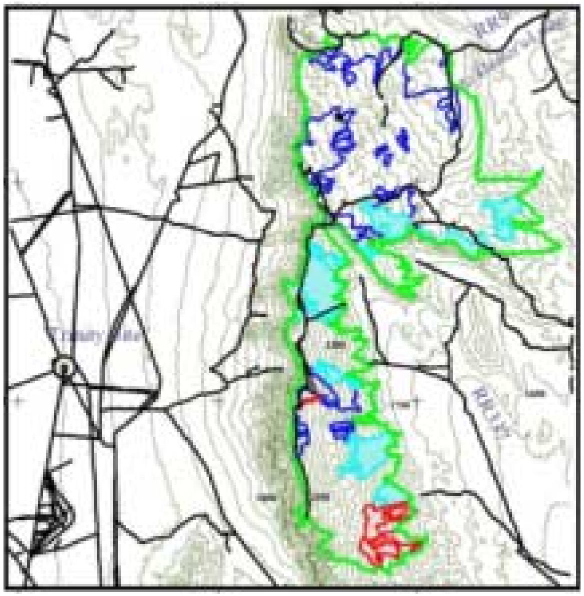
# Woodland Fire History Studies

# in the

# Oscura and Northern San Andres Mountains

# White Sands Missile Range, New Mexico



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# Woodland Fire History Studies in the Oscura and Northern San Andres Mountains, White Sands Missile Range, New Mexico[1]

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## ABSTRACT

We used a combination of dendro-ecological and historical aerial photo analysis to evaluate the past role of fire in structuring pinyon (*Pinus edulis*) and ponderosa pine (*Pinus ponderosa*) woodlands on White Sands Missile Range in south-central New Mexico. From preliminary tree fire-scar data from both pinyon and ponderosa in the northern pine San Andres Mountains we identified four fire periods: a Spanish Colonial period with high fire frequency (pre-1750); a Transition period (1750 to 1830) where fire frequencies decline; an Anglo Settlement period (1830 to 1910) with low frequencies, and a Modern Period with little fire (1910-2000). In addition, a stand analysis of ponderosa pine on Salinas Peak and Silvertop Mountain indicated episodic recruitment following either drought or fire from the 1790's up until 1950. Some recruitment continued after 1950, but limited sapling abundance precluded the sampling for precise dates of establishment. Historical photo analysis suggests that these ponderosa pine woodlands have burned at least once since the 1940's, but the frequency and their impacts are not yet well understood. The lack of dense reproduction may indicate either poor climatic and soil conditions for successful establishment, or that a surface fire regime has been re-initiated under military stewardship that has thinned samplings to low levels. The former process suggests that active silvicultural management may be required to sustain these stands. In contrast, the latter case may reflect the re-establishment of a near-normal surface fire regime that will prevent the development of fire-prone "doghair" stands of ponderosa that have become the focus of forest restoration efforts elsewhere in the Southwest.

The pinyon woodlands showed some evidence of past fire within the last 150 years. Limited fire-scar data suggests fire frequencies ranging from 30 to 100 years or more (some stands are over 400 years old). The historical photo analysis indicates that turnover of the woodlands as function of stand replacement fires ranges from 12 % per century in the Oscura Mountains to 17 to 49% per century on the northern San Andres Mountains. Detailed studies in the Oscuras showed that the woodlands exhibited a fine-patch spatial structure in response to landform, aspect, and soils patterns that are imbedded in the larger landscape fire mosaic. At upper elevations, stands often had complex multi-age class sub-structures with vertical and horizontal patterning based on recruitment cohorts (emergent canopies and patches within patches). This fine-scale pattern may be mediated by animal vectors (seed caching) and seed rain coupled with climatically driven episodic recruitment over long periods following fires. Given the long historical intervals between fires, slow turnover rates and the length time required for recovery from fire, we recommended a prescribed natural burn policy with suppression of human-caused fires.

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Photos by T. Swetnam unless otherwise noted; GIS and map graphics by Linda DeLay.

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# INTRODUCTION

On White Sand Missile Range (WSMR) there are some 130,000 acres (50,000 ha) of pinyon and juniper woodlands distributed in the Oscura and San Andres Mountains, making them one of the more significant ecosystem elements on the range. These woodlands also represent some of the largest intact occurrences in the Southwest—a legacy of the military mission where grazing and fuelwood removals have been excluded for the past 60 years. As a result, there has been a considerable effort made on the part of WSMR's Environmental and Safety Directorate (WS-ES) to ensure proper management of these woodland ecosystems in the context of the military mission.

Many management issues for pinyon and juniper woodlands were addressed by WS-ES through the Integrated Natural Resources Management Plan (INRMP), and through Boykin's (2000) analysis of fire ecology and management issues on WSMR. One outcome has been an increased awareness of the role fire has played and continues to play in determining the character of these woodlands. However, along with this came the realization that more information was needed on the fire history and ecology of WSMR woodland stands to help inform fire management and ensure sustainability while minimizing impacts on military operations. Accordingly, the New Mexico Natural Heritage Program at the University of New Mexico, in collaboration with the University of Arizona Laboratory of Tree-Ring Research, has embarked on a multiphase study of the fire history pinyon and juniper woodlands on WSMR. Through a careful analysis of the spatial and temporal role fire has played historically in structuring these ecosystems, along with an assessment of current status, their future behavior and response can be reasonably predicted in broad terms to aid management prescriptions (Swetnam et al. 1999). The goal is to provide the information necessary for ecological management of the pinyon and juniper woodlands while providing tools for effective fire management that meets military objectives.

Key questions were:

How has fire, in combination with climatic events, structured WSMR woodlands, both across the landscape and within stands?

Are woodland fire regimes on WSMR significantly different from those of other southwestern ponderosa pine and pinyon forests and woodlands?

What are the critical factors about the historical fire regime that can help guide appropriate management for pinyon and juniper woodlands on WSMR?

Our approach was to develop a preliminary reconstruction of the fire history of the woodlands in the Oscura and northern San Andres Mountains from direct fire-scar evidence on pinyons and ponderosa pines. Because pinyon pines only occasionally leave a record of fires in the form of trunk scars, the depth of the fire record can be limited. On the other hand, ponderosa pines often leave an extensive record of scars that can be accurately aged using the wealth of tree-ring chronologies that have been developed for this species in the Southwest (Swetnam 1990). Therefore, ponderosas, when surrounded by pinyons and junipers, can be used, with some limitations, to infer the fire history of the woodlands. Although ponderosa distribution on White Sands Missile Range is restricted to Salinas Peak and Silvertop Mountain, they can still provide an effective, though localized, picture of fire history in the area.

The fire history can also be evaluated indirectly by mapping changes in tree stands from historical aerial photography, and then analyzing the pinyon and ponderosa pine age structure of the stands in detail in the context of climatic patterns and the available fire-scar data. The maps can be used to analyze the spatial distribution of stands through time in relation to localized habitat conditions and in terms of the landscape as a whole. Then, through the aging of trees, and these spatial patterns are related to times of tree establishment. We suggest that individual stands reflect in their stand structure and landscape position the different fire impacts and responses from the past, and that understanding the current stand age structure and patch distribution in this historical context is fundamental for predicting the future impacts of fire.

## STUDY AREA

### Location, geology and vegetation

Located in south central New Mexico, White Sands Missile Range (WSMR) encompasses 2.14 million ac (923,358 ha) excluding the buffer extension areas (Figure 1). The missile range forms an irregularly shaped rectangle approximately 35 by 125 miles long (60 km wide and 200 km). The fire history studies focused on two sites that have the highest density and extent of woodlands on the range: the Salinas Peak-Silvertop Mountain area of the northern San Andres Mountains and the Oscura Mountains (Figure 2). The Salinas Peak-Silvertop Mountain study area was approximately 3,050 ha (7,533 ac) and the Oscura Mountains site was 13,740 ha (33,944 ac).

The San Andres and Oscura Mountains lie within the Bolson sub-section, Mexican Highlands section of the Basin and Range physiographic province, which is characterized by broad desert basins and discontinuous mountain ranges (Gile, Hawley, and Grossman 1981). The San Andres and Oscuras lie centrally and divide WSMR into two major basins to the east and west. The San Andres Mountains are structurally a large west-tilted fault block that rises to a height of 8,968 ft (2,733 m) at Salinas Peak. The mountain range is cuesta-like, with precipitous escarpments facing east towards the Tularosa Basin and long, gently dipping slopes to the west that lead down into the northern and southern Jornada basins. The smaller Oscura Mountains are to the north of the San Andres and are also a cuesta-like, fault block range, but one tilted to

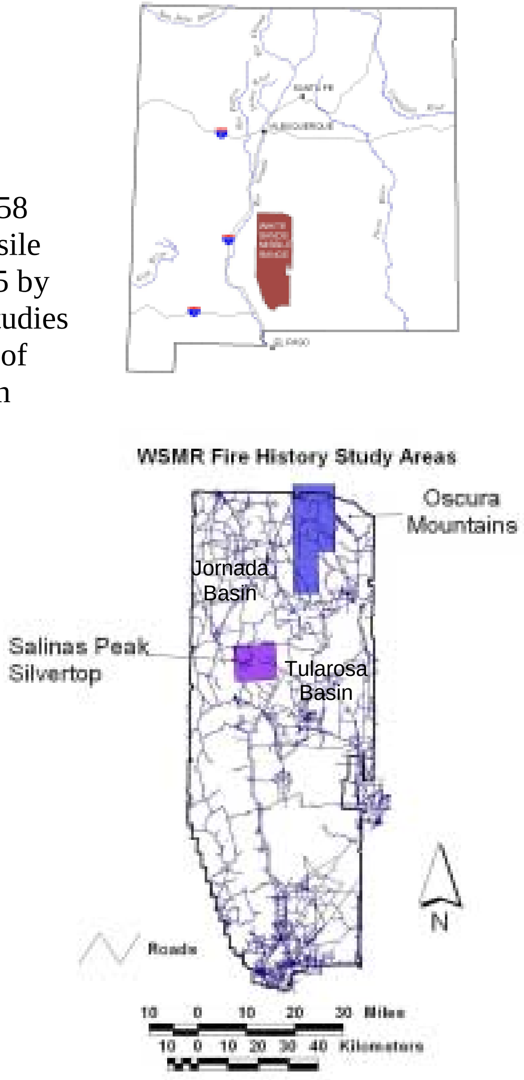

Figure 1. WSMR fire history study areas.

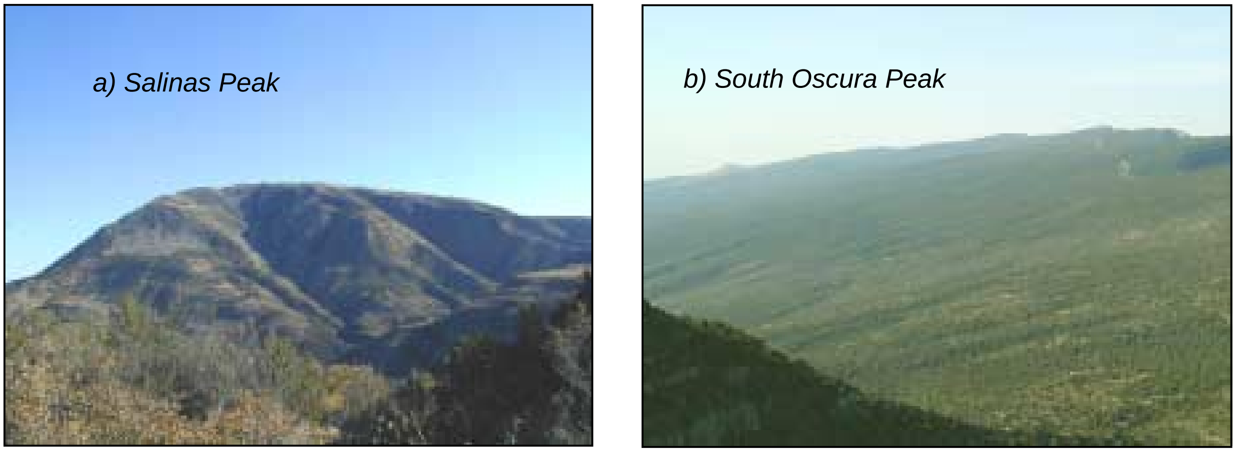

Figure 2. a) Salinas Peak along with Silvertop Mountain 4 km to the north (not shown) are topped with rhyolitic rocks over limestone and support ponderosa pine and pinyon woodlands. b) The long east-facing dip slopes of the Oscura Mountains are primarily composed of limestones and are dominated solely by pinyon-juniper woodlands and montane scrub.

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the east, i.e., the escarpment faces west with the corresponding long piedmont slope leading to the bottom of the northern Tularosa Basin. To the east, slopes gently dip into the basin fill of the Tularosa basin. Both ranges lie on Precambrian granites, metamorphic schist and gneiss that are stratigraphically complex with intermixed limestone and sandstone strata ranging in age from Cambrian to Quaternary. The exceptions are tertiary igneous rhyolitic intrusions in the sedimentary rocks that have now been exposed by erosion on Salinas peak and Silvertop Mountain (Bachman 1968; Bachman and Harbour 1970). While scattered rhyolitic intrusions also occur in the Oscura Mountains, limestones and sandstones predominate

Figure 3. Open canopied ponderosa pine/Arizona fescue woodlands on Salinas Peak.

The vegetation has been described and mapped in detail by Muldavin et al. (2000). In general, vegetation ranges from desert shrublands and grasslands in the lowland basins to ponderosa pine and pinyon woodlands at the highest elevations. Woodlands cloak the upper slopes of the Oscura Mountains and Chupadera Mesa in the north, and then extend south through the San Andres and San Augustine Mountains to the Organ Mountains at the very southern end of WSMR. These woodlands are dominated by the moderately cold- and drought-tolerant, rounded-crown conifer species common to the Rocky Mountain Biogeographic Province. At the very highest elevations of the San Andres Mountains (from 6,800 to 8,760 ft; 2,075 to 2,675 m), small stands of ponderosa pine (*Pinus ponderosa)* representing Rocky Mountain Lower Montane Woodland are found. Although tall and forest-like, the open canopies (10% cover) define them as sparse woodlands (Figure 3). They have grassy understories dominated by Arizona fescue (*Festuca arizonica*) and belong to the Pinus ponderosa/ Festuca Arizona plant association (Muldavin et al. 2000a) that, while uncommon on WSMR, is a major plant association of forested regions of the Colorado Plateau. They are limited to volcanic rhylolitic substrates that cap the tops of Salinas Peak and Silvertop Mountain in our study area.

The majority of the mountain areas are dominated by Rocky Mountain/Great Basin Woodland and Savanna, or "pinyon-juniper zone." These woodlands occur on limestone and dolomite substrates at elevations between 4,500 and 8,500 ft (1,375 and 2,600 m). At upper elevations, the woodlands are dominated by the pinyon pine (*Pinus edulis*), which have been classified into 11 plant associations by Muldavin et al. (2000). These communities form open to moderately closed canopies (generally between 25 to 70% canopy cover, but as low as 10%). The closed-canopied woodlands often have complex structure with tall (35 ft; 10.6 m) canopy emergents along with one or more sub-canopy strata (Figure 4). Understories vary from grassy to shrubby, with wavyleaf oak (*Quercus undulata*), mountain mahogany (*Cercocarpus montanus*), banana yucca (*Yucca baccata*), and Scribner needlegrass (*Stipa scribneri*) as the most common elements.


Figure 4. Pinyon pine/wavyleaf oak woodlands below North Oscura Peak at about 7,950 ft (2,425 m).

At lower elevations (4,500 to 7,500 ft; 1,375 to 2,300 m) of the foothills, mesas and valleys, oneseed juniper (*Juniperus monosperma*) becomes more prevalent than pinyon and dominates. Thirteen oneseed juniper plant associations have been described for the range; most of these have grassy understories that are most commonly dominated by grama grasses (*Bouteloua hirsuta*, ***B****. gracilis*, *B. curtipendula*, and *B. eriopoda*). These are savanna-like associations that have sparse canopies ranging from 10 to 40% cover with grassy inter-tree spaces (Figure 5). Intermixed among the woodlands are Montane Shrublands and Interior Chaparral, dominated by mountain mahogany and wavyleaf oak, particularly on sites that have been burned, or that are very rocky and have shallow soils. The shrublands become more prevalent southward through the San Andres Mountains. At the lower elevation fringes, the woodlands extend


Figure 5. Oneseed juniper/blue grama woodland savanna in Bruton Canyon at the northern, lower elevation (6,130 ft; 1,870 m) edge of the Oscura Mountains study area.

onto alluvial fans and into interior valleys where they give way to grasslands and occasionally desert shrubland.

## Climate

There are no permanent weather stations on WSMR at similar elevations to those found in the study areas. But by using regional weather stations at similar elevations, the average maximum temperatures are estimated to range from between 60° F (15.5° C) at the highest elevations down to 75° F (23.9° C) at the lowest elevations of the woodland zone. Similarly, average temperature minimums likely range from between 33° F (0.6°C) and 42° F (5.6°C). The average annual precipitation is estimated at 14 in (35.6 cm) for the lowest elevations and ranging up to 20 in (50.8 cm) at the highest. The majority (64%) of the precipitation comes during the summer in the form of intense late-summer thunderstorms of short duration (Anderson and Taylor 1983). The remainder comes as snow with very limited accumulation, even at the highest elevations.

In terms of the long-term climatic record, Grissino-Mayer et al. (1997) reconstructed an annual precipitation record for south central New Mexico based on tree ring chronologies that extends back to AD 622. They identify 17 significant droughts and 18 wet periods over the course of their record. Of those that fall within our period of analysis (1550 to 2000), the ‘1950’s drought” from 1946-1961 was the most severe, while the wettest period was from 1903 to 1921.

# METHODS

## Field sampling

### *Fire-scars*

Figure 6. An example of a pinyon log cross-section showing fire-scars (Oscura Mountains study site).

At each site (Salinas Peak, Silvertop Mountain, and in the Oscura Mountains), dead standing trees (snags) and downed logs with exteriorly evident fire-scars were identified and then sampled to maximize spatial coverage within stands (Figure 6). Additionally, trees with a maximum number of fire-scars were chosen when possible (Swetnam and Baisan 1996). Using a chain saw (Figure 6), cross-sections of the snags and logs were cut and wrapped for subsequent laboratory analysis (Arno and Sneck 1977). Each sample was labeled, sketched, and the location approximated on a topographic map. At Salinas Peak, 13 cross-sections were collected from ponderosa pine; 15 from Silvertop (6 from pinyon and 9 from ponderosa), and three from the Oscuras (pinyons only). Sampling took place during the first week of May in 2000.

### *Stand age structure*

Figure 7. To determine ages, trees were increment cored as close to the base as possible.

In order to assess stand age and tree recruitment, increment cores of trees were used to determine approximate tree age (Figure 7). On Salinas Peak, four, 20 by 20 m plots were established among a series of small stands reflecting a range of diameter root crown (DRC) classes (Figure 8). Five sound ponderosas pines were sampled in each stand with two increment cores per tree taken horizontally and at right angles from each other, and as close to the rootcrown as possible. On Silvertop, the stand as a whole was smaller and did not form discrete sampling units. Thus, 10 sound trees were selected more or less randomly across the stand. A total of 60 cores from 30 trees were analyzed.

Figure 8. a) The Silver top Mountain ponderosa pine site. b) One of the ponderosa pine stands on Salinas Peak showing discrete height and diameter classes.

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In the Oscura Mountains, the stand structure sampling focused on the high elevation pinyon woodlands. Using digitally ortho-rectified 1996 NAP aerial photography and SpaceImaging® IKONOS satellite imagery (1-meter resolution panchromatic), stands with potentially differing stand structures were photo-interpretively mapped (Figure 9). Then seven polygons were selected for sampling representing stand structures from potentially even–aged, single canopied stands to multi-aged stands with complex emergent canopies and sub-canopies. Coordinates at the center of the polygons were calculated to guide the establishment of plots. Plots were placed as close to these coordinates as possible, but adjusted as necessary to ensure capturing enough sample trees and a site representative of the polygon as a whole. Between five and 15 trees were cored per site depending on the complexity of the site (i.e., the number of different apparent tree strata). In addition, young trees less than four inches DRC were destructively sampled among the plots with a hand saw for later analysis as cross sections. A total of 123 cores from among 64 mature trees were analyzed, plus 20 cross-sections from the younger trees.

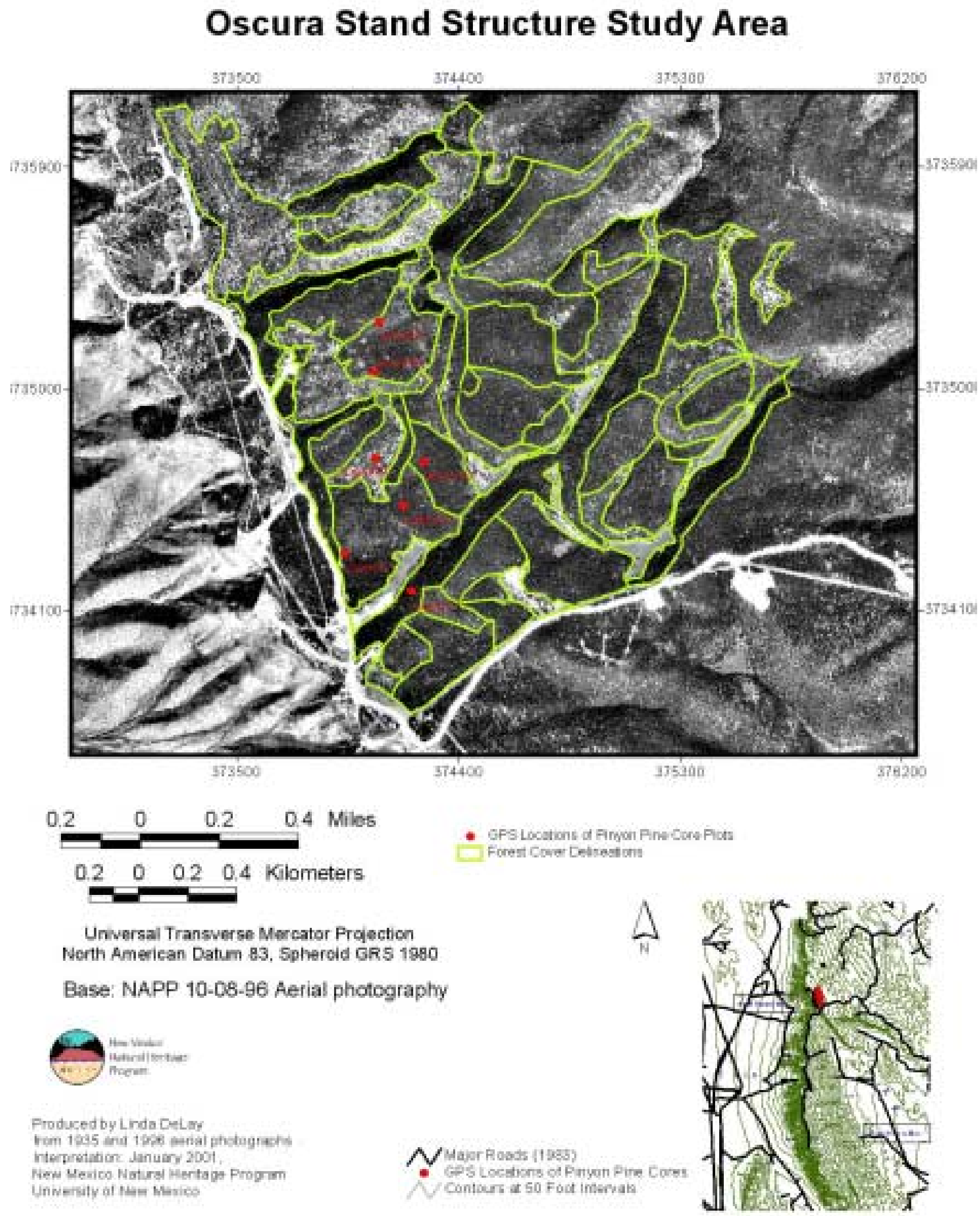

Figure 9. Study area and sampling locations for the Oscura Mountains pinyon woodlands stand structure analysis. Delineations represent potentially different stand structures, and plots were allocated accordingly.

## Dendrochronological analysis

### *Fire-scars*

Fire-scarred samples were trimmed and surfaced to optimize the visibility of ring structure. If necessary, samples were re-cut using a band saw. The reason for re-cutting was to prepare a flat, transverse surface that would facilitate sanding. The samples were sanded using successively finer grits, up to 320, and, when necessary, 400. Cross-sections were examined under a variable power 10-30x microscope. Each cross-section was dated, using dendrochronological techniques (Fritts 1976). Then, each scar on each cross-section was assigned a calendrical date. Preliminary mean fire intervals were calculated beginning from the date of the first fires in the record.

### *Stand Age Structure*

After drying, increment core samples were glued onto wooden mounts to expose their transverse surface (wood cells oriented vertically). Cores were surfaced with a belt sander using sandpaper of progressively finer grits, starting with 280 and finishing with 320. In certain cases, a 400-grit sandpaper was employed by hand to yield a high-resolution surface. Cross sections were similarly prepared by stabilizing with a backing board when necessary and then polishing with a belt sander. Cores and sections were examined under a variable power 10-30x microscope and the year of the innermost ring was determined by crossdating.

Pith ages were estimated by visually assessing the curvature of the innermost 10-15 rings and extrapolating towards the center when it was not present on the sample. Sets of nested, regularly-spaced circles printed on transparencies were used as guides. Pith dates were compiled and analyzed to assess establishment and stand development patterns.

## Spatial analysis of woodland patch structure through time

### *Comparative historical fire patch spatial analysis*

For the comparative analysis of potential fire patches between 1935 and 2000, we employed a technique similar to that reported by Miller (1999). We acquired sets of 1935-36 Soil Conservation Service 1:31,680 black and white photography, 1996 1:40,000 NAPP (10-3-96) aerial photographs, and 2000 SpaceImaging® IKONOS satellite imagery with (1-meter resolution panchromatic) over a study area that encompassed the pinyon-juniper woodland associated with the east side dip slope of the Oscura Mountains (Figure 10). The aerial photos were scanned at a resolution of 600 dpi and 1000 dpi, respectively, and then mosaicked and geo-rectified for use in ERDAS Imagine software and by Earth Data Analysis Center, Albuquerque, New Mexico. Stereo pairs of the photos (1996: photo positives; 1935-36: prints) were examined under a stereoscope and potential historical fire patches were delineated on an overlay of acetate film. Compared to the surrounding landscape, potential fire patches were defined as areas of decreased vegetation cover with contrasting border divisions (Figure 11). Some patch borders lying within sparse vegetation were, however, less distinct, particularly at lower elevations in the older photography. Although some patch boundaries could have resulted from physical attributes rather than fire, in general, the delineated patches did *not* correspond to, or they crossed over, landscape features such as different soils, aspects and slopes, etc.

Percent tree canopy was estimated for each polygon using standardized comparative randomized point coverages in increments of 10% as a visual guide. After repeated visual checks, estimates of cover were estimated to be accurate within ± 10%. One person made all the estimates to maintain relative precision of the estimates. Generally, >20% canopy cover differences between periods were required to signify change and indicate a possible fire patch.

An estimate of the age of fire patches was based on tree cover and the year of detection on aerial photographs. Patches were called new if they contained 0 to 10% tree cover or if the patch was evident in 1996 but not in 1935-36; patches were called old if they had greater than 10% tree cover. The polygons were then screen-digitized using ERDAS IMAGE software to calculate areas. Due to image distortion in some areas of the mosaic of these digital aerial photos, we adjusted the boundaries of the scar in the 1935 to fit the topography of the 1996 photos. This process made past and present comparisons of the area possible. We used ESRI ArcView 3.1 to analyze change in area and to display the results spatially.

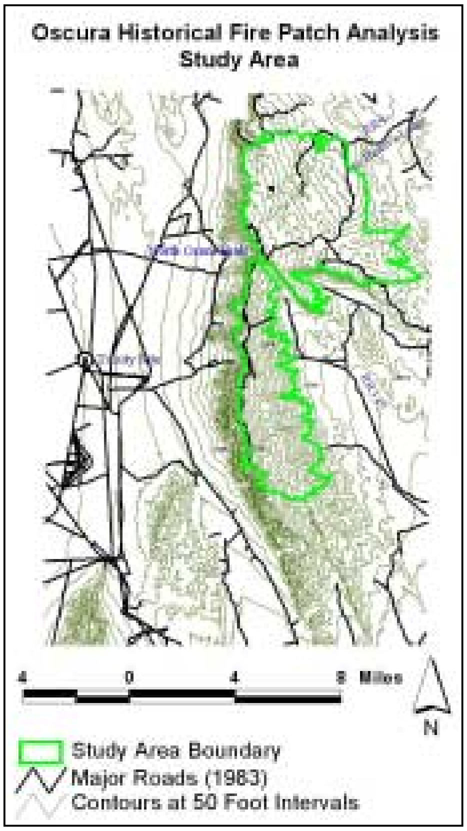

Figure 10. Study area for fire-patch analysis through time.

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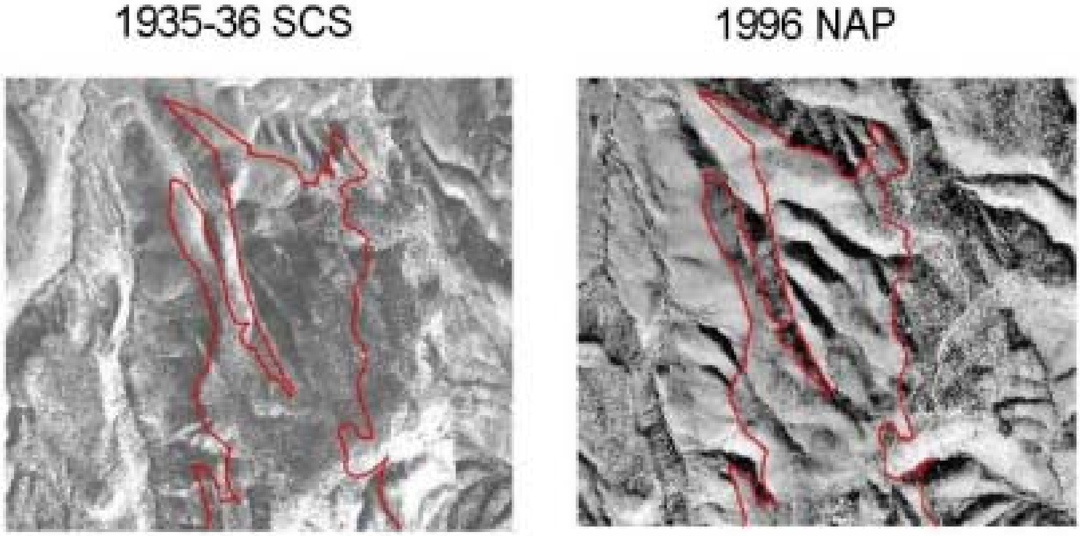

Figure 11. An example of a potential fire-patch delineated in the 1996 NAP photography (at Silvertop Mountain) and then overlain onto the 1945-36 Soil Conservation Service photography to detect differences in woodland cover.

*Stand structure spatial analysis*

Over a subset of the Oscura Mountain study area, woodland stands were further delineated with respect to aspect and slope, and canopy structure and cover using the 1996 photography and IKONOS imagery. The focus was on the upper elevation old growth pinyon-dominated stands to the east of North Oscura Peak (Figure 12). We used the same 10% cover classes as in the above fire patch analysis to classify stand canopy cover in each polygon. The 1996 polygons were then overlain on the 1935-36 photography to determine the changes in cover during the ensuing 61 years on a stand-by-stand basis. This stand map was then used to analyze more closely the relationship between potential fire patches and terrain and also it was the first step in the development of the higher resolution stand map used to design the above stand structure studies.

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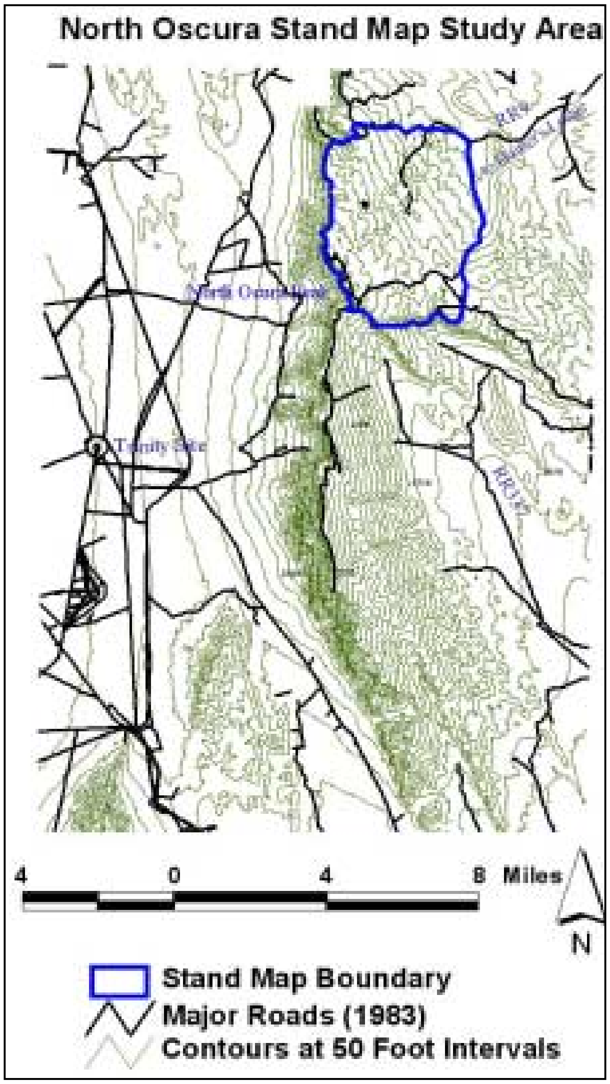

Figure 12. The study area for the stand structure spatial analysis was limited to the northern Oscura Mountains.

# RESULTS

## Salinas and Silvertop

### *Historical fire regimes from fire-scars*

Preliminary fire reconstructions using ponderosa pines from Salinas Peak and Silvertop Mountain suggest that fire regimes have changed over the course of the 400-year record (Figure 13). In the ponderosa pine record there appear to be four distinct periods reflecting differences in frequency and extent of fire. The earliest is the Pre-settlement/Spanish Colonial Period extending from 1600 to about 1750 where frequent, small patchy fires were the norm as indicated by the many events that scarred only one or two trees at a time versus the relatively few events that sacred many trees simultaneously across the stands. During this period, the site mean fire interval (SMFI) on Salinas Peak was 15.8 years, and on Silvertop, 17.25 years, for an average of 16.2 years (the point mean fire interval or PMFI was also 16.2 years). The highest number of recorded fires occurred during suspected regional droughts of 1666 and from 1728-1735 (possibly extending to 1750 based on Betancourt et al. (1993) and Swetnam and Betancourt (1998)). Since early Spanish use of these mountains was limited, this may represent a pre-Columbian fire regime indicative of the modal climatic conditions of the period (near normal precipitation punctuated by sporadic drought and wet periods). This high-frequency fire regime may have been augmented by Native American practices, but their activities in the study area are not well documented.

From 1750 to about 1830, there occurred a Transition Period with few fires on Salinas Peak and a reduced number on Silvertop (PMFI of 37 and 23.5, respectively). On Salinas Peak, there were only two fires recorded during the 100-year period (1789, 1810, 1829). The fire-scars were from different trees in different stands, but the trees either had fire-scars before or after this period, or both (trees SAL12, SAL 15 and SLP01), indicating that they were “sensitive” trees. On Silvertop there were five fires (two of which scarred multiple trees) compared to 14 in the previous Colonial Period of 150 years. The period was labeled as transitional because Spanish and Anglo-American settlement effects such as fuelwood harvesting and extensive grazing were probably just beginning to occur but still not yet large factors in the depression of fire incidence during this time. Rather, climate may have been the primary driver. On a regional basis, the years from 1740 to approximately 1780 were considered climatically highly variable with numerous oscillations between drought and wet periods and correspondingly high variance in fire frequencies (Swetnam and Betancourt 1998). Four out of the five fires on Silvertop occurred during the window from 1750 to 1790. In contrast, the period from 1780 to 1830 was regionally one of wet winters and springs and associated with lower fire frequencies. In keeping with this pattern, we uncovered only three fires during this period and from different years, but more sampling is in order confirm the paucity of fires during later part of the Transition period.

There is a distinct period from about 1830 to 1910 that we have associated with Anglo-American settlement that is particularly evident in the record from Salinas Peak. Fire frequencies increased somewhat (but not to the previous levels), but fires also appeared to be larger in extent and presumably more intense (the 1860 fire was a major event that killed several trees). During this period, livestock grazing levels likely peaked, reducing fuels and hence the potential for fire. Fire probably still occurred periodically following good precipitation years

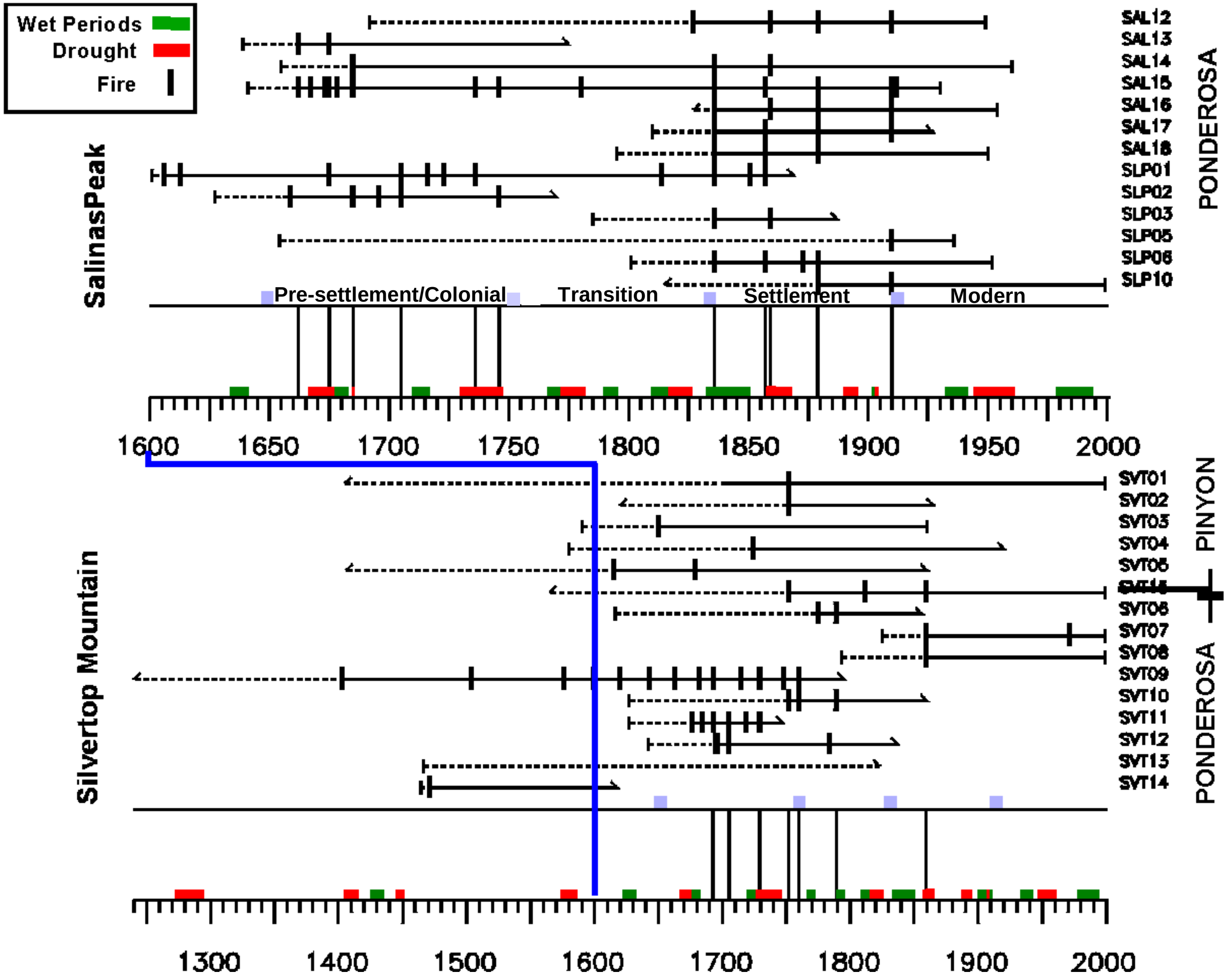

Figure 13. Fire chronology for fire-scarred trees on Salinas peak and Silvertop Mountain. Because Silvertop has a deeper record it is offset from the Salinas Peak as indicated by the blue line, and has cruder timescale. In addition, on Silvertop, six pinyon pines were sampled along with nine ponderosa pines. Horizontal lines are the sampled time spans for individual trees and the vertical black tick marks are fire dates recorded on those trees. A composite record for each site is shown at the bottom of each diagram where long tick marks represent fires that scarred at least two trees at a site. Wet and dry periods are based on Grissino-Mayer et al. (1997).

where fuels built up despite grazing (grazing pressure may also have been less on the mountain tops during good years because of increased forage at lower elevations).

The Modern Period begins after 1910 where only one fire (1971) was recorded from one tree. As a caveat, the sample size was diminished significantly because many of the ponderosa pines sampled had died during the drought of the 1950's. Yet, this is an era when fire suppression had became the norm while at the same time grazing continued, up until military acquisition in 1942. Furthermore, the dramatic drop off in fires at the turn of the twentieth century has been well noted both regionally and throughout the western United States (Swetnam 1990; Veblen et al. 2000). The small sample size also precludes an analysis of the post-1942 non-grazing period, but the spatial analysis presented below does suggests that there was likely more than one fire on Salinas and Silvertop during the post-1940 period. Fine-grass fuels are now plentiful in these ponderosa /Arizona fescue woodlands, and, hence, they are very prone to increased surface fires. The impacts of increased surface fire on the stands is uncertain—high frequency fires can eliminate reproduction, but fires also reduce tree seedling competition with grass under favorable climatic conditions (see *Salinas and Silvertop Stand Structure* below). To aid in development of a management prescription, more in-depth studies are needed to document a possible shift in fire regime in the context of current fuel conditions and pine reproduction status.

In pinyon woodlands on Silvertop, the fire regime is somewhat different and the shifts over time are less pronounced. Although the pinyon fire-scar samples were limited, there was some indication that the overall fire frequency in the pinyon woodland was lower than in ponderosa pine (30 to 60 years and an average of 43 years versus 10 to 30 years in ponderosa). As with the ponderosa record, the Spanish Colonial Period still had the most events, but only one date, 1752, is replicated among the tree clusters—indicating that when fires occurred they were patchy. There was only one fire recorded during the Transition Period (1808) and one during the Anglo Settlement Period (1859). After 1859, there were no fires recorded in the pinyon fire-scar record, but based on the analysis of historical aerial photography and file records, fires did occur occasionally during the Modern Period. As we will show below, some of these were large stand replacement fires.

### *Stand structure and fire*

Recruitment of ponderosa pine on Salinas and Silvertop has been episodic over the past 200 years (Figure 14). Each sampled group tended to be more or less even aged, and the establishment of each group tended to occur after either major climatic events or fires. Recruitment after fire may have been aided by a combination of good precipitation and reduced grass canopies due to the fire (or possibly grazing). In our sample, there were few trees established during the Spanish Colonial Period that are alive today (i.e., over 250 years of age). A cohort was established on Salinas following a fire in 1790 with subsequent favorable wet periods (SP-4 and SP-5). Similarly, on Silvertop most of the living trees are under 150 years of age with establishment having occurred following an 1859 fire (ST-1). Both SP-2 and SP-3 appear to have been primarily established during favorable moisture conditions during the early part of the twentieth century. There are likely other cohorts on Salinas Peak that may fill in gaps in the

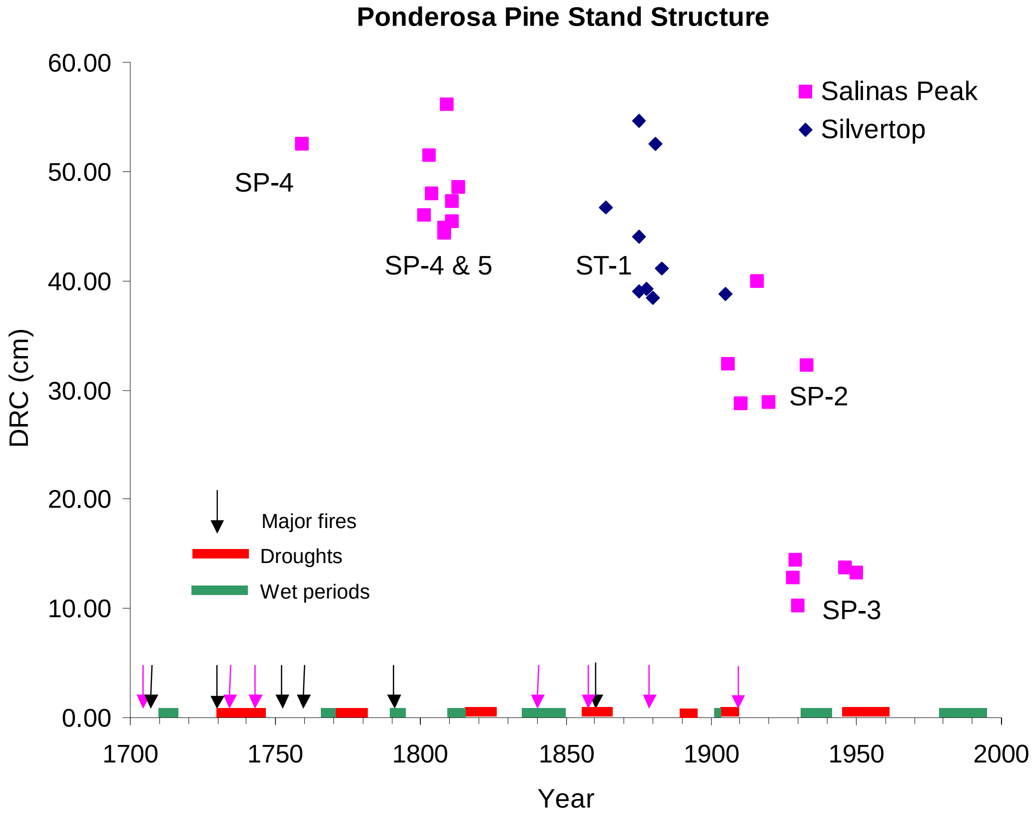

Figure 14. Age and diameter root crown (DRC) relationships among stands on Salinas Peak and Silvertop Mountain. Individual stands are indicated by sample number. Major fires are based on Figure 13. Wet and dry periods are based on Grissino-Mayer et al. (1997).

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record and give a fuller picture of the episodic recruitment that has occurred. In particular, there are some groups of younger samplings and scattered individuals that were likely under 50 years of age, but because there were relatively few individuals, they were not destructively sampled at this time to get precise age determinations.

As a final note on stand structure, the observations on fire-scar samples indicate that many of the older trees on Salinas died during the 1950's drought, but this not readily apparent on Silvertop among either the pinyon or ponderosa. Mortality events were different there and need further study. Understanding more about ponderosa and pinyon mortality can affect management decisions, particularly with respect to prescribed burns and other silvicultural prescriptions.

### *Spatial fire patch analysis*

While only one fire on Salinas Peak (1910) and one on Silvertop Mountain (1971) are indicated in the tree fire-scar record for the twentieth century, the analysis of historical aerial photography indicates that there are some 20 forest and woodland patches that possibly burned during this period, representing over 40% of the pinyon and 29% of the ponderosa pine woodlands (Table 1). Whether each patch represents a separate fire event remains to be confirmed with tree and shrub age sampling. It is likely that they do not, and that the number of fire events was probably fewer than ten, with perhaps only four of these being large fires that burned at a landscape scale (Figure 15). The average pinyon patch size was under 75 ha, with only few over 500 ha. There were also three patches in pinyon and two in ponderosa that have been interpreted from the degree of crown closures as being from the fire events during the ninetieth century.

Most of the older patches (prior to 1932) were at lower elevations at the ecotone from pinyon-dominated woodlands to juniper savannas. The long, relatively continuous west-facing slopes of the mountain range add an element of aridity plus the potential for surface fires to move upslope out of the grasslands and through the savannas. When the fires reached the denser woodlands of higher elevations, the discontinuous surface fuels may have disrupted fire spread. However, periodically, crown fires did occur removing large swaths of woodland. The most recent burn patches were closer to the mountaintops and human installations, and appear to have been started locally either by lightning or humans. There is little evidence that the ponderosa pines ever formed closed-canopied woodlands, and it appears that surface fires were the norm, running through the fine grass fuels and sporadically killing younger ponderosa pines.

Table 1. Salinas Peak-Silvertop potential landscape fire patches as estimated from 1935 aerial photography. Matrix (OG) refers to old growth stands with little evidence of fire.

| Patch type | Area (ha) | % of total area | Number of patches | Mean patch size (ha) |
|---|---:|---:|---:|---:|
| *Pinyon Pine* | | | | |
| 0 to 60 years | 551 | 20 | 9 | 61 ± 88 |
| 60 to 100 years | 523 | 19 | 8 | 104 ± 90 |
| >100 years | 457 | 17 | 3 | 76 ± 83 |
| Matrix (OG) | 1210 | 44 | na | na |
| Total Pinyon | 2818 | 100 | 20 | na |
| *Ponderosa Pine* | | | | |
| 0 to 60 years | 68 | 29 | 6 | 11 ± 22 |
| >100 years | 39 | 17 | 2 | 19 ± 11 |
| Matrix (OG) | 124 | 54 | na | na |
| Total Ponderosa | 231 | 100 | 8 | na |

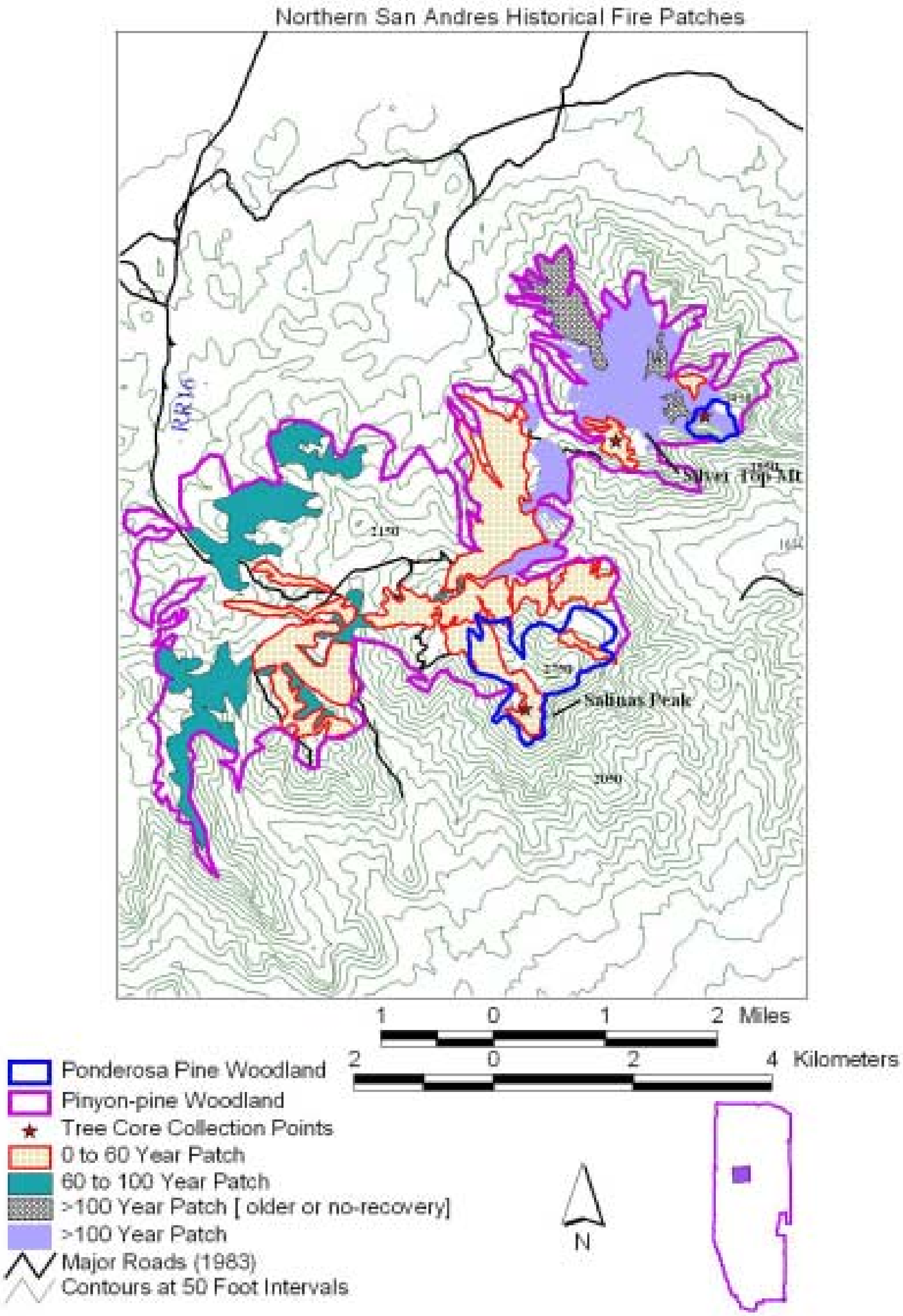

Figure 15. Potential fire-patches at Salinas Peak and Silvertop Mountain based on comparative aerial photo analysis.

## Oscura Mountains

### *Landscape woodland stand pattern*

The pinyon-juniper woodlands of the Oscura Mountains present an intricate picture of stand structure in relation to fire and climatic events (Figure 16). While the west-facing escarpment slopes support mostly montane scrub and only scattered pinyons and junipers, the long east-dipping slopes support some of the largest stands of contiguous, minimally disturbed woodlands in the Southwest (approximately 13,750 ha or 34,000 ac). While the dip slopes are relatively uniform, they are cut by several small canyons creating a moderate degree of landscape heterogeneity (Figure 16b). This, coupled with a long elevation gradient from 6,000 ft to 7998 ft (1,825 to 2438 m), has led to a diverse complement of pinyon-juniper communities in terms of floristic composition and vertical structure. At the lower elevations, the woodlands are dominated by junipers with scattered pinyons, normally forming a singletree layer with grassy understories of varying densities. At higher elevations, pinyons dominate and form heterogeneous multi-tiered canopies (Figure 16c) with various mixtures of shrubs and grasses in the understory. Canopy density varies both as a function of habitat and possibly of fire (Figure 16d and see *Spatial fire-patch analysis* below). Cool, north-facing slopes tend to be dominated by pinyon-wavyleaf and Gambel oak communities, while south-facing slopes are drier and dominated by scattered grasses, wavyleaf oaks, and yuccas. The gentle dip slopes have mosaics of communities that are commonly dominated by wavyleaf oak or bunch grasses such as Scribner needlegrass and sideoats grama. This diversity in structure, composition, and terrain has led to a wide range of fuel structures and fire behavior through time in these woodlands. But lacking ponderosa pine for fire-scar material, inferences on the role of fire in these complex woodlands relied upon the small sample of pinyon fire-scars found coupled with an analysis of landscape fire patches and stand age structures.

### *Spatial fire patch analysis*

The spatial pattern of pinyon fire patches in the Oscura Mountains was similar to that of the northern San Andres, but frequency and extent appear to be less (Table 2). On a century basis, the overall turnover rate based on fire patches was only 11 to 12 %. In part, this is because the majority of the pinyon and juniper woodlands occur on long, east-facing slopes (versus west-facing on either Salinas Peak and Silvertop) where cooler, more mesic conditions may act to limit the initiation and spread of fires. The majority of fire-patches tended to be at lower elevations adjacent to the juniper savannas along the lower foot slopes and valley bottoms (Figure 17). Since lightning caused fires in grasslands are prevalent on WSMR, it would be quite possible for fires initiated in the grasslands to spread upslope through the juniper savanna into the pinyon woodlands and occasionally burn all the way to the ridgeline. Regardless, most of the fire patches were 60 years old or older. Only one patch can be definitely be ascribed to a fire in the last 60 years, and it occurred on a lower east-facing slope below South Oscura Peak (Jim Site fire of 1996). It was a lightning-caused crown fire that if it had not been suppressed, might have spread to the ridgeline. There was evidence of older fire-patches at higher elevations that were probably started by lightning, but with the exception of a large fire just north of North Oscura Peak, most of these appear to be localized small patch fires.

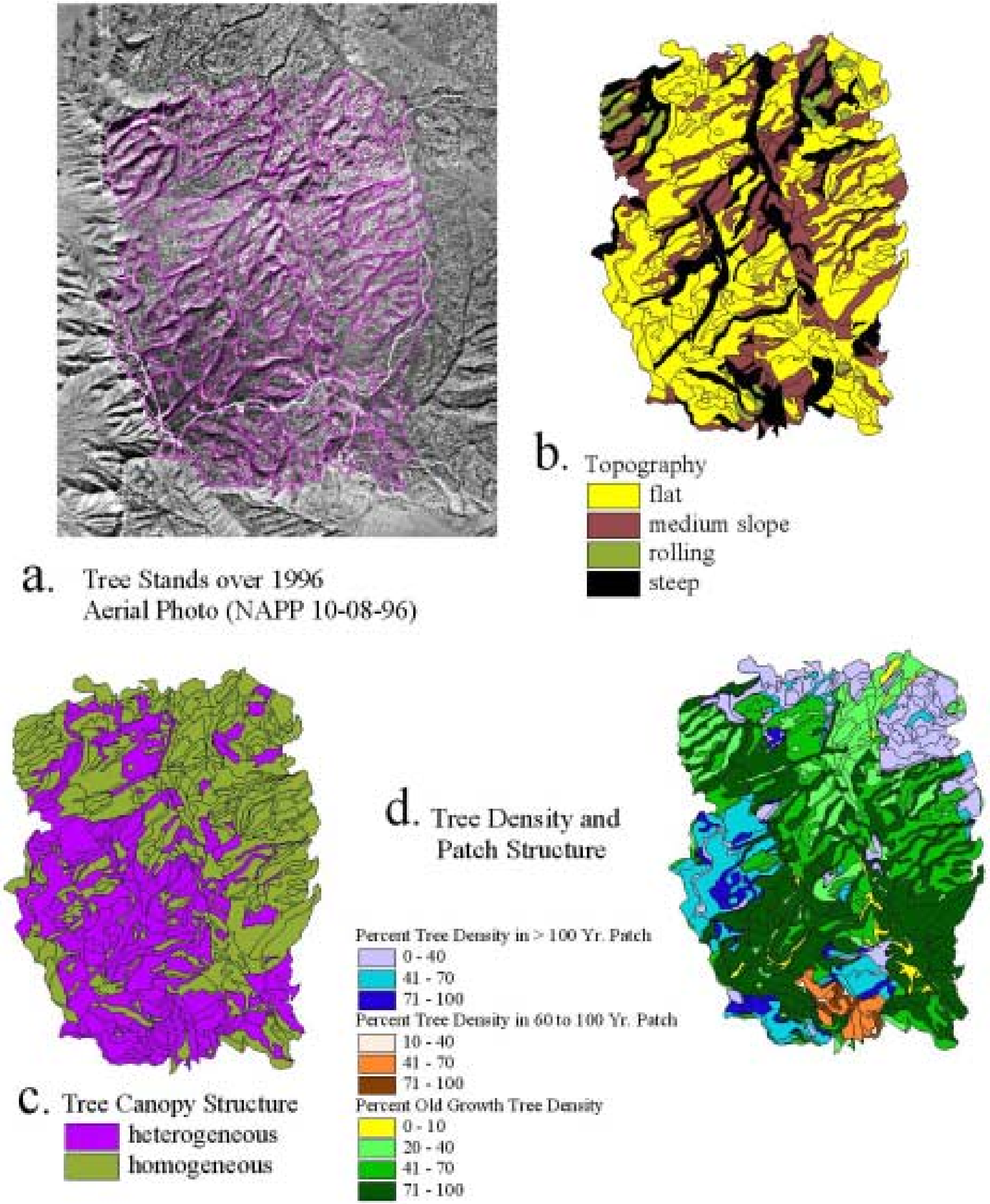

Figure 16. Stands of pinyon-juniper woodlands of the northern Oscura Mountains were delineated in the 1996 NAP photography (a) and 2000 IKONOS satellite imagery based on vertical canopy structure (c), canopy density (d), and were often correlated with topography (b).

Table 2. Oscura Mountains potential landscape fire patches as estimated from 1935 aerial photography. Matrix (OG) refers to old growth stands with little evidence of fire.

| Patch type | Area (ha) | % of total area | Number of patches | Mean patch size (ha) |
|---|---|---|---|---|
| *Pinyon Pine* | | | | |
| 0 to 60 years | 286 | 2 | 2 | 143 ± 191 |
| 60 to 100 years | 1180 | 9 | 11 | 107 ± 104 |
| >100 years | 1639 | 12 | 20 | 81 ± 124 |
| Matrix (OG) | 10636 | 77 | na | na |
| Total | 13743 | 100 | 33 | 94 ± 118 |

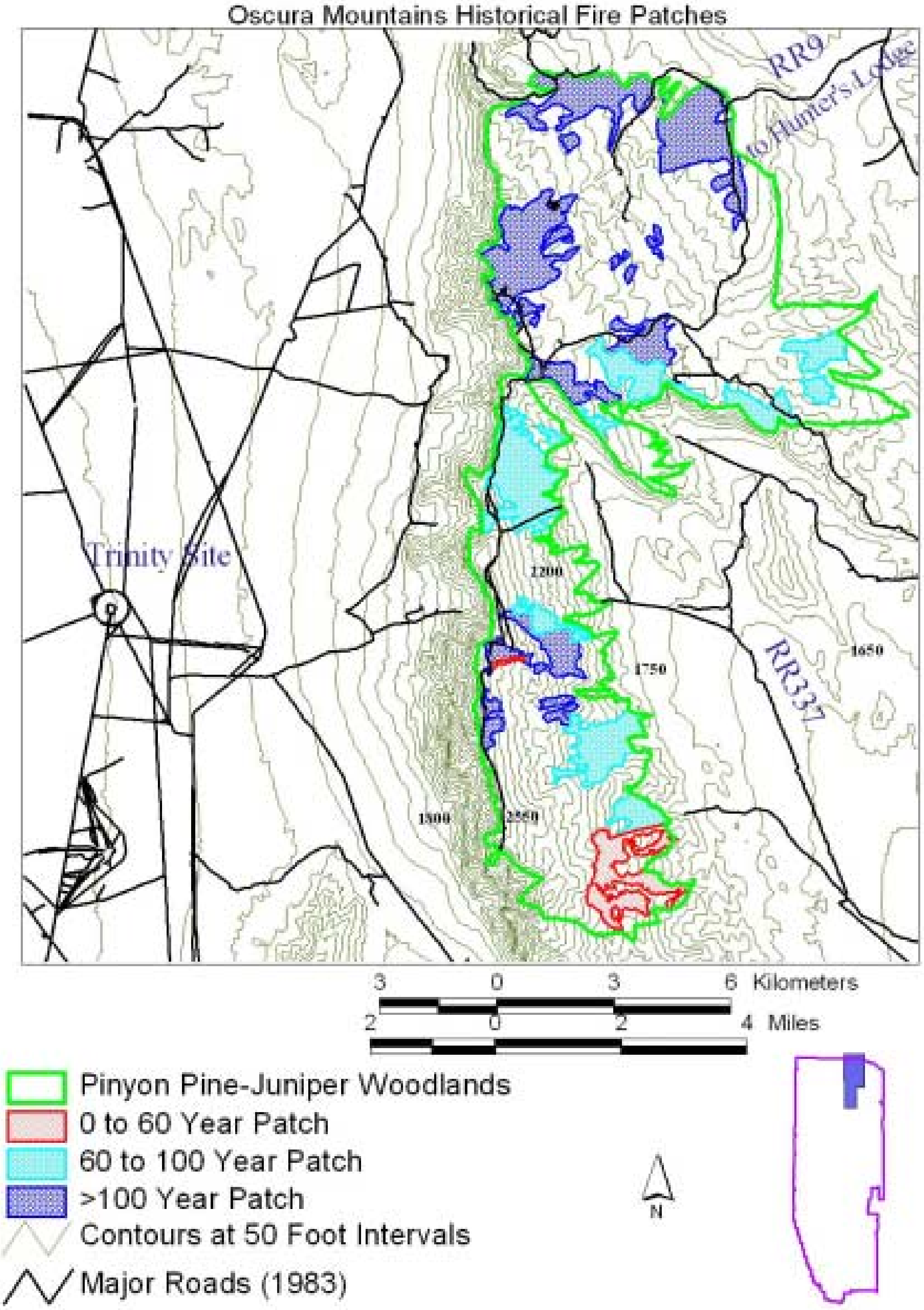

Figure 17. Potential fire-patches on the Oscura Mountains based on comparative aerial photo analysis.

*Oscura pinyon stand structure and fire*

Stand structure analysis and the limited fire-scar material found among the pinyons were used to further evaluate the complex spatial pattern in terms of fire history. Attention was focused on the upper elevation woodlands just below North Oscura Peak (Figure 18). The hypothesis was that those stands that could be differentiated in the recent photography ought to have different age structures and potentially different fire histories. Among the seven stands analyzed, thus was found to be partly the case (Figure 19). Overall, there appeared to be distinct cohorts of trees in each stand that tended to be established during non-drought periods. Some of the gaps in ages also correspond to the few fire events that were recorded as fire-scars, suggesting the possibility that less fire resistant younger trees may have been removed from the stands by low intensity surface fires during those periods (but it must be noted that fire evidence in the form of charred stumps or scattered charcoal was not abundant within the stands). Of note is the fact that no significant cohort, nor fire, has been uncovered between 1840 and 1880—a non-drought period where recruitment might be expected.

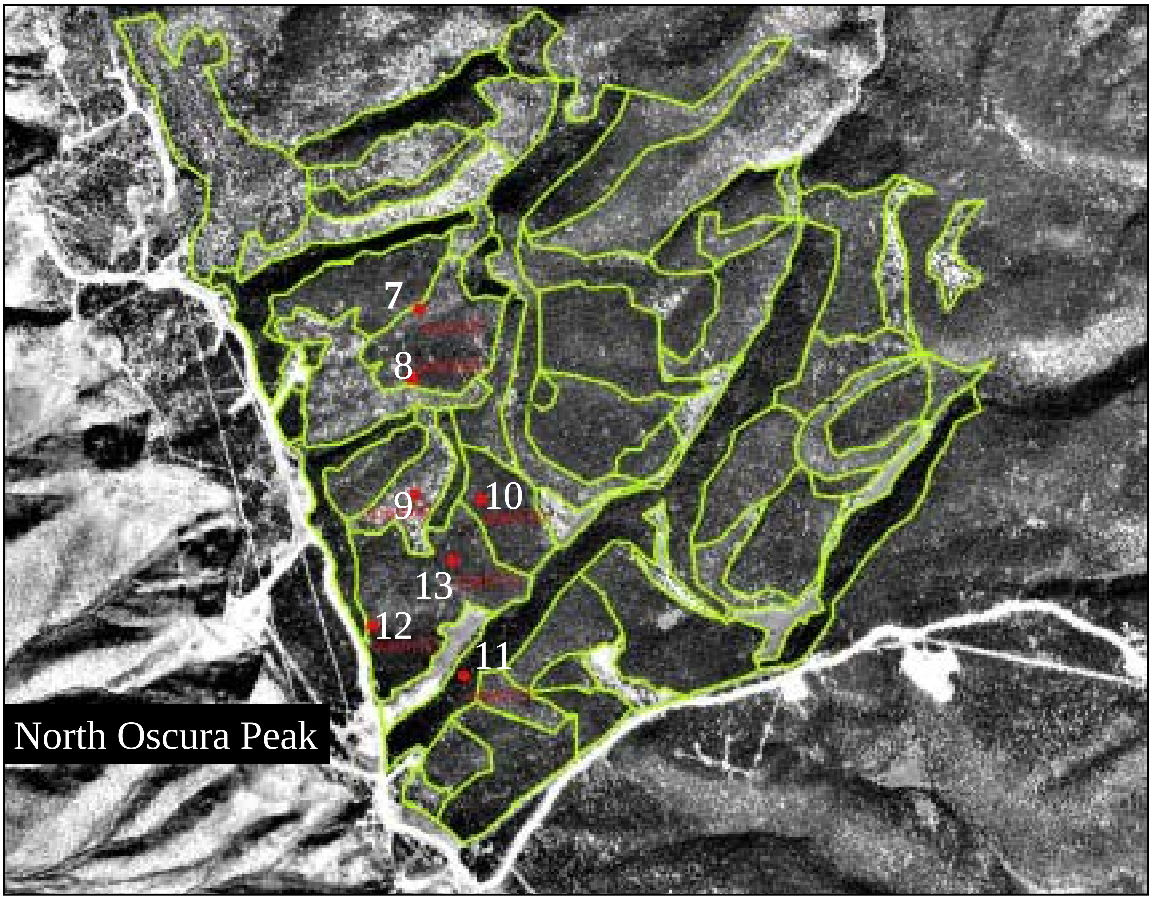

Figure 18. North Oscura Mountains stand structure sampling points distributed among stands of differing vertical structure, canopy density, and terrain based on aerial photo interpretation. Numbers in white are the stand numbers used in Figure 19 and in the text.

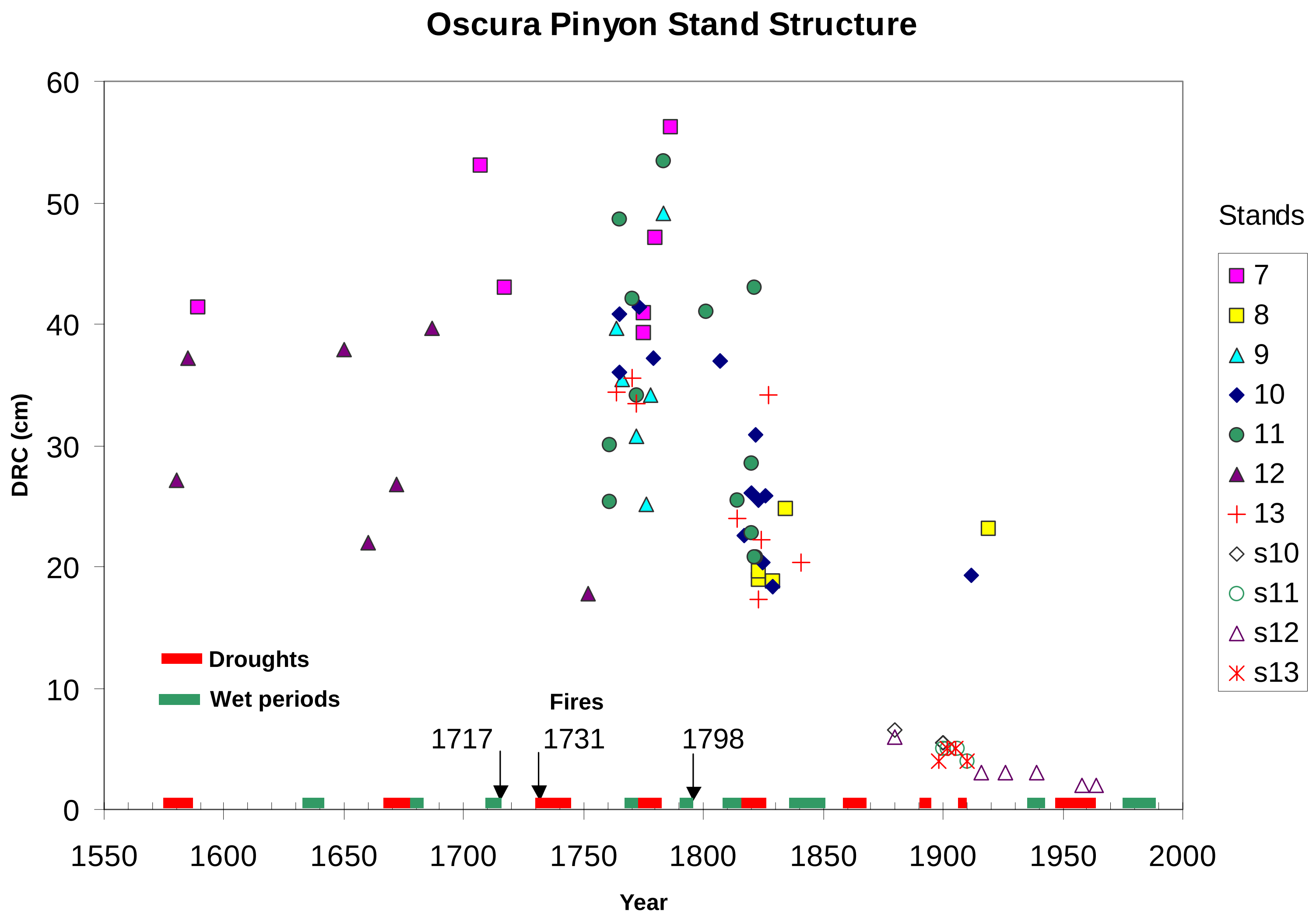

Figure 19. Age and diameter root crown (DRC) relationships among stands below North Oscura Peak. Fire dates are based on fire-scar samples of pinyons found in two of the stands (12 and 10). Wet and dry periods are based on Grissino-Mayer et al. (1997). Stand locations are shown in Figure 18.

There were structural differences among stands, even across relatively short distances (1,000 m), yet similarities despite contrasting habitats. Stands 7 and 12 were the oldest with trees approaching 400 years in age, and they also had the most complex stand structures, with possibly four or more establishment cohorts. These “old growth” woodlands had staggered height classes in the canopy and sometimes dense “doghair” stands in the understory (Figure 20). While stands 7 and 12 had similar old growth stand structures, they were separated spatially by other stands that lacked the older cohorts (stands 8, 9, 10, and 13). This suggests that the earlier fire events such as those in 1717 and 1731 may have had a significant impact on these stands, e.g., a stand replacement fire may have occurred in the early 1700’s resulting in the initiation of new stands at sites 8, 9, 10, 11, and 13, but a fire event that did *not* remove the canopies at sites 7 and 12.

Figure 20. Small, but dense “doghair” stands of pinyon pine reproduction often occurred under canopies and in open areas within the woodlands

Not all stands that seemed different in the aerial photos had different stand structures. In both stands 10 and 13, cohorts were established in the 1760’s, 1820’s and after 1910. Hence, while there were slight differences in canopy density, aspect, and slopes among these adjacent stands, they were not functionally different with respect to the impacts of past fires. Furthermore, stand 11 on the opposite steep north-facing slope from 10 and 13 had essentially the same stand structure despite a strong difference in habitat type, suggesting that the historical contingency of a major fire event can overshadow site differences in the development of stand structure. The influence of past fires is also suggested in stand 8 with its lack of trees older than 200 years, possibly the result of the 1798 fire event (Figure 21). In contrast, stand 9 lacks the 1820’s cohort, but whether surface fire played a role in eliminating this cohort is unclear. An alternative explanation is that the interaction of climate and local edaphic conditions precluded the successful establishment of the 1820’s cohort (yet this stand showed successful recruitment in the twentieth century).

Figure 21. Some stands had relatively young trees (<200 years), possibly as the result of an earlier stand-replacement fire.

Although the sampling was limited, there is a suggestion of similar fire regime periods to those found in the northern San Andres Mountains: 1) a Spanish Colonial Period prior to 1750 with sporadic recruitment tied to climatic events and possibly relatively frequent small patch fires (more sampling depth is needed to reach a definitive conclusion on this); 2) a Transition

Period from 1750 to 1830 with high levels of recruitment and little drought or fire; 3) an Anglo Settlement Period from 1850 to 1910 with little recruitment, but also little evidence of fire (although based on the San Andres data, some large fires would be expected during this period; a more in depth search for fire-scars is needed to confirm a lack of fire); and 4) the post- 1910 Modern Period with ongoing recruitment without fire (although the historical aerial photos indicate a fire early in the twentieth century less than one km away to the southeast of the sampled stands).

## DISCUSSION

With respect to the ponderosa pine woodlands of Salinas Peak and Silvertop Mountain, their status remains uncertain. Clearly, fire frequencies were depressed beginning in the later half of the ninetieth century with near cessation of fire through first half of the twentieth. Our expectation was that this should have led to the development of dense “dog hair” stands of pine reproduction, as has happened throughout much of the ponderosa pine forests in the west (Keane et al. 2002). The reproductive cohort from around 1919 that is usually associated with these dog hair stands in the Southwest (Savage et al. 1996), is present only in small numbers on Salinas Peak, and not on Silvertop. This may be a function of the poor reproductive success in a marginal habitat for ponderosa pine (although it is likely that these stands have managed to persist on these mountain tops throughout the Holocene and before). Alternatively, it is possible that a surface-fire regime may have resumed on the mountain tops following the establishment of the military reservation in 1942 , and at least for a short period of time, eliminating much of the 1919 cohort and preventing the development of dog hair thickets. The cessation of grazing and limited active fire suppression, particularly in the early years, along with plentiful lightning may have provided the ideal conditions for a high frequency surface-fire regime thought to be the norm for ponderosa pine savanna woodlands (Covington and Moore 1994). Our spatial fire-patch analysis suggests that fires did occur on top of Salinas within the last 60 years, but how many and their extent could not be determined. Additional age sampling among younger cohorts along with extended searches for fire-scars will be needed to further understand the effects of military management on these stands. This is also an important regional question, because these stands could represent a valuable *in-situ* example of a long-term outcome from what is now a widely adopted prescription of reintroducing surface-fire regimes to restore southwestern ponderosa pine forests.

In pinyon pine woodland, our results suggest that patch and stand structure, although seemingly predicated on landform, aspect and soils patterns are imbedded in a larger landscape-level fire mosaic. Based on historical air photo analysis, most fires started in or near juniper savannas and spread upslope into the pinyon zone, and were likely limited only by the availability of continuous surface fuels. At higher elevations, the different ages of pinyon patches suggests that smaller local crown or surface fires likely occurred, but they have been difficult to detect in the pinyon fire-scar record. Occasionally, large stand-removing crown fires swept through the closed canopied pinyon woodlands to be followed by a long-term process of relay succession from open ground through montane shrublands and finally woodlands (possibly mediated by bird caching of pinyon nuts and seed rain from newly maturing and residual trees). Floyd et al. (2000) working in similar forest-like pinyon woodlands at Mesa Verde National Park in southeastern Colorado also describe a scenario of small local patch fires initiated by lightning strikes but with limited spreading, and occasional large stand replacement fires driven by extreme drought conditions. The result is pinyon woodlands that exhibit a complex multi-age class sub-structure that has both vertical and horizontal patterning (emergent canopies and patches within patches) driven by recruitment cohorts during inter-drought periods and occasional fires, both large and small. Similar complex, fire-induced stand structures have been reported for Mexican pinyon (*Pinus cembroides*) forests in central Mexico by Segura and Snook (1992).

Given that we had relatively few fire-scar records in pinyon, it is difficult to evaluate natural fire intervals. Our best estimates point to intervals ranging anywhere from 30 to 100 years or more, with a variable spreading from local patch fires to wide spreading fires. At the landscape level, turnover likely takes place over four centuries or more (given that there are stands with trees over 400 years old in them). Floyd et al. (2000) also reported similar long turnover at Mesa Verde. This long-turnover regime is in dramatic contrast to the classical historical southwestern ponderosa pine fire regime evident in the Salinas Peak and Silvertop record—a high surface fire frequency on the order of three to ten years that served to maintain open, park-like stands. Such a high-frequency fire regime is also a possible scenario for the lower elevation juniper woodland savanna where quick burning grass fuels would have maintained an open woodland by elimination of most younger trees (occasional young trees would escape fires long enough to reach maturity and a certain degree of fire resistance). This is in keeping with a maximum natural fire frequency of 50 years for Mexican pinyon woodland-savannas reported by Moir (1982) for the Chisos Mountains in Big Bend National Park.

Our preliminary results indicate that the WSMR high-elevation forest-like pinyon pine woodlands have yet to show a fire regime that is significantly outside the “historical range of variability” as defined by Swetnam et al. (1999). This is in keeping with conclusions drawn by Floyd et al. (2000) for similar pinyon woodlands at Mesa Verde. Hence, an active prescribed landscape-scale burn program with planned high frequency ignitions following a ponderosa pine model would be inappropriate. Such a program would imprint an artificial pattern on the ecosystem with unknown impacts on water transport, sediment yield, flora and wildlife populations. Instead, given the long historical intervals between fires and the extended length of time required for recovery from fire, we would recommend a passive prescribed natural burn policy with suppression of only human-caused fires. In contrast to proactive strategies that have been proposed for WSMR by some fire professionals (see Boykin 2000), we suggest that any prescribed management burns in pinyon woodlands be limited and used primarily to buffer military facilities from fire hazards. Even then, fire needs to be used with discretion to avoid accidental ignition of the woodlands on a large scale. Floyd et al. (2000) recommended a similar approach towards protecting archeological and visitor facilities at Mesa Verde National Park .

Our studies contribute to the growing body of evidence that fire plays a unique and critical role in the structure and dynamics of southwestern pinyon woodlands from the individual tree to the landscape mosaic (Moir 1982; Bradley et al. 1992; Gottfried et al 1995; Floyd et al. 2000). What was once thought of as only an infrequent, incidental process in these ecosystems, is now seen as integral to their functioning. The key element is that these processes take place over long periods and hence these woodlands will require well-planned and patient management strategies. To aid that planning process, additional studies are needed on the age and canopy structure of patches as one moves down slope towards the juniper woodland savanna. Of particular value would be to identify in the landscape the transition between what are essentially the forest dynamics of the pinyon woodlands and the grassland dynamics of the juniper savannas. Knowing where this transition occurs can aid in fire management planning because of the dramatically different fuel structures and fire regimes between the two communities. In addition, detailed studies of within-stand structure of pinyon woodlands that include the role of animal vectors, and plant competition, as well as abiotic factors are key to understanding how these systems rebuild themselves after fire, and will serve to inform the prescriptions for long-term sustainable ecological management.

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# ADDENDUM

## Oscura Mountains Vegetation

## Past and Present

### Introduction

To provide a context for the fire history studies of the Oscura Mountains, a map of historical vegetation was constructed based on General Land Office (GLO) survey records of the late ninetieth and early twentieth centuries. The primary goal was to delineate the extent of pinyon-juniper woodlands some 80 to 120 years before the present—a period that coincides with of marked increase Anglo-American settlement, and hence, probably represents our best estimate of pre-settlement vegetation conditions (in fact one the main purposes of the GLO surveys was to legally delineate and describe lands for potential settlement). By building such historical maps and comparing them to modern day vegetation maps, we can help address such questions as the degree of pinyon-juniper "encroachment" that has occurred over the past century, and relate that to historical fire patterns and ultimately inform long-term fire and vegetation management.

GLO surveys are available for much of the United States and contain vegetation descriptions of the Township/Range/Section grid of the Public Lands Survey System (PLSS; U.S. Bureau of Land Management 1973). GLO surveys have been used to construct paper maps of historical vegetation in the Southwest ( Buffington and Herbel 1965; York and Dick-Peddie 1969; and Bahre 1991), while Rich et al. (1999), Muldavin et al. (2000a) and Yanoff (pers. com.) have developed GIS-based reconstructions that allow digital spatial map analysis of vegetation change. GLO surveys reconstructions provide a continuous and relatively dense spatial grid of PLSS-linked data that can be "clipped" to cover a particular landscape feature, such as a watershed. In addition, since the PLSS configuration is standardized and regular with vegetation descriptions associated along evenly spaced one-mile section lines, the GLO records can be interpreted as a systematic and random sample for statistical analysis. A template methodology developed by Rich et al. (1999) has made which makes obtaining and importing digitized coverages of the PLSS grid and GLO survey record information relatively simple and straightforward.

The surveyor vegetation descriptions highlight major plant lifeforms (trees, grass, and shrubs) and often provide information on status ("dense timber", "good grass", etc.). Bahre (1991) points out several limitations for using GLO surveys for reconstructing historical vegetation and assessing vegetation change. These include sometimes incomplete and inconsistent vegetation descriptions, qualitative and ambiguous references to plant abundances, and the use of obscure common names of plants. He concedes, however, that GLO data are the best resource for understanding ninetieth century vegetation in the Southwest. While we encountered some technical issues, we found that at the level of precision and scale at which we were addressing questions, that most uncertainties could be addressed satisfactorily. We present below an example reconstruction from four townships that encompass the Oscura Mountains using an iconic format overlain on the current vegetation as mapped from satellite imagery by Muldavin et al. (2000b).

## Methods

Most of the Oscura Mountains were surveyed by the General Land Office between 1882 and 1914 under the GLO's cadastral survey program, copies of which are held on microfiche at the offices of the Bureau of Land Management (BLM) in Albuquerque NM. As surveyors measured and marked township, range, and section boundaries, they recorded basic information on vegetation. For most townships, data were recorded for all internal boundary lines between sections, and a general description was written depicting overall vegetation in the township. For some townships, data were also recorded for boundaries lying along township edges. In the case of overlapping data, the oldest data was taken for analysis. We transcribed the GLO survey notes directly from microfiche to a Microsoft Access database

We interpreted the historical data on a section line by section line basis. The surveyors' notes are nearly always entered in a very standardized format, with information on timber, undergrowth, and grass in distinct positions summarizing composition along the length of the one-mile section line. From one township to another, the order of these three types of information varies, but within a given township, the order is typically highly consistent. The words "timber," "undergrowth," and "grass" are used frequently, but even when these words are absent, it is normally clear which type of vegetation the surveyor is referring to

Based on the most common terms, we assigned section lines to classes following the classification in Table A. Our classification is based on major vegetation types, as well as on modifying terms used in the surveyors' notes (e.g., "good," "scattered"). Table B shows the examples types how the historical data represented by terms in our classification.

Whenever timber was present, we classified the vegetation into one of two woodland classes. The most common terms describing timber in the surveyors' notes are "pinon" (likely *Pinus edulis* ), "juniper," or "cedar" (likely *J. monosperma*). If both species were indicted then the section line was classified as Pinyon-Juniper; if juniper was explicitly referenced and pinyon was not, then is was classified as Juniper only. Then the tree classes were further defined with respect to density as specified explicitly in the surveyor notes (dense timber, timber, scattered timber, or no timber).

With respect to undergrowth, we defined four types. The term "undergrowth" can be somewhat misleading in the surveyors' notes, since this term is often used when no trees are present. We assume that the term simply refers to woody plants of a low, shrubby stature. When only "pine," "pinon," "juniper," or "cedar" appeared as undergrowth, we assigned the section line to "Conifer Scrub." If "oak," or "scrub oak" occurred with or without conifers, we assigned the vegetation to Mountain Scrub. "Oak brush" appears most often in the notes, and in this context, it likely refers to *Querus undulata* or *Q. turbinella*.

The Desert Scrub category contains numerous references to specific elements, but because our focus is on upper elevation woodland and scrub types, we have grouped them together here in one class. The word "mesquite" appears frequently in the surveyors' notes, and we assume they used it to refer to the same species of mesquite we find in the region today, *Prosopis glandulosa*. The term "greasewood" is seen throughout the surveyors' notes.

Addendum Table A. Historical vegetation classes. See Addendum Table B for examples of class assignment.

| Cover Class Type | Cover Class |
|---|---|
| Timber Type | Pinyon-Juniper |
| | Juniper |
| Timber Density | Dense Timber |
| | Timber |
| | Scattered Timber |
| | No Timber |
| Undergrowth | Mountain Scrub |
| | Conifer Scrub |
| | Desert Scrub |
| Grass cover | No Understory |
| | Good Grass |
| | Medium Grass |
| | Poor Grass |
| | No Grass |

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This term has commonly been used to refer to *Larrea tridentata* (Kearney and Peebles 1951, Turner et al. 1995), and that is how we interpret it here. The term "black brush" also appears in the surveyors' notes. Following Kearney and Peebles (1951) and Turner (personal communication), we interpret this term as referring to *Flourensia cernua*, now known more commonly as tarbush. We include these two species in our desert scrub category.

Occasionally surveyors explicitly indicted no undergrowth was present. In addition, we did not use information on the presence of yucca, agave, or cactus in classifying vegetation. Species in these groups tend to occur within many different vegetation types ranging from grassland to desert shrubland to woodland. Yucca, agave, and cactus do not normally occur in communities by themselves, and they are generally poor indicators of other vegetation types.

We divide grass into four categories: good, medium or undefined, poor, or absent. The terms "good grass," "fair grass," and "poor grass" are ubiquitous in the surveyors' notes. Because of the surveyors' apparent economic emphasis, as suggested by frequent references to timber and grazing, we assume that the terms "good," "fair," and "poor" refer to the suitability of the grass for grazing. We use the term "medium" to represent grass identified as either "fair" or undefined with respect to condition, (i.e., "grass" without a modifier).

Addendum Table B. Examples of historical vegetation class assignment based on the original GLO survey vegetation description. See Addendum Table A for list of possible classes.

| GLO Vegetation Description | Class 1 | Class 2 | Class 3 | Class 4 |
|---|---|---|---|---|
| Good grass. Timber, cedar and pinon dense. Undergrowth-cedar bushes dense. | Pinyon-Juniper | Dense Timber | Conifer Scrub | Good Grass |
| Poor grass. Timber, cedar and pinon dense. | Pinyon-Juniper | Dense Timber | Poor Grass | |
| Grama grass, pinon & cedar timber | Pinyon-Juniper | Timber | Medium Grass | |
| Timber, pinon and juniper | Pinyon-Juniper | Timber | | |
| Good grass, scattering timber | Pinyon-Juniper | Scattered Timber | Good Grass | |
| Good grass; timber scattering pinon & cedar; dense undergrowth of pinon & cedar on 80 chains | Pinyon-Juniper | Scattered Timber | Conifer Scrub | Good Grass |
| Timber and undergrowth, cedar, pinon and oak brush | Pinyon-Juniper | Mountain Scrub | | |
| Fair grass. Timber scrub cedar and pinon. Undergrowth, cedar and oak bushes | Pinyon-Juniper | Timber | Medium Grass | Mountain Scrub |
| Poor grass; timber scattering pinon and scrub cedar, undergrowth, oak bushes | Pinyon-Juniper | Scattered Timber | Mountain Scrub | Poor Grass |
| Undergrowth, scattering scrub cedar, oak and pinon | Mountain Scrub | | | |
| No grass. Timber, a few scattering scrub cedars. Undergrowth, cedar bushes. | Juniper | No Grass | | |
| Good grass, no timber. Undergrowth, cedar bushes | Good Grass | Conifer Scrub | No Timber | |
| Good grass, no timber | Good Grass | No Timber | | |
| Grama grass, no timber | Medium Grass | No Timber | | |
| Undergrowth, dense greasewood and mesquite | Desert Scrub | | | |

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We decided to create vegetation classes that combine different grass categories with different woody species categories partly because information on both grass and woody species is commonly recorded along individual section boundaries in the surveyors' notes. This reflects the reality that grass co-occurs with woody species throughout the study area, and that many areas are impossible to classify simply as grasslands, shrublands, or woodlands along a given section line. By using classes that include information on both grass and woody species, we are able to retain information on both types of vegetation that would be lost if we attempted to classify areas into "pure" grassland or other vegetation types. Since many land managers and scientists in the region are interested in both grass condition and woody species density, we felt it was important to retain as much information on both aspects of the vegetation as possible.

## Results and Discussion

For mapping purposes, each cover class from Table A was assigned a specific icon, and then icons from each cover class type were overlain in the center of each respective section line (see map in back pocket). The resulting section grid of iconic representations of historical vegetation was then placed against a backdrop of current vegetation as mapped from LANDSAT Thematic Mapper satellite imagery (Muldavin et al. 2000).

At this time, a formal spatial analysis was not performed because of the limited sample size of four townships, but several general patterns can be discerned with respect to historical and modern vegetation distributions. The location of juniper-only woodlands has not shifted dramatically, although, if the modern map is correct, there appears to be more scattered juniper woodlands now at lower elevations at southern end of the Oscura Mountains (but aerial photo interpretation suggests that even within these patches the trees are scattered,). At higher elevations, most areas that are currently mapped as pinyon woodland were historically recorded as pinyon-juniper dense timber or pinyon-juniper timber. There is even some indication that pinyon-juniper woodlands were denser in the past along the lower slopes. The exception is the presence of scattered timber into the upper reaches of the Helms valley watershed (Sections 8, 17 and 20 in Township 7S) with our historical aerial photo interpretation of a fire patch in this area of between 60 and 100 years of age (see main text Figure 17). Lastly, post-fire Mountain Scrub vegetation was already prevalent along the western escarpment between 1882 and 1914 as it is today, suggesting that fire was as important then as it is now in shaping the vegetation of this rugged, steep landscape.

Since the Oscura Mountains map covers only four of the estimated 90 townships that make up White Sands Missile Range (WSMR), the inferences that can be drawn from it are limited by its spatial extent. Still, it provides an example of the potential of this type of map to inform us about the degree of ecosystem change that has occurred on WSMR over the past 125 and gives us reference points for effective natural resource management in the future. Since GLO records are available for all of the townships of WSMR, the re-construction of the historical vegetation for the entire range is possible, and this would make a more comprehensive analysis possible across a wide variety of ecosystem types. Historical reconstructions such as this are one of few tools we have for understanding long-term ecological processes and patterns across the landscape. Such a comprehensive analysis would not only serve WSMR natural resources mangers well in shaping successful ecology-based management strategies, but would also benefit the community of resource mangers as whole across the Southwest.

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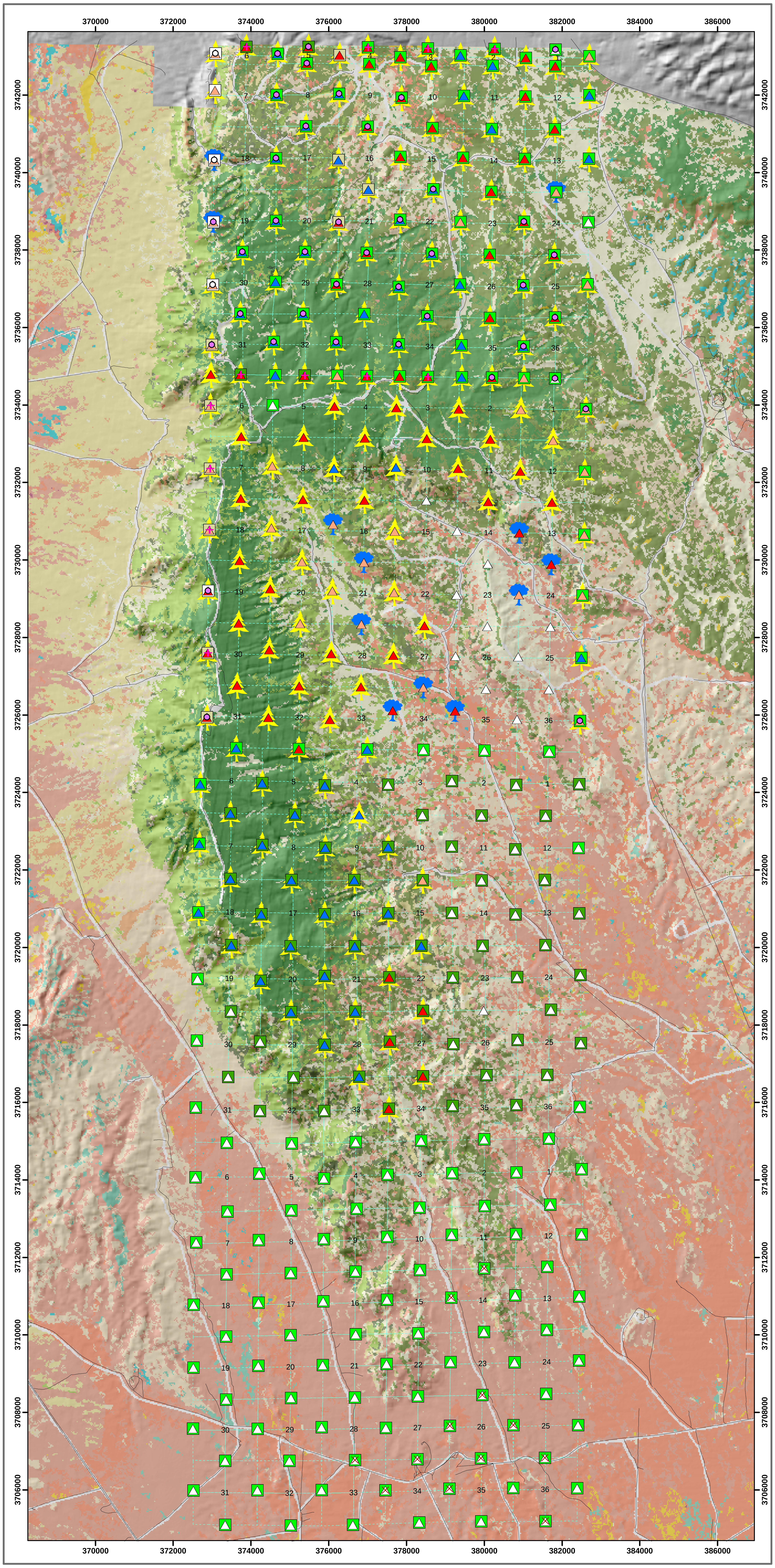


# White Sands Missile Range, NM
# Oscura Mountains
# Vegetation Past and Present

| **Historical Vegetation** | |
|---|---|
| 🌳 | Juniper |
| 🌲 | Pinyon-Juniper |
| ▲ | Dense Timber |
| ▲ | Timber |
| ▲ | Scattered Timber |
| △ | No Timber |
| + | Mountain Scrub |
| ● | Conifer Scrub |
| × | Desert Scrub |
| ○ | No Understory |
| ■ | Good Grass |
| ■ | Medium Grass |
| ■ | Poor Grass |
| □ | No Grass |

| **Current Vegetation** | |
|---|---|
| ■ | Acacia Shrubland |
| □ | Alluvial Flats -- Barren |
| ■ | Black Grama Lava Grasslands |
| ■ | Creosotebush Shrubland |
| ■ | Desert Plains Grasslands |
| ■ | Foothill-Montane Temperate Grasslands |
| ■ | Fourwing Saltbush Shrubland |
| ■ | Gypsum Duneland -- Barren |
| ■ | Gypsum Duneland -- Vegetated |
| ■ | Gypsum Interdune Swale Grasslands |
| ■ | Interior Chaparral |
| ■ | Juniper Woodland |
| ■ | Lowland Basin Grasslands |
| ■ | Malpais Lava Scrub |
| ■ | Mesquite Shrubland |
| ■ | Military Disturbance |
| ■ | Mimosa Shrubland |
| ■ | Mixed Foothill-Piedmont Desert Grasslands |
| ■ | Mixed Lowland Desert Scrub |
| ■ | Montane Scrub |
| ■ | Montane Valley Dune Woodland |
| ■ | Pickleweed Shrubland |
| ■ | Piedmont Desert Grasslands |
| ■ | Piedmont Temperate Grasslands |
| ■ | Pinyon Pine Woodland |
| ■ | Playa |
| ■ | Ponderosa Pine Forest |
| □ | Road Disturbance |
| ■ | Rock Outcrop / Talus |
| ■ | Sandsage Shrubland |
| ■ | Tamarisk Shrubland |
| ■ | Tarbush Shrubland |
| ■ | Vegetated Gypsum Outcrop |
| ■ | Wetlands |

Note: historical vegetation derived from the surveyor notes taken as part of the General Land Office cadastral survey program between 1882 and 1914. Points represent summaries of the dominant vegetation as noted along the one-mile section lines and the township boundaries. Current vegetation was extracted from the White Sands Missile Range vegetation map developed by Muldavin, E., G. Harper, P. Neville, and Y. Chauvin (2002).

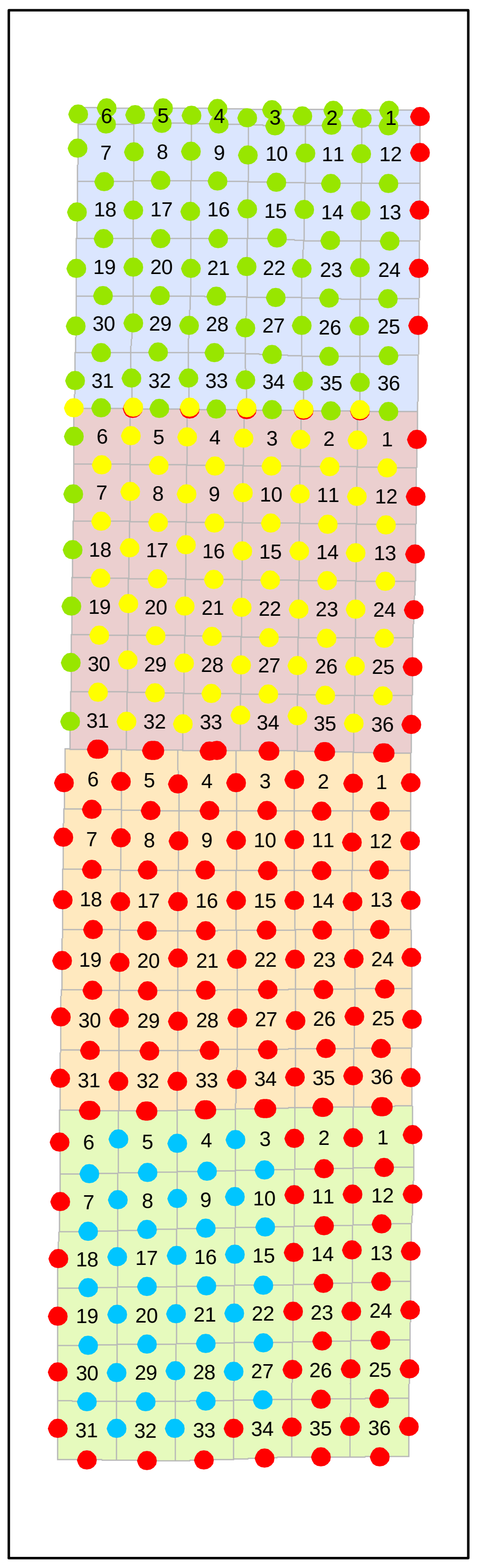
## Land Survey Year

**Survey Year**

| | |
|---|---|
| ● | 1882 |
| ● | 1883 |
| ● | 1890 |
| ● | 1914 |

**Township** (all R6E)

| | |
|---|---|
| ■ | T06S |
| ■ | T07S |
| ■ | T08S |
| ■ | T09S |



Map created by
Natural Heritage New Mexico
Museum of Southwestern Biology
University of New Mexico

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