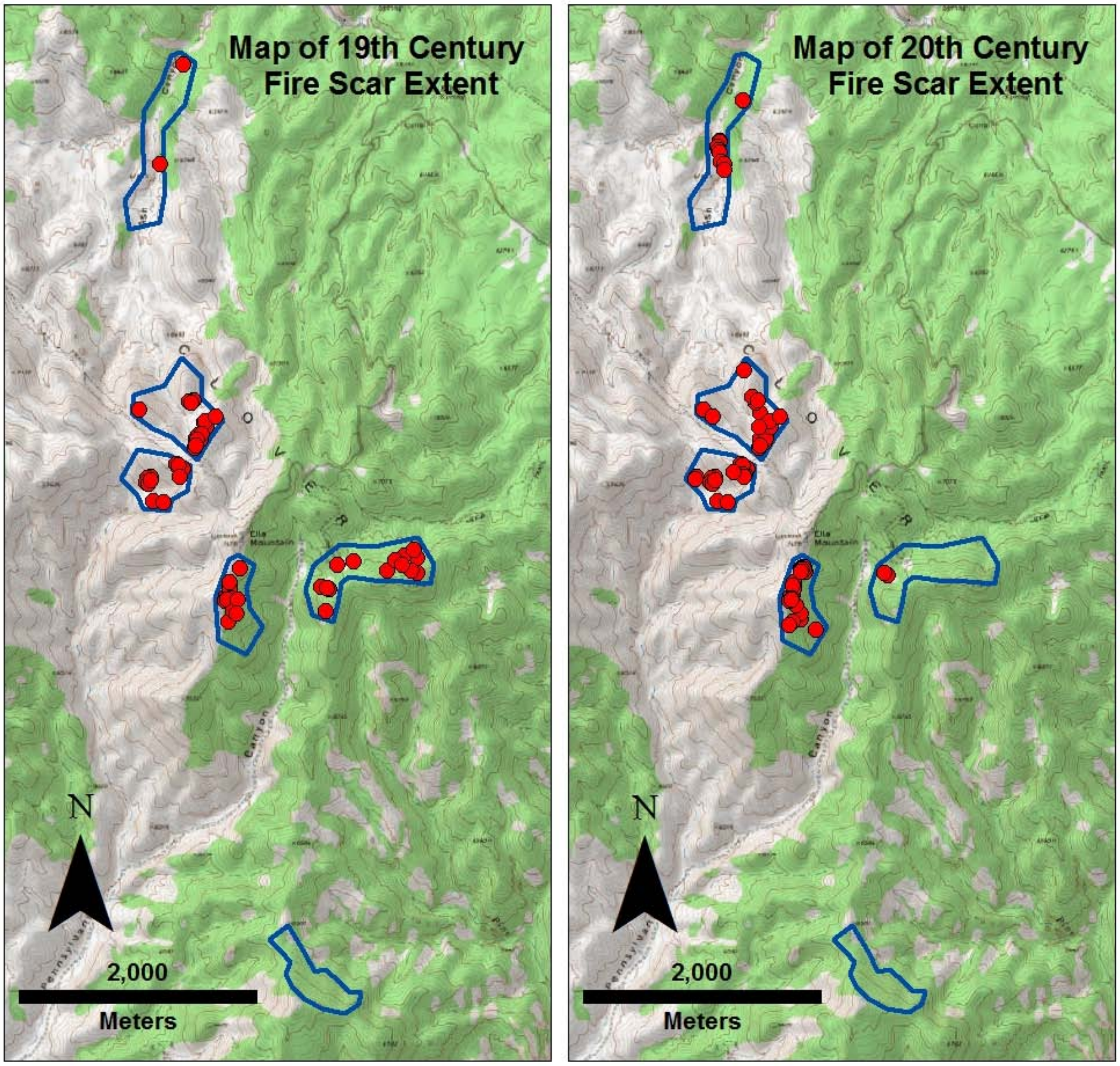


Figure 27. Maps of fire scar distribution by century. Red dots represent locations of fire scars; blue outlines show the location of ponderosa stands. The lack of fire scars throughout the study area during the 17th century is most likely because of low sample depth at that point in the record. The 19th and 20th centuries are generally similar in spatial distribution of fire scars.

Figure 27 continued.

B.



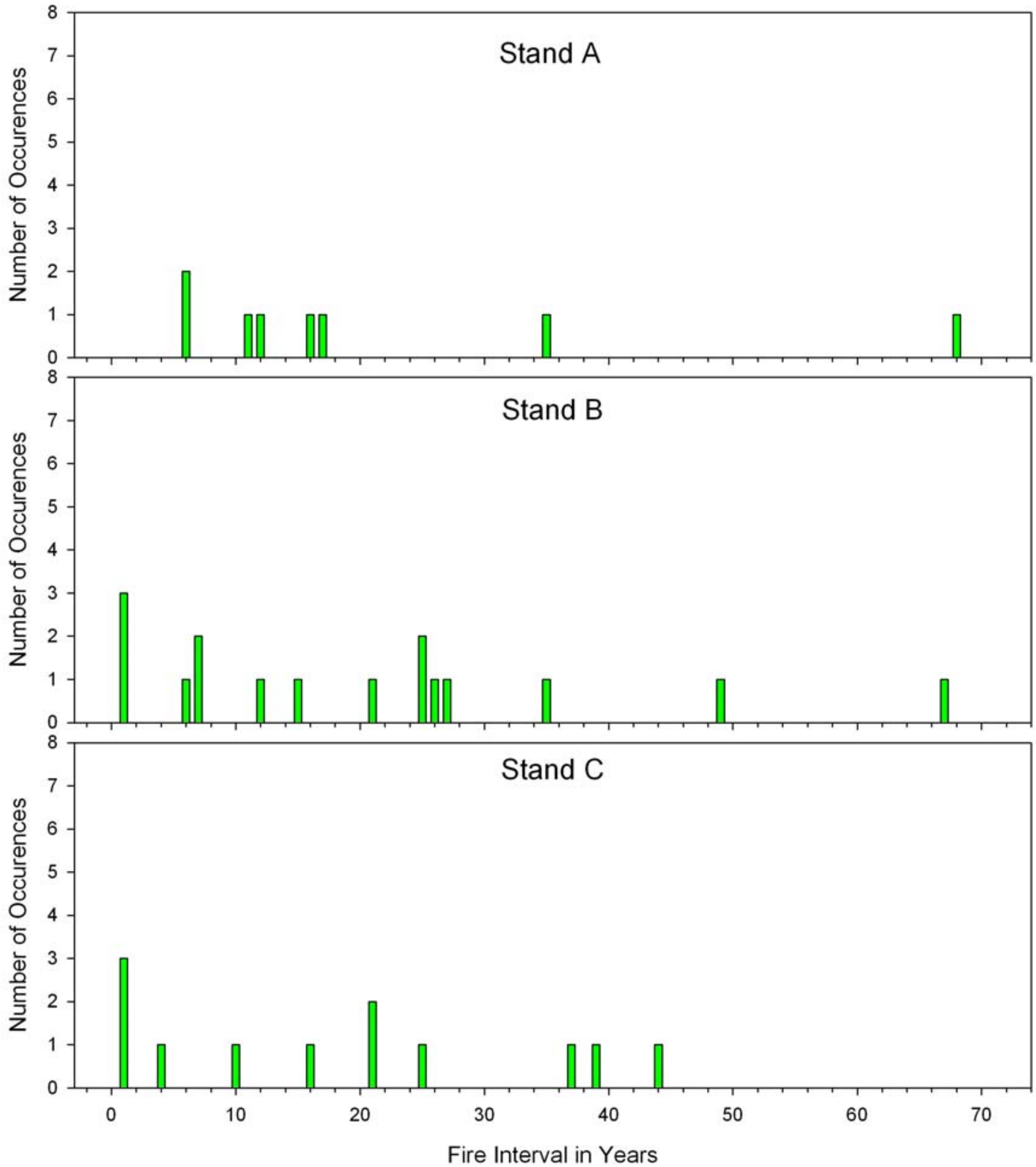
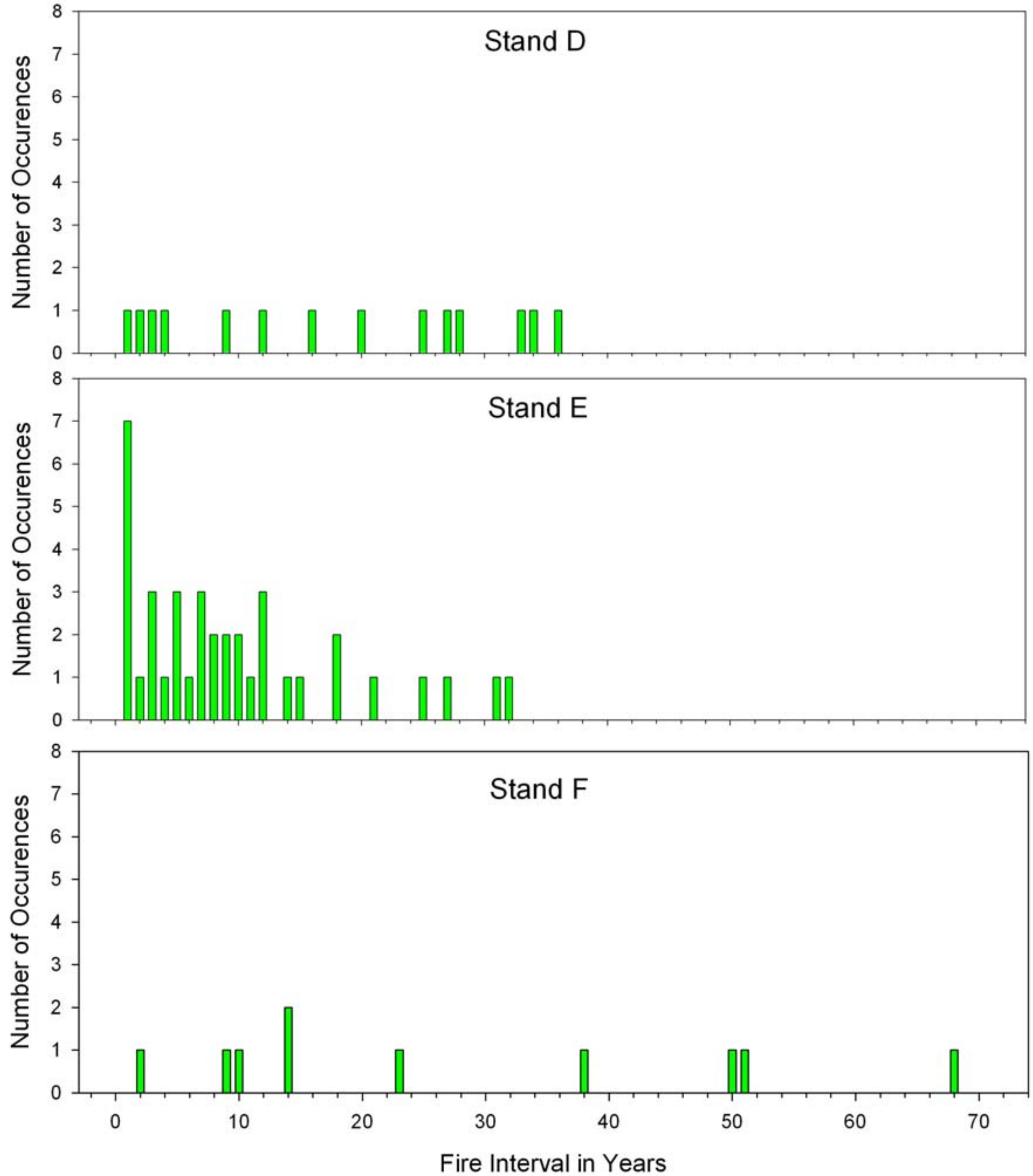


Figure 28. Histograms of fire intervals for each stand.

Figure 28. continued



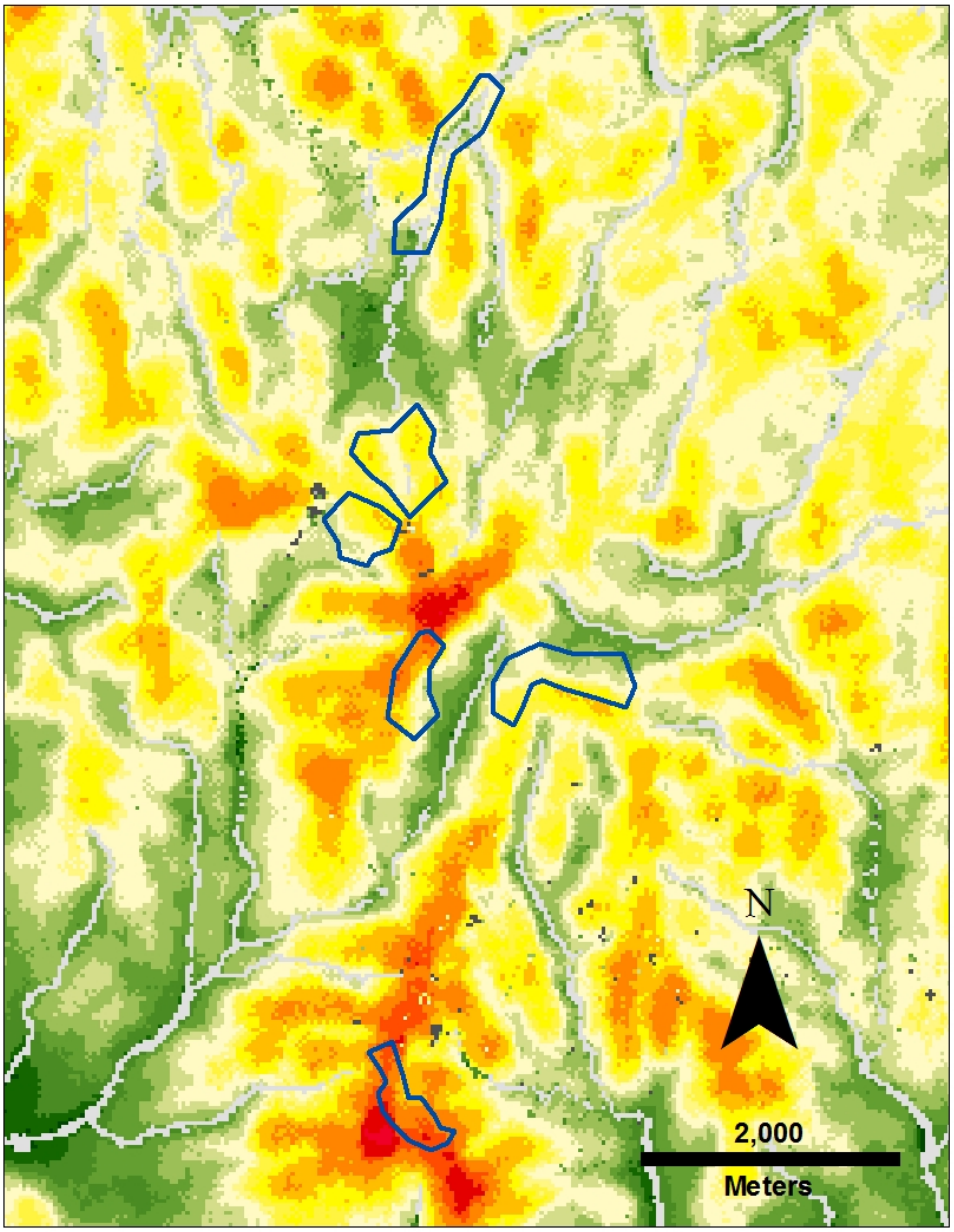


Figure 29. Map of fire intervals for the Clover Mountains from LANDFIRE project data. Ponderosa stands are outlined in blue. Length of fire intervals increase with colors from red to green. Red areas represent fire intervals of 36-50 years. Orange areas represent fire intervals of 51-70 years. Yellow areas represent fire intervals of 71-100 years. White and green areas represent fire intervals of 101-1000 years.