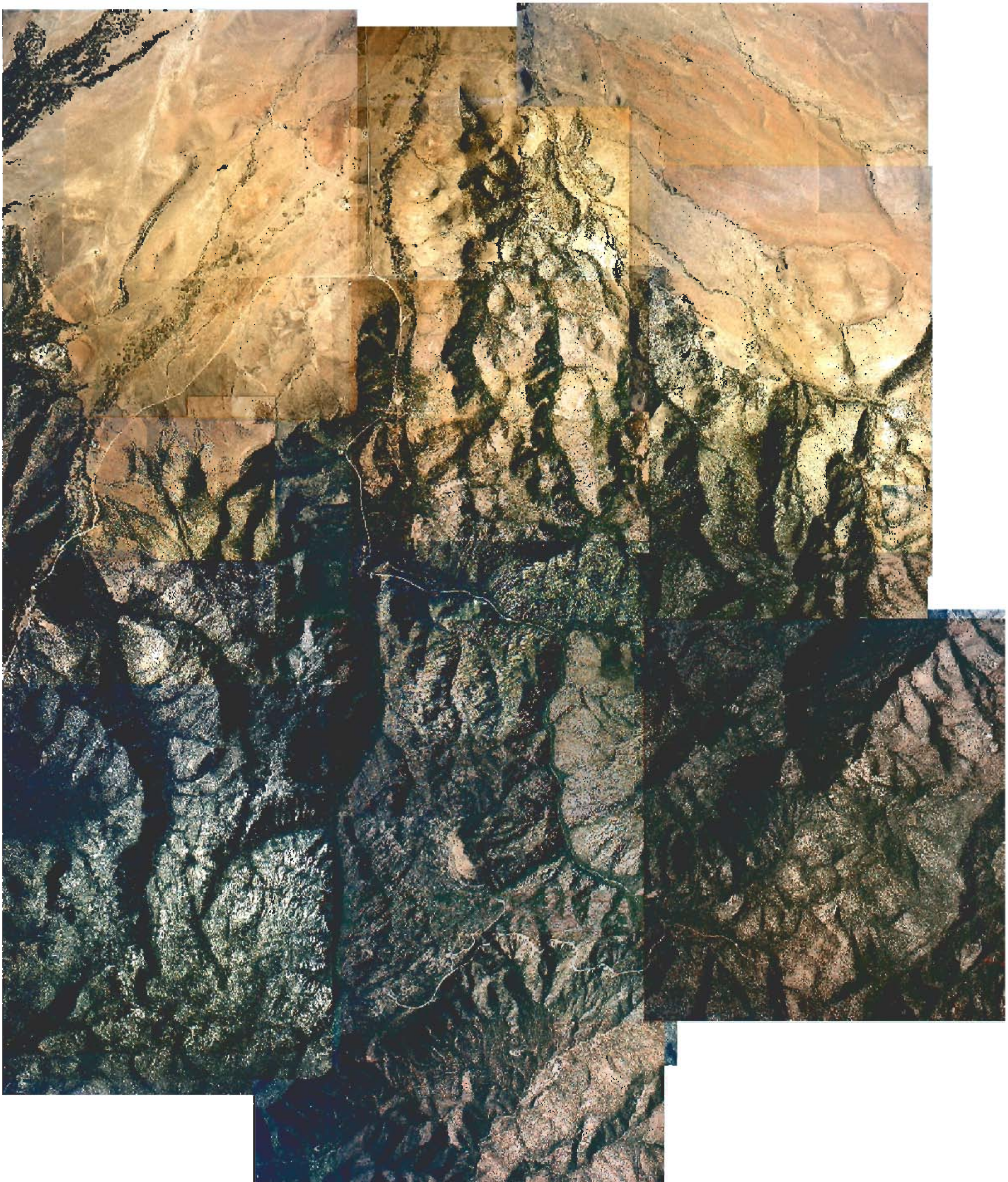
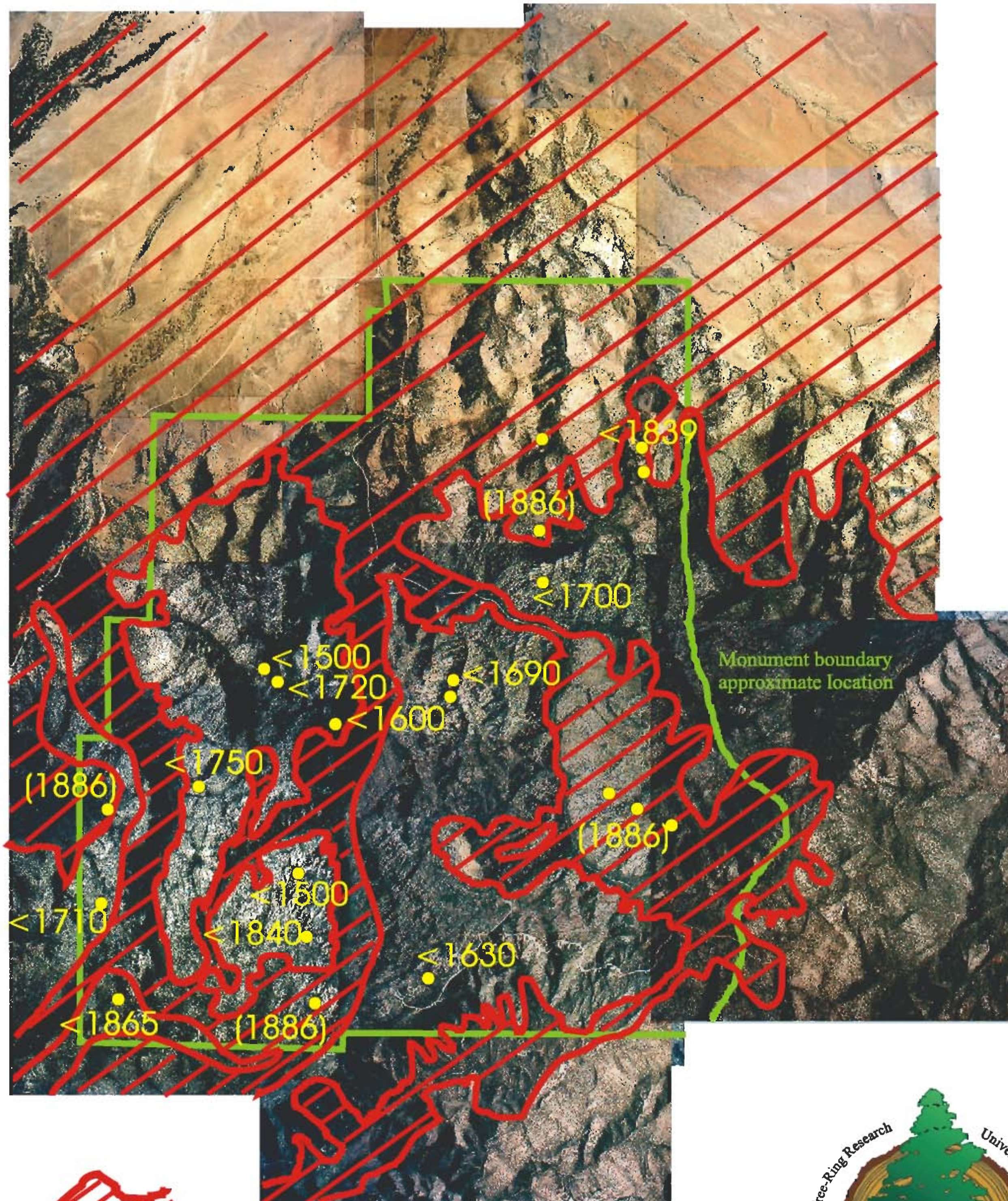


Chiricahua National Monument

photo mosaic from 1:18,000 NPS coverage of 10-31-94



Estimate of area burned in the June 1886 fire

<1500 Pinon stand location and origin date

Laboratory of Tree-Ring Research
University of Arizona, Tucson
Fire History

Final Report

Fire History in Chiricahua National Monument

Christopher H. Baisan
Kiyomi A. Morino

July 2000

Fire History in Chiricahua National Monument

Front cover: Color aerial photo mosaic of Chiricahua National Monument and vicinity.

Inside: Photo mosaic with possible perimeter of the June 1886 fire around Chiricahua Monument. Interpretation is based on fire scar evidence (fire presence) and tree age data (fire absence for tree age >130 yrs.) developed for this study.

Back cover: Tiled image of the 1938 Roseberry and Dole vegetation map.

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Fire History in Chiricahua National Monument

ABSTRACT

Dendrochronologically based fire history and GIS-based vegetation sampling were used to document fire regime characteristics across a range of vegetation types. Fire-scarred wood samples were collected from logs in canyon environments that support suitable tree species (i.e. pine, pine/oak and mixed conifer forest types). This data was analyzed in conjunction with a large number of previously collected samples. Woodland, grassland, and chaparral communities were sampled with transect-style plots at randomly selected points distributed across three major vegetation classes. These classes were based on a field-compiled vegetation type map (Roseberry and Dole 1939). Plot sampling strategy was designed to document fire evidence, vegetation structure and species composition as it might relate to fire regime characteristics.

Fire dates derived from fire scars supported previous studies that concluded 1: Fires spread readily throughout the canyon matrix utilizing the fuel bed available in this relatively productive environment; 2: Local ignitions were uncommon with many fires spreading into the area from outside the Monument proper.

We concluded from plot data that 1: The composite vegetation map derived from the 1939 version was substantially correct, however, the map contains some errors in assignment and changes in vegetation have occurred this century; 2: Tree age data suggests invasion of chaparral and woodland/grassland types by woody shrubs and trees, particularly *Pinus discolor* (piñon pine) and *Arctostaphylos sp.* (manzanita) over the past century.

Direct fire evidence (charred wood fragments, charred snags, or fire scars) was common and noted in all vegetation types, however, not every plot showed such evidence.

Three general modes of fire regime were identified based on tree ages and fire scars. 1: Frequent (i.e. 2-15yrs.), low severity fires in oak-woodlands, grassland, and mixed-conifer and pine forest. Most prevalent in major drainages and along the western and southern borders of the Monument; 2: Infrequent (20-100yrs.), high intensity fires in the chaparral type; 3: Very infrequent (80->400yrs), high and mixed intensity fires in isolated or protected sites dominated by piñon and/or *Cupressus arizonica* (Arizona cypress).

Image based vegetation classification was performed with both color aerial photography and TM satellite imagery and compared with the 1939 map. The fine-grained classification based on the aerial photography perhaps best reflects the complexity of the vegetation and terrain. However, an updated version of the relatively coarsely resolved vegetation map produced by Roseberry and Dole may be most appropriate for management purposes. Currently available photography and remote sensing products are not ideally suited for vegetation classification in this terrain. Color infrared photography currently under development by the US Geological Survey would provide an improved fine-scale base for plant community classification and change detection.

INTRODUCTION

Knowledge of fire regimes, including the frequency, areal extent, and intensity of past fires, is needed to evaluate and plan prescribed burning programs in wilderness and parks. There is widespread agreement among most forest scientists and land managers that fire is essential for the healthy functioning of forest and woodland ecosystems of the arid west, and that this process should be reintroduced in wilderness and parks where it has been artificially excluded by humans. Fire regimes are, however, highly variable both spatially and temporally, even within forest types. Documentation of past fire regimes is therefore one of the first and most basic scientific inventories that is necessary to improve understanding of the fire process within specific management units (Kilgore 1987, Swetnam et.al. 1999).

Few studies of fire history or fire effects in Madrean evergreen woodland or Arizona chaparral have been conducted, but the presence and importance of fire within the various woodland community types has long been noted (Leopold 1924; Le Sueur 1945; Wallmo 1955; Marshall 1957, 1963; Moir 1980, 1982; Niering and Lowe 1984). Marshall (1963), surveying birds in the Mexican pine-oak woodlands, compared woodlands of Mexico to those in the United States and felt fire played a different role due to the differences in fire suppression policies at the time of his study. In Mexico, where fire suppression was minimal, he found the woodlands to be open with a dense grass understory. Across the border in the United States where fire suppression was sophisticated and generally effective, Marshall observed that woodlands were stunted, had heavy fuel accumulations, and little grass understory. Fires that did occur were often severe and killed many of the overstory trees and understory plants. Fire history work by Kaib and others 1996 and Kaib 1998 concluded that fires were common in canyon and woodland environments along the west face of the Chiricahuas. Fule and Covington (1997) have documented surface fire regimes further to the south in the Mexican state of Durango.

Previous fire history studies in Chiricahua National Monument (CHIR) documented fire frequencies of 1 to 50 years within Rhyolite Canyon and associated pine forest (Swetnam et. al. 1989, 1991). However these studies did not directly address the role of fire in the intervening plant communities, and questions regarding implementation of prescription burning programs in these areas had been raised (Bennett and Kunzmann 1992). A variety of sources have suggested that changes in land use, land management and fire suppression policies has significantly impacted these communities as well (e.g. Bahre 1985, 1991). Repeat photography (Figure 1) also suggests that changes in species distribution and composition have occurred this century.

This study utilized a variety of techniques to investigate fire regimes in the woodland, chaparral and piñon-juniper-cypress stands that dominate over 70% of the terrain within CHIR boundaries. The intent was to generate additional information on fire regimes in these vegetation communities that could be integrated with the previous work. A 1930's vintage, field produced, vegetation map for CHIR existed that could provide a basis for systematically examining these communities. However, it's accuracy in representing the current state of the vegetation was unknown, given the 50 year period since the map was produced. Remote sensing imagery and

Figure 1. Comparison views of lower Bonita Canyon looking west. The upper view is ca. 1900 while the lower is ca. 1990. Note the change from agricultural land to juniper woodland and the general increase in woody plants, particularly juniper and manzanita over the years.

computing tools are now available that could potentially be used to assess the current relevance of this map, and perhaps amend it. Additionally, assuming the community boundaries could be verified, it might provide the basis for a fire-regime map that could be utilized in inventory, assessment, planning, and monitoring of resources. However, the image resolution necessary to distinguish plant communities in complex terrain still limits the usefulness of these tools in a fine-grained landscape. Some of these issues were addressed in this study as various vegetation mapping techniques were compared.

DESCRIPTION OF THE STUDY AREA

Chiricahua National Monument is located in southeastern Arizona, at the north end of the Chiricahua Mountains (Figure 2). Elevations within the Monument range between 1,579 and 2,408 m (5,180 and 7,825 feet). Terrain is extremely rugged and is dissected by several large, steep-walled, canyons (Bonita, Rhyolite, and Jesse James) which drain to the west into the Sulfur Springs Valley. Streamflow is intermittent and the channels well developed with relatively broad, boulder-strewn bottoms. Separating the canyons are rocky uplands.

Soils are shallow on the uplands, but relatively deep and stable in canyon bottoms. They are generally gravelly to moderately coarse and are derived from a substrate of rhyolitic tuff (Reeves 1976, Pallister and du Bray 1997). Slopes are of varying degree and exposure, but aspects are predominately north or south. Aspect is especially important in determining species composition through the effects of insolation and evapotranspiration.

Climate of southeastern Arizona is semi-arid, characterized by low rainfall, relatively high temperature and evaporation, and low humidity. Precipitation is distinctly bimodal with wet winters and summers and a pronounced foresummer drought (April-June) and a less predictable fall drought (Figure 3). Summer rains in the form of thunderstorms occur from July to September with moist air usually flowing from the southeast. Winter storms from December to March are usually derived from frontal systems from the northwest (Sellers et al. 1985). Average temperatures for oak woodland stations in southeast Arizona are highest in late June and early July and lowest during January. Average minimum temperature for January is -1°C (30 °F) while average maximum is 13.2°C (56 °F). In July the average minimum and maximum temperatures are 15.5 and 31.7°C respectively (60 and 89 °F) (Chiricahua National Monument records, 1948-1997).

Vegetation of CHIR is diverse, a consequence of a range of elevation, precipitation, temperature, topography, soil, and fire regimes (Figure 4). Plant species composition is strongly influenced by distinct regional plant communities located to the north, east, and south, leading to a high degree of biotic complexity not found at higher latitudes. Higher elevation, mesic montane conifer forests found within protected habitats in Chiricahua National Monument have northern affinities while lower elevation semi-desert grasslands have affinities to the east. Madrean evergreen oak woodland, comprising 60% to 65% of the vegetation cover in the monument, is strongly influenced by the Sierra Madre where the distributional center of oak woodland is located. The type within Rhyolite Canyon also has some affinities with more northern and western interior chaparral (Reeves 1976, Murray 1982).

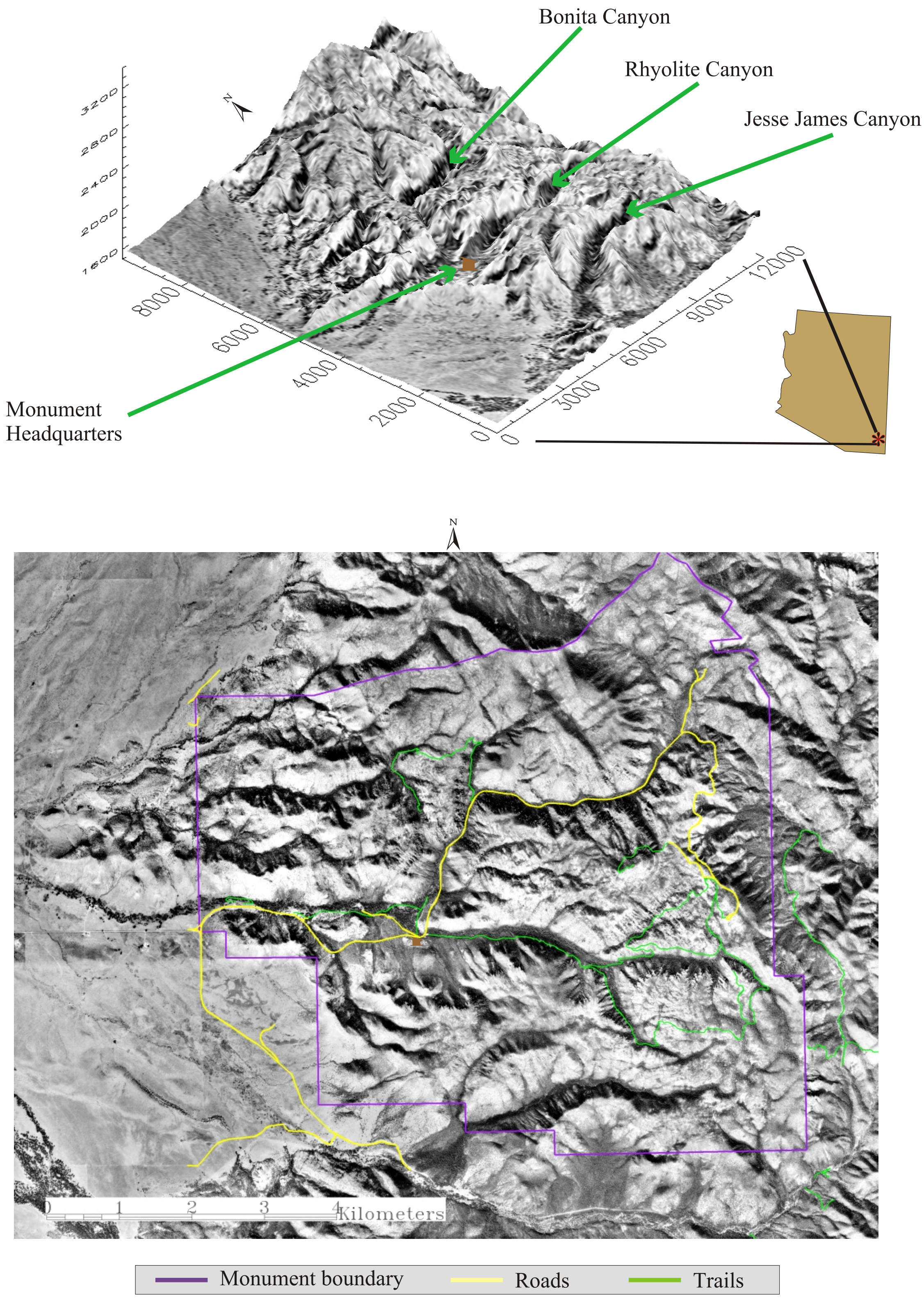


Figure 2. Orthophoto mosaic of Chiricahua National Monument.

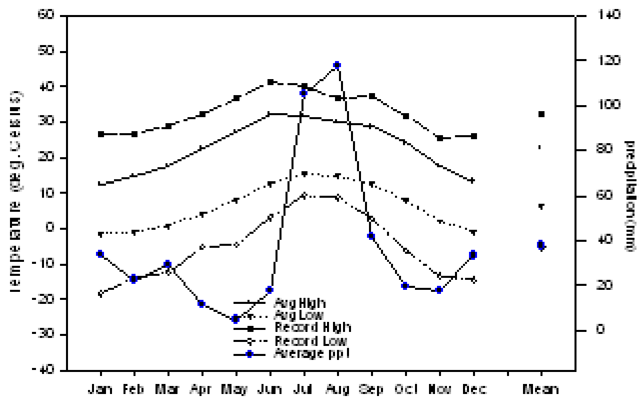


Figure 3. Weather data for Chiricahua National Monument

Major tree species occurring in the study area are: *Pseudotsuga menziesii* (Douglas-fir), *Pinus ponderosa* (ponderosa pine), *P. leiophylla* var *chihuahuana* (chihuahua pine), *P. engelmannii* (apache pine), *P. discolor* (border piñon), *Cupressus arizonica* (Arizona cypress), *Quercus chrysolepis* var *palmeri* (canyon live oak), *Q. rugosa* (netleaf oak), *Q. hypoleucoides* (silver-leaf oak), *Q. emoryi* (emory oak), *Q. arizonica* (Arizona white oak), *Arbutus arizonica* (Arizona madrone), and *Juniperus deppeana* (alligator-bark juniper). Detailed descriptions of the vegetation within the monument can be found in Roseberry and Dole (1939), Moir (1975), Reeves (1976), and Murray (1982). Major plant associations are interior chaparral, semi-desert grassland, montane conifer forest, relict conifer forest, and Madrean evergreen woodland.

The fire season in southeastern Arizona occurs mainly in the late spring and early summer, prior to the inception of the "Arizona monsoon", and occasionally extends throughout the summer into October (Barrows 1978). The pre-monsoon season is a period of high temperature, low humidity and dry vegetation. Weak storm cells sometimes develop in which virga and lightning are common. Lightning during this period often results in isolated or clustered ignitions that are associated with specific storm systems (Bock et al. 1976, Murray 1982).

METHODS

Dendrochronology

Additional fire scarred specimens were collected in the areas not previously sampled, specifically in Bonita Park and in Sarah Deming Canyon. Fire-scarred and charred remnant wood samples were also collected near several vegetation sample points. These samples were prepared and analyzed using standard dendrochronological techniques. Fire scar information from these samples was integrated and analyzed with data from previous studies.

Increment cores collected from fire-sensitive species, primarily piñon pine, in the vicinity of vegetation plots were used to estimate time-since-last-fire. Maximum age of these samples was inferred to represent the approximate time elapsed since the area had last burned. Piñon pine was chosen as it is a common, usually cross-datable, fire-sensitive species that would be expected to have a low survival rate in moderate to high intensity fires that characterize chaparral vegetation. It also would have difficulty in successfully recruiting into grass and woodland communities subject to frequent, low intensity fires. Cores were mounted in wooden mounts, surfaced and crossdated using standard dendrochronological procedures. In a few cases, where crossdating proved impossible, ring counting was used to estimate age. When the core did not include the pith a circular guide was used to estimate the number of rings missed and an approximate pith date was noted. No correction was applied to estimate age at coring height, so age estimates derived are conservative.

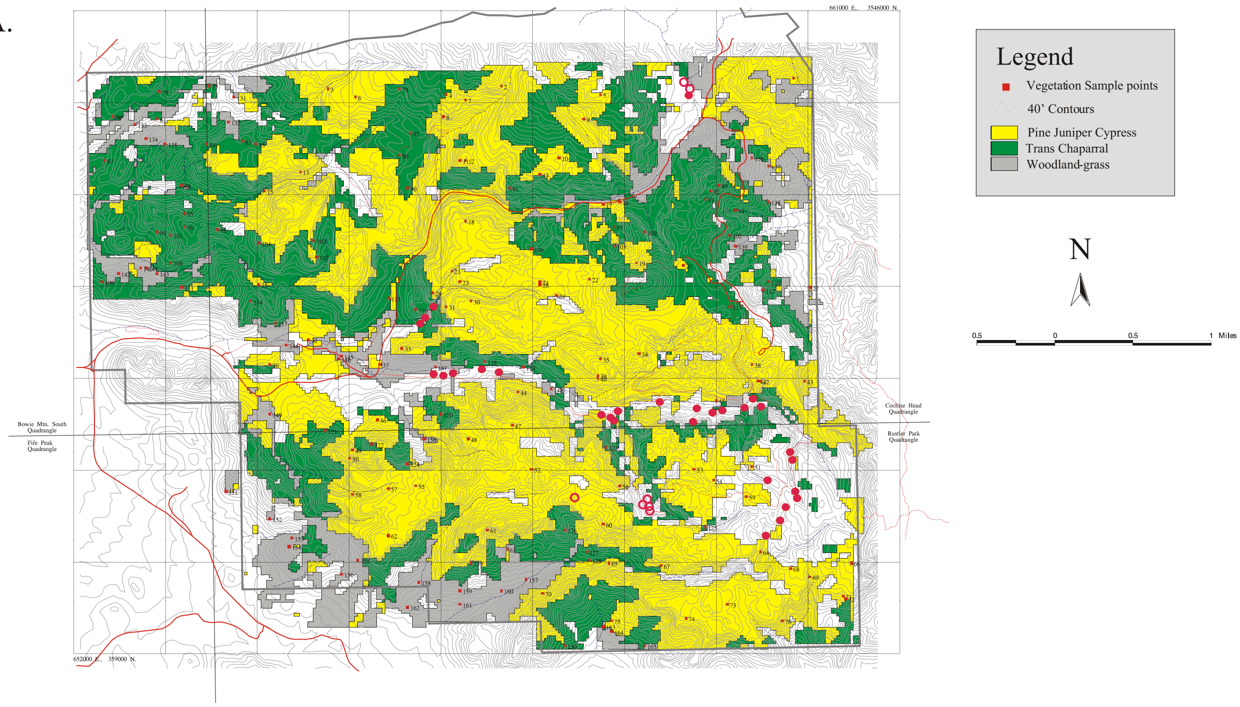
Fire Regime Assessment: Species Composition and Vegetation Mapping

In order to gather fire regime information within the chaparral, woodland and grassland plant communities the following strategy was used. A vegetation map for Chiricahua National Monument had been previously developed by Roseberry and Dole in 1939 based on field surveys (Figure 4). A digitized version of this map produced by the University of Arizona Advanced Resources Technology Laboratory was used to segregate the landscape by vegetation class. The original 10 vegetation types specified on the map were combined to define four broad categories of vegetation: conifer forest (class 1); piñon-juniper-cypress woodland and forest (class 2, PJC); chaparral (class 3, CHA); and open woodland and grassland (class 4, W/GRA). One hundred and sixty five points were randomly distributed across these classes, excluding the conifer forest type for which sufficient fire history information already existed (Figure 5). Based on the relative area occupied by each class, and allowing for a target of fifteen to thirty "visitable" points in this rugged terrain, the points were distributed as follows:

Class 2:	76 points
Class 3:	54 points
Class 4:	35 points

Points were located in the field using a precise global positioning unit (GPS) and verified on the appropriate USGS 7.5 min. quadrangle map. Obvious transitions in vegetation type were avoided, in order to gather measurements within a relatively homogeneous area. At each point visited, species composition was determined using a line-intercept method modified for this study. At each point a 30 meter tape was laid out in a randomly selected direction. Vegetation intersecting a vertical plane defined by the tape was recorded by species and the following characteristics noted: length of intercept and plant height. This information was used to calculate percent cover by species. Additionally, direct evidence of fire in the vicinity of the plot was noted if present (i.e. charred debris or snags, fire scars), and increment cores were collected from canopy-dominant piñon or other suitable species for indirect assessment of time-since-last-fire.

A.



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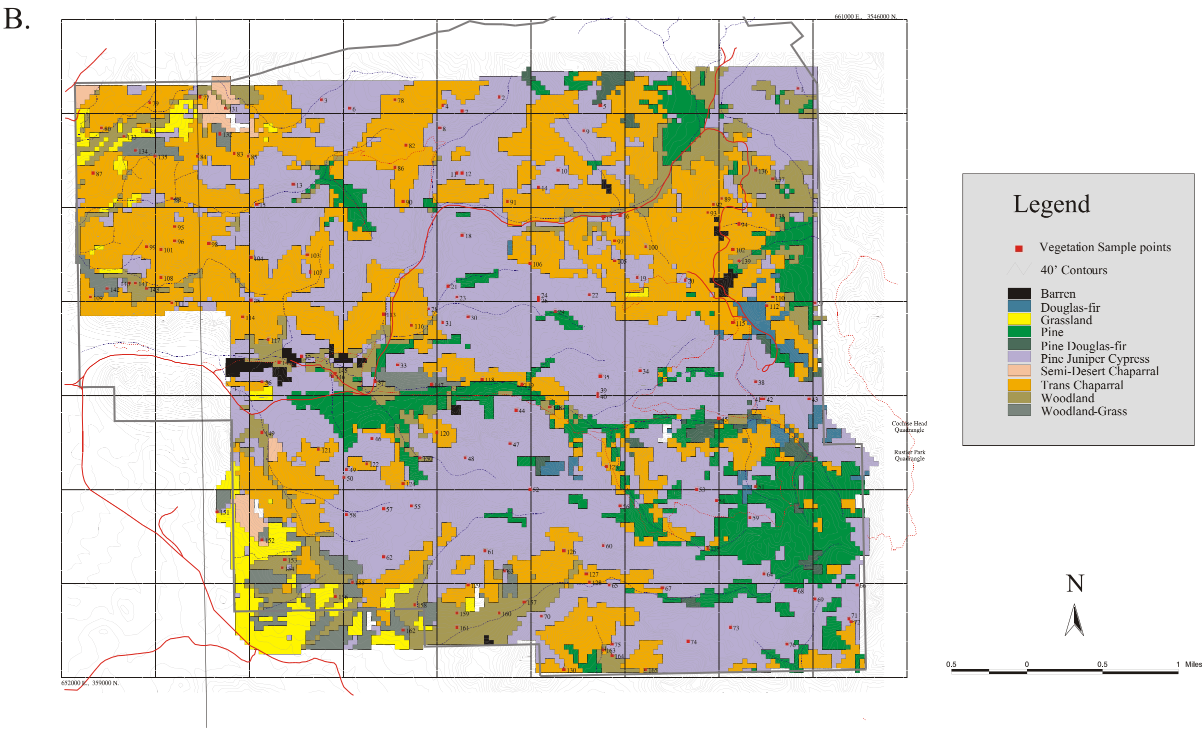


Figure 4. Original polygons digitized from Roseberry and Dole 1939 (B) and composite map utilized for distribution of sample points (A). Sample points are noted as numbered red squares, firescar sample locations are red circles, with new samples denoted by open circles.

RESULTS

The discussion of results that follows is broken into four subsections that correspond to the generalized fire regime types: canyon woodland and coniferous forest, piñon-juniper-cypress woodland and forest, transition chaparral, and grassland and open woodland. While connectivity is relatively high between the canyon forests and woodlands, the PJC woodlands and forest stands are generally isolated by rock and chaparral buffers. Thus while fire spread between the first two might be commonly expected this would not commonly involve spread into the PJC.

Canyon Woodlands and Coniferous Forest

Occupying about 10 to 15 % of the landscape, coniferous forest and woodland occurs primarily within the main stem and major tributaries of Rhyolite, Bonita, and Jesse James Canyons. An upland area between Rhyolite and Jesse James also supports pockets of coniferous forest.

The occurrence of episodic surface fires was documented at intervals of one to fifty years in this vegetation type by previous studies (Swetnam et. al. 1989, 1991). Additional samples were collected to improve the spatial resolution of the data set for this study. The integration of these samples generally corroborated previous findings for these communities and provided some additional insight into patterns of fire spread.[1]

Fire-scarred samples from Sarah Deming Canyon were successfully cross-dated (Table 1). Several sections were also collected from Bonita Canyon and from the vegetation sample points, however these were not dated because of difficulties with false rings and suppressed growth. Interval data from the samples was used to compare with the dated set in order to generate estimates of fire frequency. Fire dates from the dated samples were integrated into a comprehensive data set that included all previously collected firescar samples.

Table 1. Fire-scarred samples.

Location	No. of Samples	No. Dated
Sara Deming Canyon	4	4
Bonita Canyon	3	0
Vegetation Sample Points	8	1

[1]Figures 4 and 8B show the location of these samples.

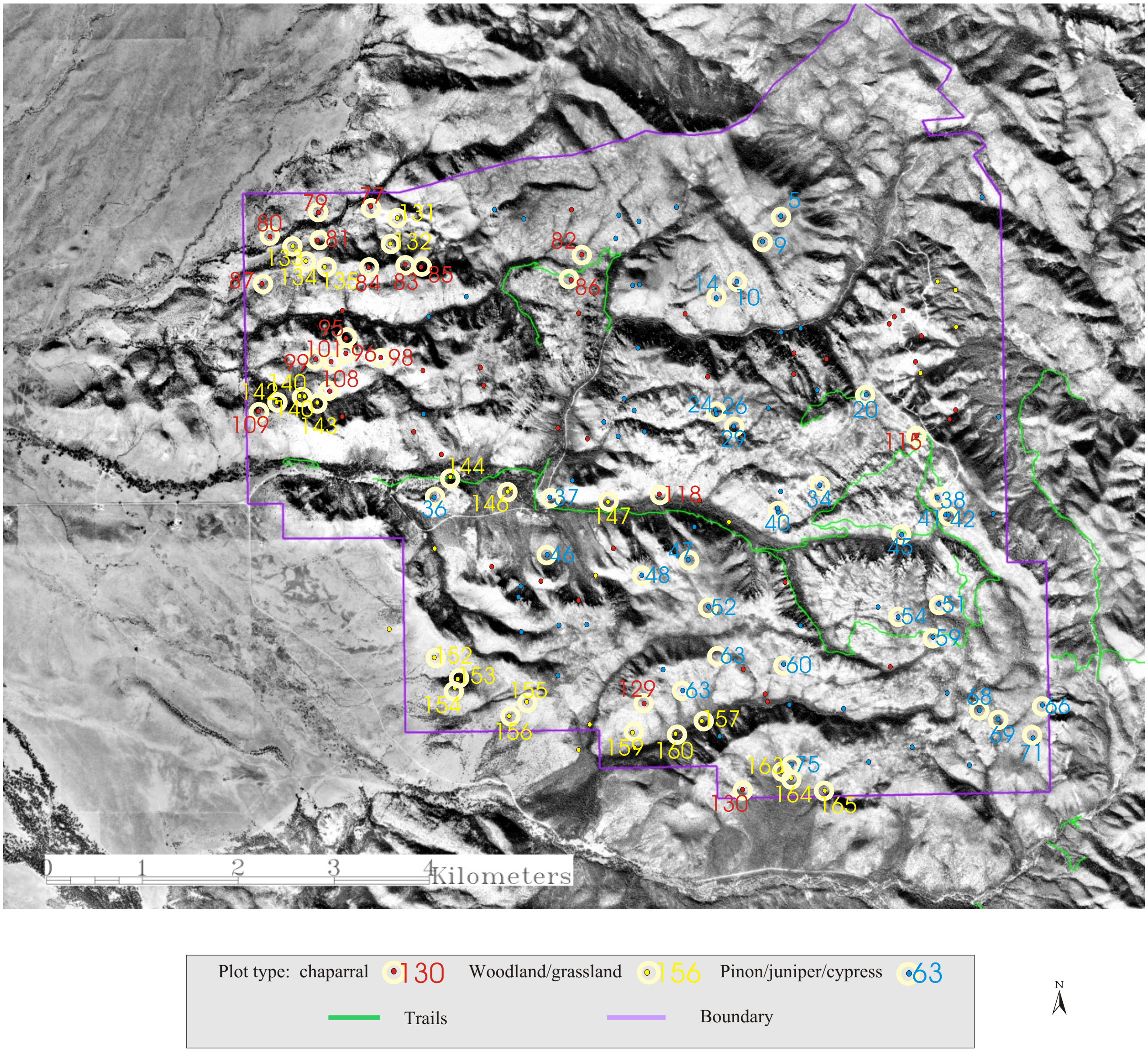


Figure 5. Orthophoto mosaic of the study area showing the locations of random sample points. Those that were visited are shown circled and numbered.

Remote Sensing Image Analysis

Imagery utilized for this study included a 30m satellite TM (Thematic Mapper) scene of southeastern Arizona, color aerial photography from USFS coverage and gray-scale USGS 1m digital orthophoto quarter quads for Chiricahua National Monument (Fife Peak, Bowie Mountain South, Cochise Head, and Rustler Park; all NAD-27). USGS 7.5' digital elevation model (DEM) coverage at 30m was used to display imagery on simulated topography. The 1939 vegetation map mention above, as digitized by the Advanced Resources Technology group at the University of Arizona, was used for comparative purposes.

Image Processing

A geo-referenced base image covering the area of interest was assembled using the USGS orthophoto quads (see Figure 2). Additional non-georeferenced imagery was rectified and warped to match the base image. A supervised classification procedure (maximum likelihood) based on field data and observations was used to produce estimates of vegetation cover type. Clustering, or other grouping algorithms were applied if deemed appropriate. Results were compared with the 1939 vegetation map.

ENVI 3.0 by Research Systems International was used for all image processing tasks with the exception of the analysis of topographic position of the random points. ArcInfo was used for this task due to cross-platform image registration problems that could not be resolved in ENVI. USGS digital orthophoto quads were used as a base product against which to rectify all other imagery. The six quarter-quads covering CHIR were manually tone-adjusted and mosaiced. A geographically similar portion of the TM scene was clipped and geo-referenced with the orthophotos before further processing. Additionally, an approximately 2½ by 4km. rectangular area east of the Visitor Center was chosen for purposes of comparative analysis (Figure 6). This sub-area contained all vegetation types, was contained on a single aerial photograph, thus minimizing problems with differing exposure and lighting in the photographs, and was centered over the most intensively studied area of the Monument. Coverage from the aerial photography and the TM scene was warped and geo-referenced for this purpose. Thirty to fifty points were located on paired images and used to warp the target image (Figure 7). Arc-Info grid coverages produced by the ART lab for their Chiricahua National Monument work were imported and used to display boundaries, roads, and trails, etc. Vegetation was analyzed both for this sub area, utilizing the various image types, and for the entire monument using the TM image cropped to the Monument boundaries.

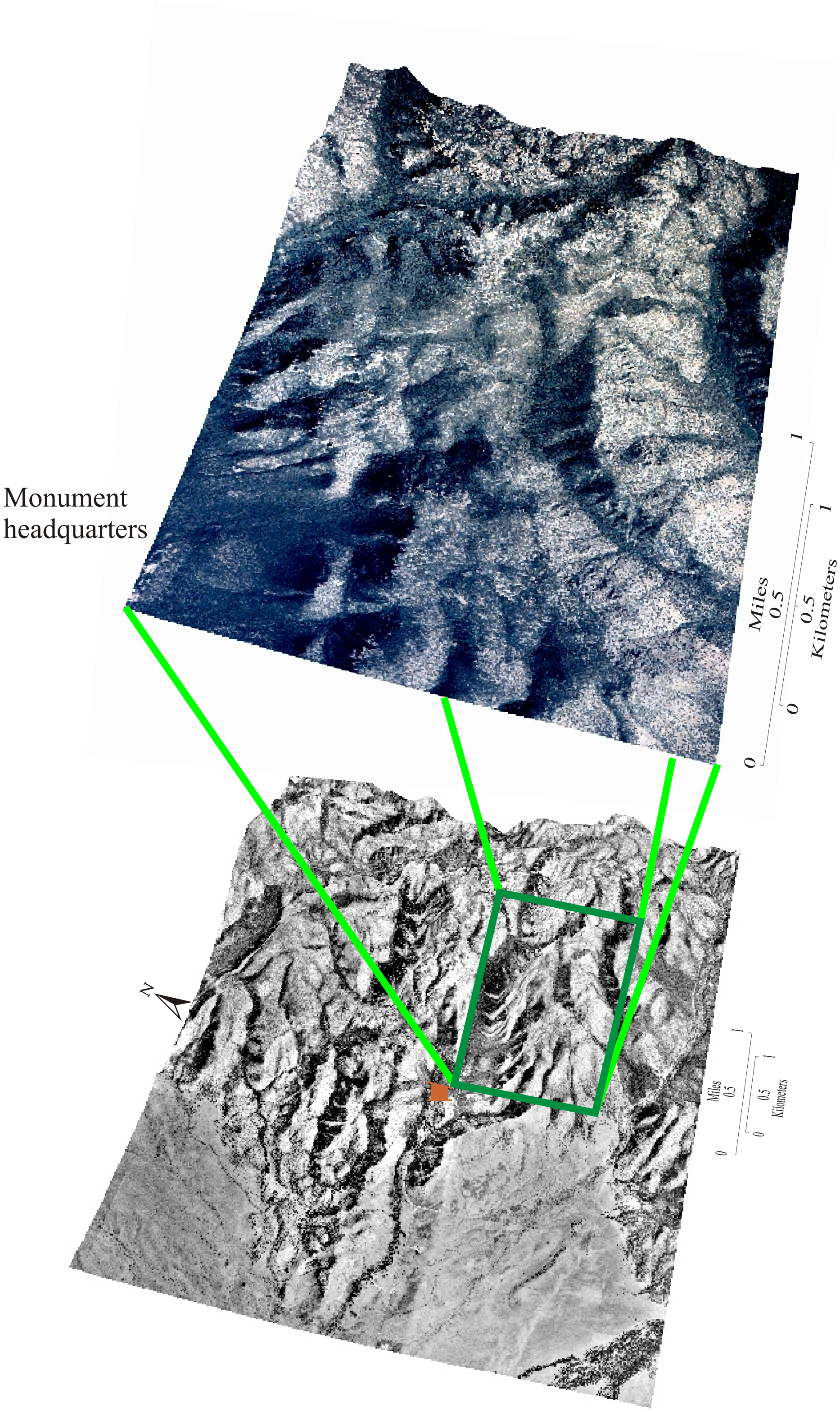


Figure 6. Portion of Chiricahua national Monument study area used for vegetation classification. Monument headquarters is located near the northwest corner of the inset.

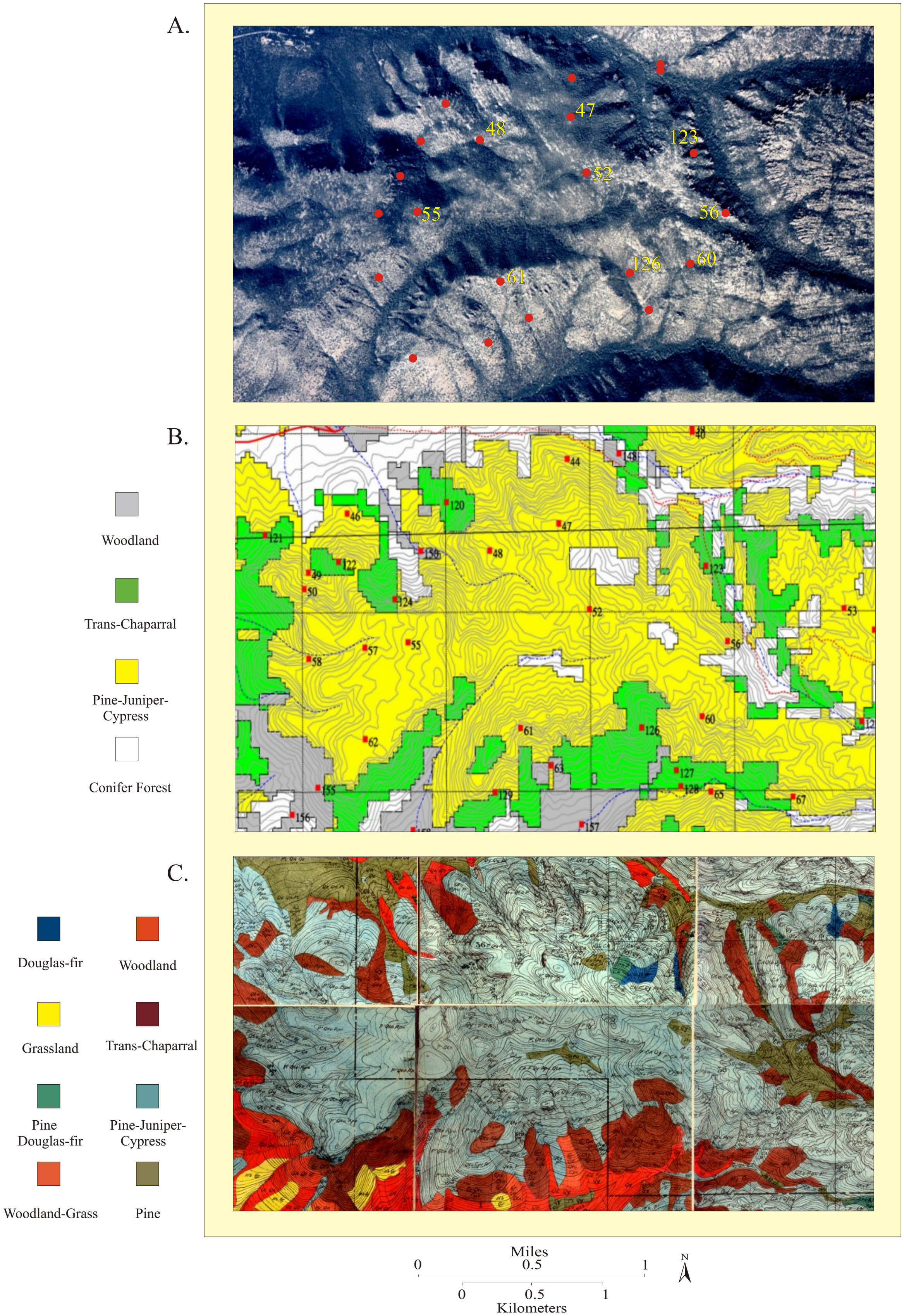
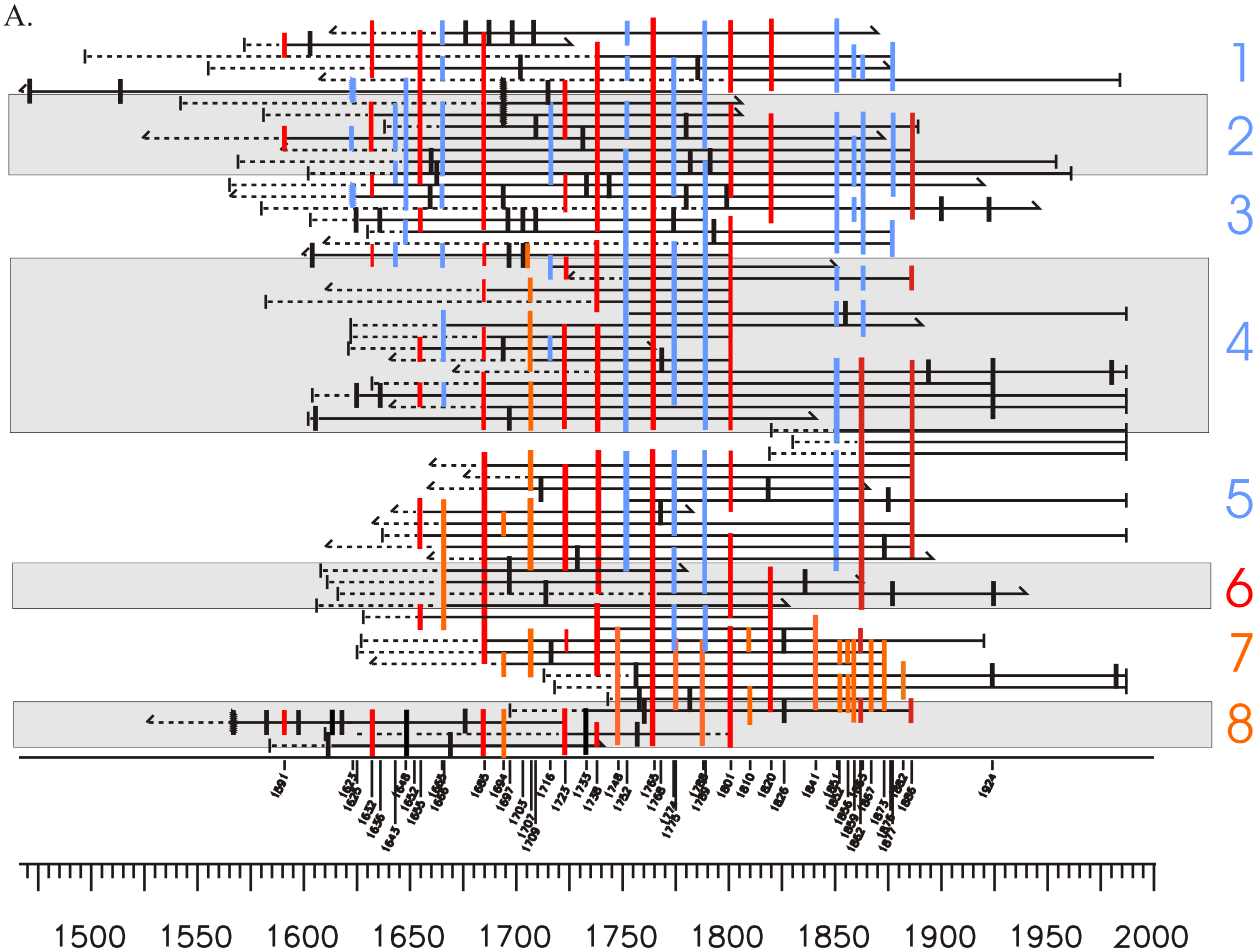


Figure 7. Three views of the sub-area used for experimental vegetation classification. (A.) aerial photography. (B.) the Roseberry and Dole vegetation map digitized and composited, and (C.) the hand drawn original The vegetation sampling points are shown on A and B.

A.



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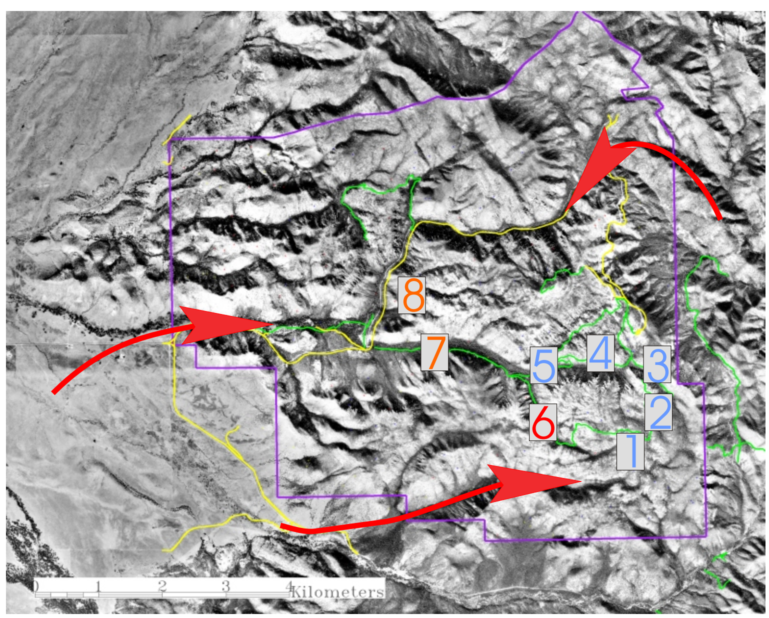


Figure 8. (A) Fire chronology chart for Rhyolite canyon and associated drainages Horizontal lines represent individual tree records while vertical bars represent fire events. Upper canyon fires are shown in blue, lower canyon fires in orange, and canyon-wide fires in red. Black bars represent smaller or more localized events. Locations of tree-groups are shown on orthophoto below (B). Red arrows denote probable paths of fire spread into the Monument.

Figure 8A shows the fire chart for all dated fire-scarred samples collected within the Monument, including those for the current study. Sixty two individual tree records are denoted by the horizontal lines in the chart. Trees were loosely grouped by geographic proximity into eight clusters and their locations noted on the orthophoto mosaic (Figure 8B). The dotted portion of each horizontal line represents the period of time prior to the first fire scar and is considered a non-recording period for analytical purposes. Fire occurrence, denoted by vertical bars in the chart, is color coded by geographic area. Vertically aligned red, blue, and orange bars represent relatively widespread fires associated with portions of the Rhyolite drainage. Orange for lower canyon fires, blue for upper canyon fires, and red for canyon-wide fires. Black bars indicate smaller or more patchy fires that probably burned less area.

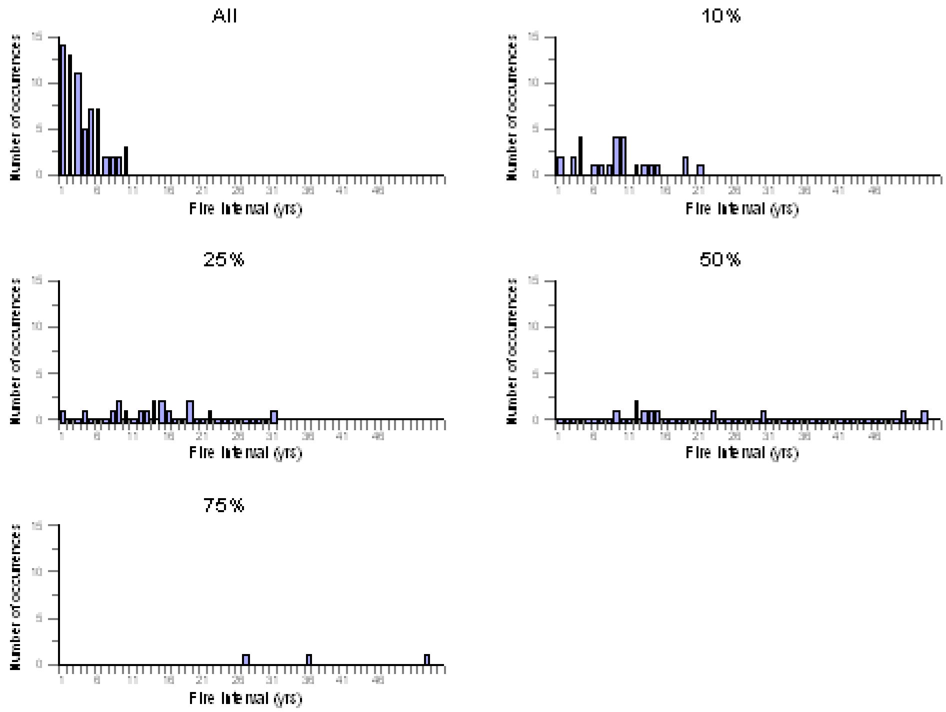
Several patterns are apparent in the data. Extensive fires, those scarring a minimum of 25% of the sampled trees, were common in the canyon system occurring approximately every 13 years with a range of 1 to 31 years (Table 2). Fires scarring at least 50 % of the sampled trees occurred approximately every 21 years ranging from 9 to 53 years. Four fires occurred that scarred at least 75 % of the samples. The dates of these fires: 1685, 1738, 1765, and 1801, coincide with fire dates in the central portion of the Chiricahuas and indicate fires occasionally burned throughout large portions of the entire mountain range. Such fires also undoubtedly had a significant impact on vegetation in plant communities adjacent to the conifer forest types routinely affected by surface fires. Tree establishment dates ca. 1700 at some vegetation plots in the PJC vegetation type may represent recruitment following the fire of 1685. Fire events occurring one-year apart generally represent fires occurring in different parts of the canyon system. Minimum intervals for fire reoccurrence at a point were typically on the order of 9 - 16 years and probably represents a combination of the time necessary for fuel build up to support fire spread over a large area and the co-occurrence of ignition and suitable weather conditions. This is longer than for other similar areas in the southern portion of the mountains (Kaib 1998) and may be due to the low rate of local ignitions and dependency on spread from adjacent areas. The 50 year fire-free interval in Rhyolite above Sarah Deming Canyon remains a prominent feature of the reconstruction. As was previously suggested (Swetnam et. al. 1991), we believe this gap to be the result of a geomorphic process, most probably flooding, that disrupted fuel continuity in this area of the canyon.

Table 2. Fire interval statistics (1650-1900).

	Mean interval	Weibull mean	Minimum	Maximum
All scarred	3.8*	3.3	1	10
10 % scarred	9	8	1	21
25 % scarred	13.6	12.7	1	31
50 % scarred	23	20.9	9	53
75 % scarred	38.7	39	27	53

* intervals in years

A.



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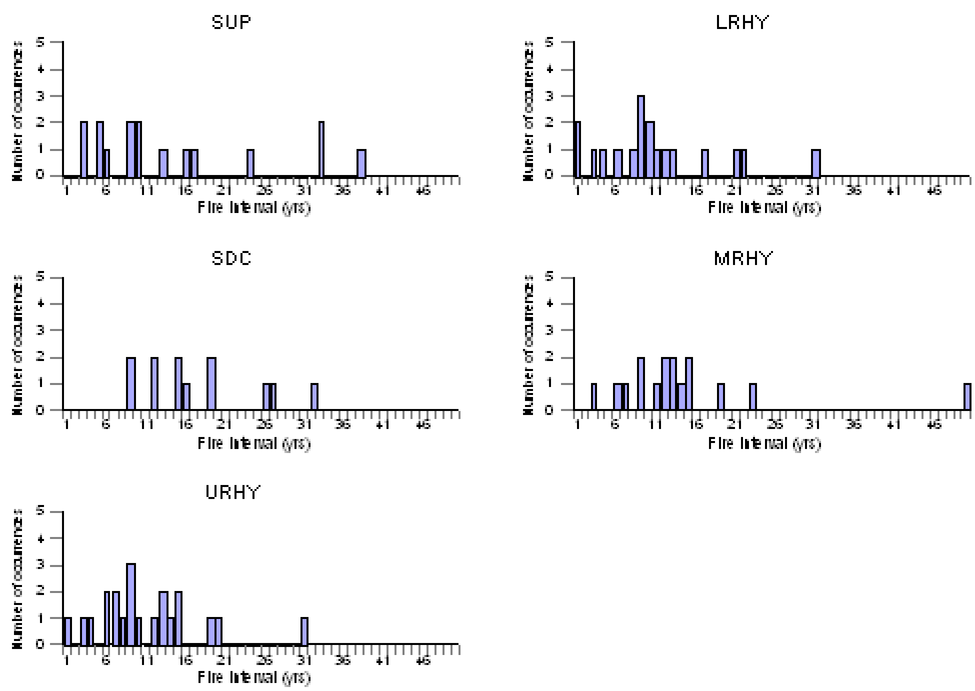


Figure 9. Fire interval distributions for CHIR canyon woodlands and conifer forest. Set A. portrays data for all sites combined at various percent-scarred levels. In set B. the data is divided by sub-site (SUP = Surprise Canyon, LRHY = Lower Rhyolite, SDC = Sara Deming Canyon, MRHY = Middle Rhyolite Canyon, URHY = Upper Rhyolite Canyon). See Figures 5 and 8b for site locations.

Evidence from the fire scar record and age structure data from Arizona pines and Douglas fir also suggest the occurrence of a severe fire in 1591 that reset the demography in the conifer forest of Rhyolite Canyon (Swetnam et. al. 1991, Barton et. al. Submitted).

Although fire-scarred samples collected in Bonita Park were not dated, intervals between fire scars could be estimated on one of the samples. It showed evidence of at least 10 fire events over a 115 year period for a MFI of 11.5 years and a standard deviation of 6.5 years. The minimum interval recorded was 4 years and the maximum was 21 years. While this data is not, by itself, definitive it does provide a conservative estimate of fire occurrence for this area. Additionally, comparison with other sub-site statistics shows that these values are similar to those at the other sites (Tables 3a and 3b). With the stricter requirement of at least 2 trees scarred or 10% scarred (more than 10 trees recording fires) the mean is almost identical to the values for lower and upper Rhyolite Canyon.

Table 3a. Sub-site fire intervals, all fires (1650-1900).

Site	Mean interval	Weibull mean	Minimum	Maximum	Trees
Surprise Canyon	14.6*	12.4	3	38	4
Lower Rhyolite	8.4	7.8	1	19	8
Sara Deming Cyn.	17.6	17.3	9	32	4
Middle Rhyolite	10.4	9.4	2	33	26
Upper Rhyolite	6.5	5.2	1	31	20
Bonita Park **	11.5	--	4	21	1

* intervals in years
** ring-counted, one tree

Table 3b. Sub-site fire intervals, 10% scarred or 2 trees (1650-1900).*

Site	Mean interval	Weibull mean	Minimum	Maximum	Trees
Lower Rhyolite	10.9	9.3	1	31	8
Middle Rhyolite	15.4	14.1	7	50	26
Upper Rhyolite	11	10	1	31	20

* sites with low sample depth omitted

Bonita Park is separated from the rest of the canyon system by a relatively narrow and mesic canyon corridor that contains Shake Spring. This bottleneck may have been a fire barrier in the past, however, the fire of 1886 burned this stretch as documented in the military records from Fort Bowie. Fires may typically have spread from areas to the east up through Whitetail Canyon and into Bonita Park. Given this evidence it does not appear that the Bonita Park area had a significantly different fire regime than other portions of the Monument supporting coniferous forest.

Piñon Juniper Cypress Woodlands and Forest

Comprising roughly 40% of the landscape within the Monument, Piñon - Juniper - Cypress (PJC) is the largest single vegetation type within CHIR. It is relatively varied in composition with woodland sites often characterized by an understory of chaparral, while some canyons (e.g. Echo Canyon) support stands of high-canopy cypress dominated forest often with an oak understory component. Although the presence of the fire-sensitive conifer species (e.g. piñon and cypress) was considered diagnostic, various oak species and manzanita were well represented.[2] Manzanita was the most common single species, as measured by percent cover, followed by piñon, canyon live oak/toumey oak, and cypress. While fire evidence, generally in the form of charred wood or burned juniper snags, was common in these sites (Table 4), evidence of recent fires was rare. Fires scars were noted on some cypress and piñon trees suggesting the occasional occurrence of surface fires, however, this was the exception rather than the rule.

Table 4. Fire evidence.

Plot type	Number w/fire evidence	Percent
PJC	9	30
CHA	7	25
W/GRA	6	25
total	22	30

Increment cores from dominant, fire-sensitive trees in the vicinity of vegetation sample points were dated to provide estimates of time since last fire (Table 5, Figure 10A and 10B). While in a few cases we were unable to cross-date these samples, we were able to estimate approximate ages in all cases. The age range and variability was used to help characterize the pre-settlement fire frequency when aggregated for each vegetation type.

[2]For species composition by cover type see Figure 11.

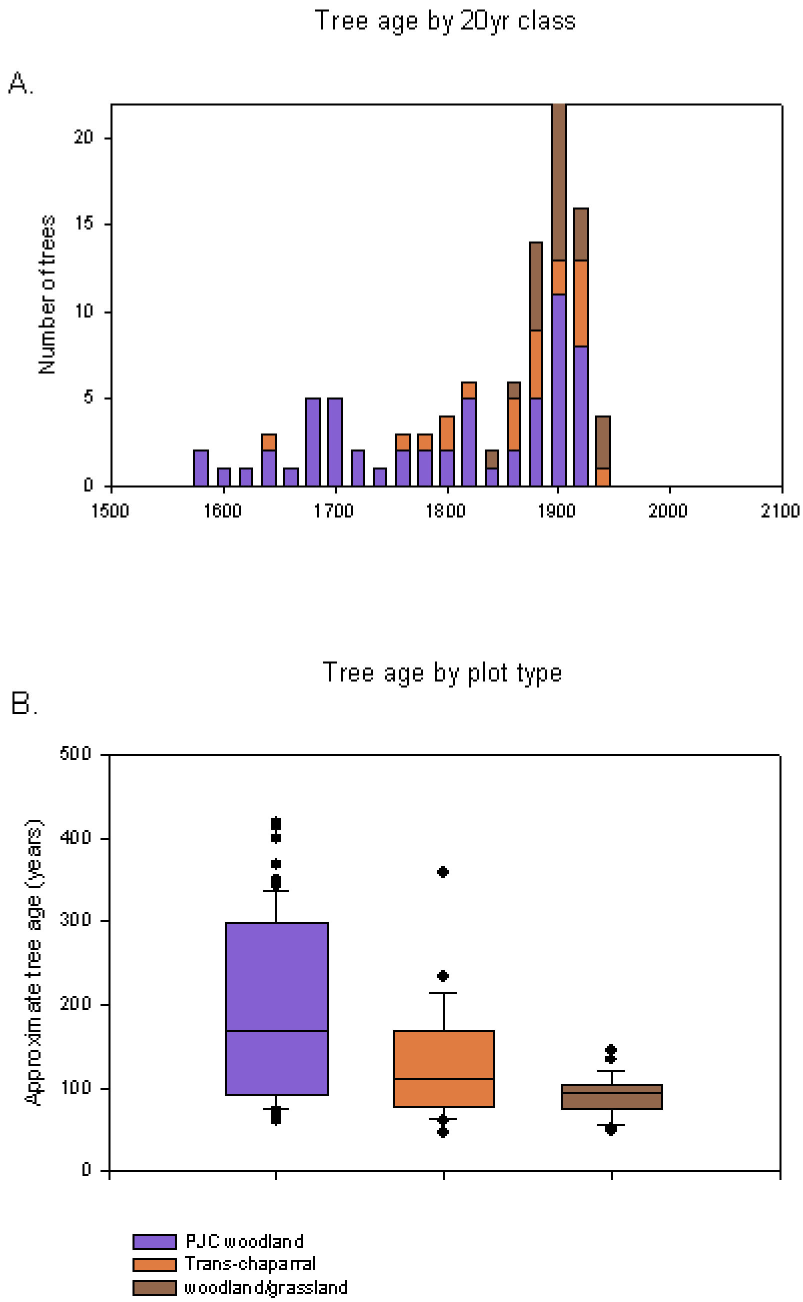


Figure 10. Distribution of dominant tree ages by plot type.

Table 5. Time-since-fire samples.

Plot type	No. of samples	No. dated
PJC	63	57
CHA	20	20
W/GRA	24	21
total	107	98

The results for the PJC type showed the widest variation in tree age of the three types considered with a mean age of 190 years and a standard deviation of 107 years.[3] The minimum age was 61 years and the maximum 419. This data is consistent with infrequent, episodic fire occurrence at irregular intervals. A mode at 299 years may be related to recruitment following the widespread fire of 1685 (Figure 10A). Burned or charred wood samples were collected at several sample points. While these samples were not dated, they were ring-counted to estimate their age at mortality (Table 5).

Table 6. Charred remnant samples.

Plot number	No. samples	Avg. estimated age	Current stand age
24	2	305	>300
26	2	210	>300
SDT*	3	330	--
Total/avg	7	288	>300

* Piñon stand, not a sample point.

This data is also consistent with long-interval fire occurrence, as stands currently about 300 years old previously supported trees of similar age. Stands appeared to attain maximum age in areas surrounded by barren, rocky areas that could have served as barriers to fire spread. Based on the tree-age data fire frequency was estimated to vary from 50 to 100s of years with a mean near 200 years. Relative proximity to areas with higher fire frequencies and the presence and effectiveness of fire barriers undoubtably had an effect on the rate of fire occurrence at particular points.

[3]Coniferous forest and canyon woodland was excluded from this analysis as fire frequency in this type had previously been documented with evidence from fire-scars.

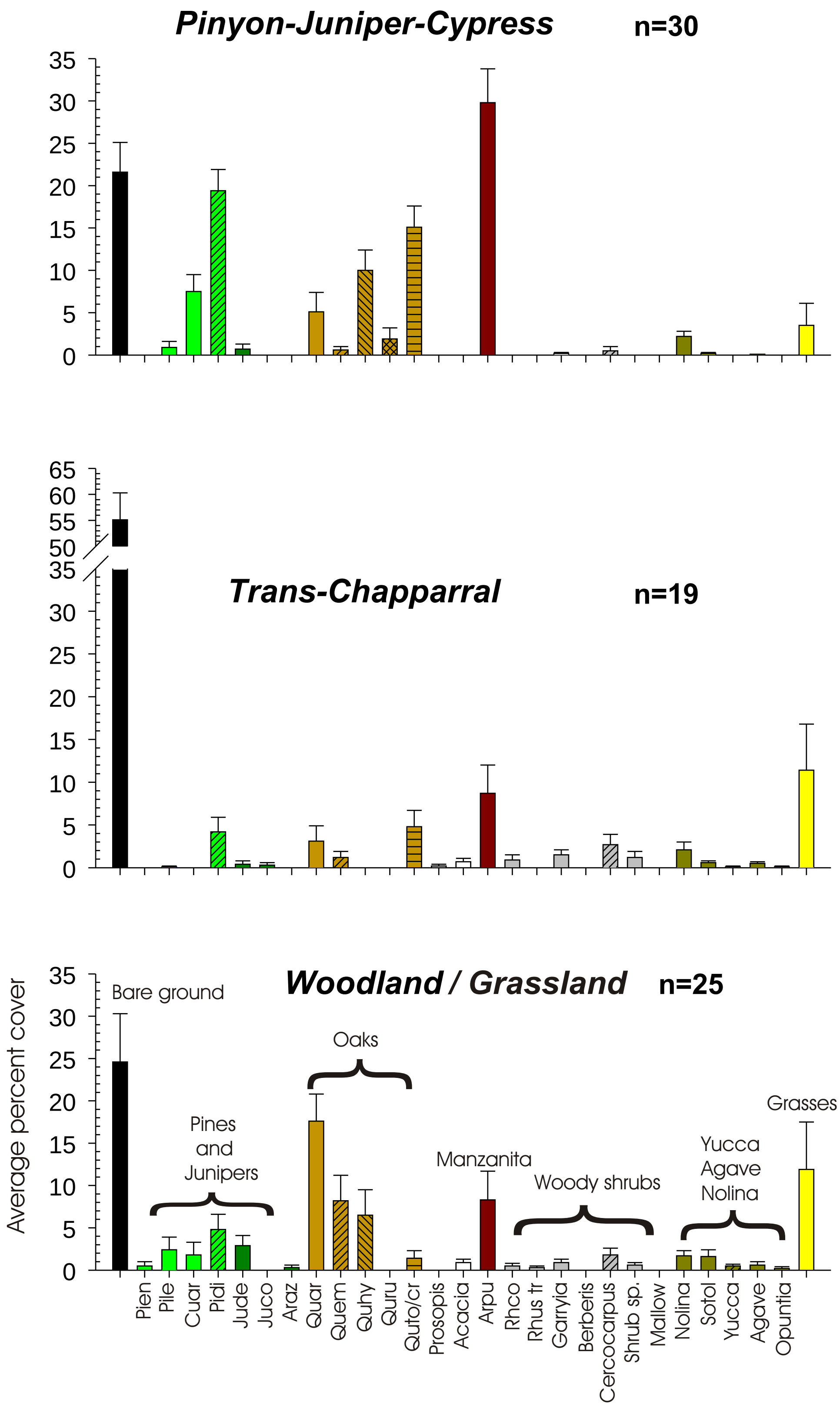


Figure 11. Distribution of species by plot type.

Transition (Trans) Chaparral

This community was mapped at approximately 15% of the Monument. Characterized by an abundance of manzanita and other woody shrubs, plots in this type also had a large proportion of grasses (11% cover) and the greatest proportion of bare ground (55% cover) (Figure 11). Twenty five percent of the plots showed direct evidence of fire (Table 4). Tree ages (Figure 10B) ranged from 46 to 359 years with a mean of 130 years. The box and whisker plot, Figure 10B, shows a tighter age distribution than the PJC type that is consistent with a somewhat higher fire frequency. It is also probable that lack of fire over the last century has had a larger impact than in the PJC community. Roughly half of the piñon aged were less than 110 years old (median age was 112) and the last large fire in CHIR occurred 113 years ago. It is possible the a large portion of this community burned at that time. The fine fuel provided by the grass component would have provided fuel continuity and encouraged fire spread from adjacent woodland and forest areas with higher fire frequencies. Fire return intervals for this type probably ranged from 30 to 80 or 90 years. At longer intervals a gradual conversion to PJC woodland would probably begin to occur. Conversely, PJC stands that burn over might be converted to this vegetation type, at least for an interim period pending re-establishment of the conifers. Given the general propensity for this type to increase and invade open areas following the cessation of surface fires, it is likely that the proportion of this cover type has increased significantly in this century.

Grassland and Open Woodland

Comprising roughly 20% of the Monument vegetation, these communities are widely assumed to have sustained fire frequencies of 8 to 15 years in the past (Kaib et. al. 1996, Kaib 1998). Tree age data suggested that these areas have been invaded by the fire-intolerant piñon over the last century. Woody shrubs such as manzanita are also likely to have increased their representation during this period. Evergreen oaks, grasses, and manzanita dominated the cover in these plots (Figure 11). Fire evidence was observed in one quarter of the plots in the form of charred wood and fire-scarred oak trees. While direct evidence to support estimates of past fire frequency was not found, the mean fire-intolerant tree age of 92 years suggests that fires were frequent enough to prevent successful establishment of these species prior to the turn of the century.

Vegetation Sample Points and Vegetation Mapping

The 74 points visited were a subset of the 165 points originally identified. To check for bias in the subset the topographic position of these points was compared to that of the full set (Figure 12). Slight differences in slope and aspect distributions for the Trans-Chaparral plots were noted. However the distributions were deemed similar enough to proceed with analysis.

Data from the vegetation sample points was consolidated into percent cover by species and species groups (Table 7, Figure 11).

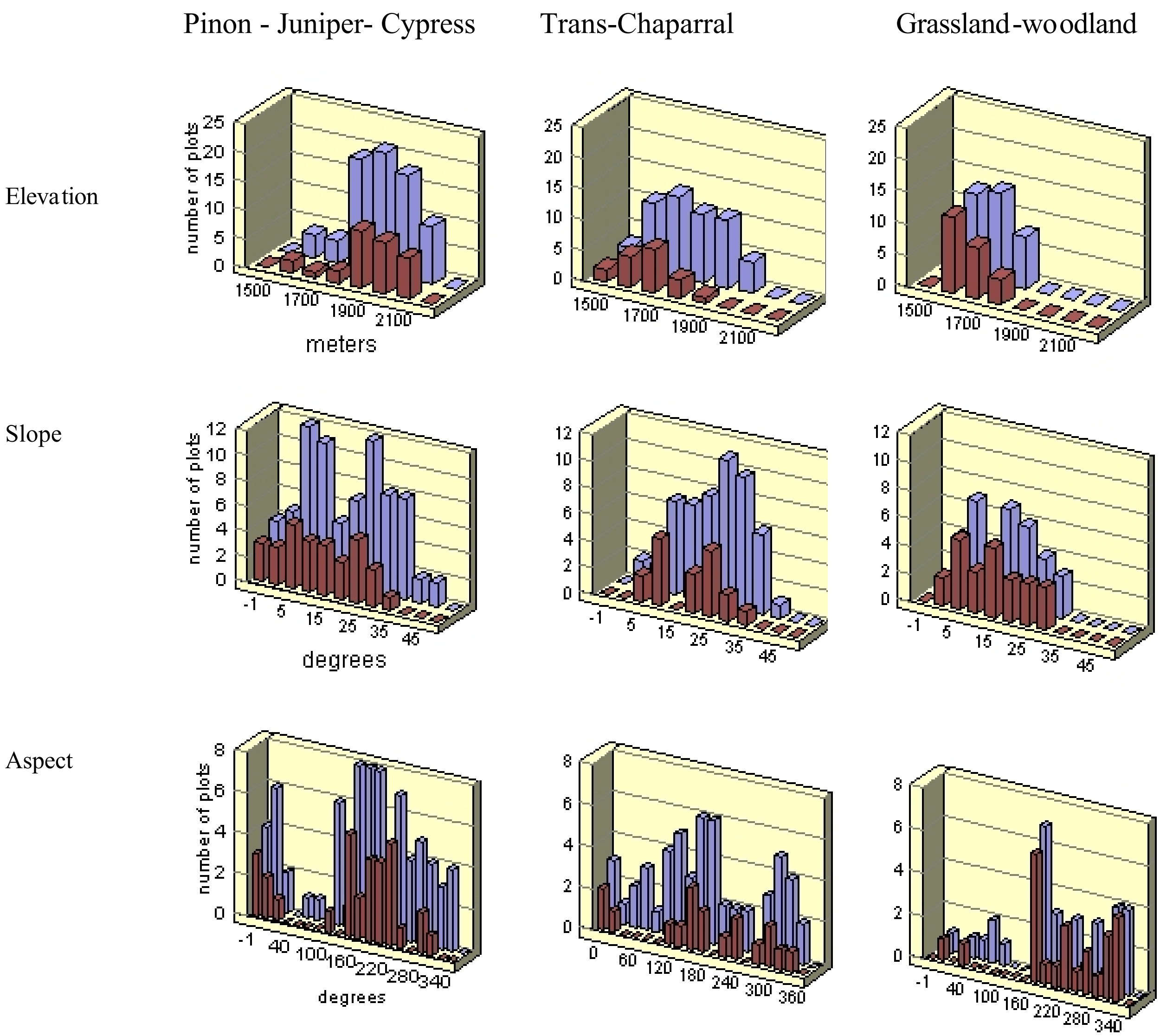


Figure 12. Topographic distribution and comparison of random points and the sampled subset. All Y axes are numbers of plots. For X axes elevation in meters, slope in degrees, aspect in degrees. The value -1 represents flat surfaces for slope and aspect. Blue bars denote the entire set, brown the subset. Distributions are generally similar, with the exception of slope for chaparral.

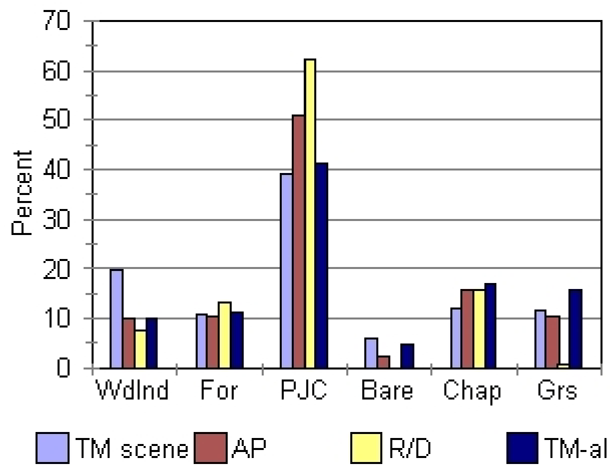


Figure 17. Percent cover type for each of the different mapping techniques. The first three bars compare the area of the clipped image (Figure 14) and the fourth is for the Monument as a whole based on the TM image (Figure 17). TM = Thematic Mapper satellite image, AP = aerial photograph, R/D = Roseberry and Dole. Wdlnd = woodland, For = forest, PJC = pinon juniper cypress, Bare = barren, Chap = Chaparral, Grs = grassland.

Table 7. Plot composition species list.

Figure legend	Common name	Latin name
Pien	Apache pine	*Pinus englemanii*
Pile	Chihuahua pine	*Pinus leiophylla*
Cuar	Arizona cypress	*Cupresses arizonica*
Pidi	Border piñon	*Pinus discolor*
Jude	Alligator-bark juniper	*Juniperous deppeana*
Juco	Common juniper	*Juniperous communis*
Araz	Arizona madrone	*Arbutus arizonica*
Quar	Arizona white oak	*Quercus arizonica*
Quem	Emory oak	*Q. emori*
Quhy	Silverleaf oak	*Q. hypoleucoides*
Quru	Netleaf oak	*Q. reticulata*
Quto/cr	Toumey and Canyon live oak	*Q. toumeyi, Q. chrysolepis*
Prosopis	Mesquite	*Prosopis sp.*
Acacia	Acacia	*Acacia sp.*
Arpu	Manzanita	*Arctostaphylos*
Rhco	Sumac	*Rhus communis.*
Rhus tr	Sumac	*Rhus trilobata*
Garrya	Silk tassel	*Garrya wrightii*
Berberis	Barberry	*Berberis sp.*
Cercocarpus	Mountain mahogany	Cercocarpus sp.
Shrub sp.	Miscellaneous woody shrubs	– --
Nolina	Bear grass	*Nolina microcarpa*
Sotol	Sotol	*Dasilerion whelerii*
Yucca	Yucca	*Yucca sp.*
Agave	Century plant	*Agave sp.*
Opuntia	Prickly pear, cholla	*Opuntia sp.*

Examination of this data suggested that the 1939 map by Roseberry and Dole was substantially correct. Some errors in assignment were noted, primarily where high-canopy cypress stands in drainages were mapped as "Pine" or "Pine/Douglas-Fir". Plot types were clearly distinguishable despite overlap in species composition. The woodland/grassland plots were perhaps the most diverse, with a wide range of woody perennial species well represented. It is probable that this abundance of woody species is due, in part, to lack of fire over the last century. Additionally, portions of the relatively large areas mapped as trans-chaparral may represent areas invaded by woody shrubs over this century.

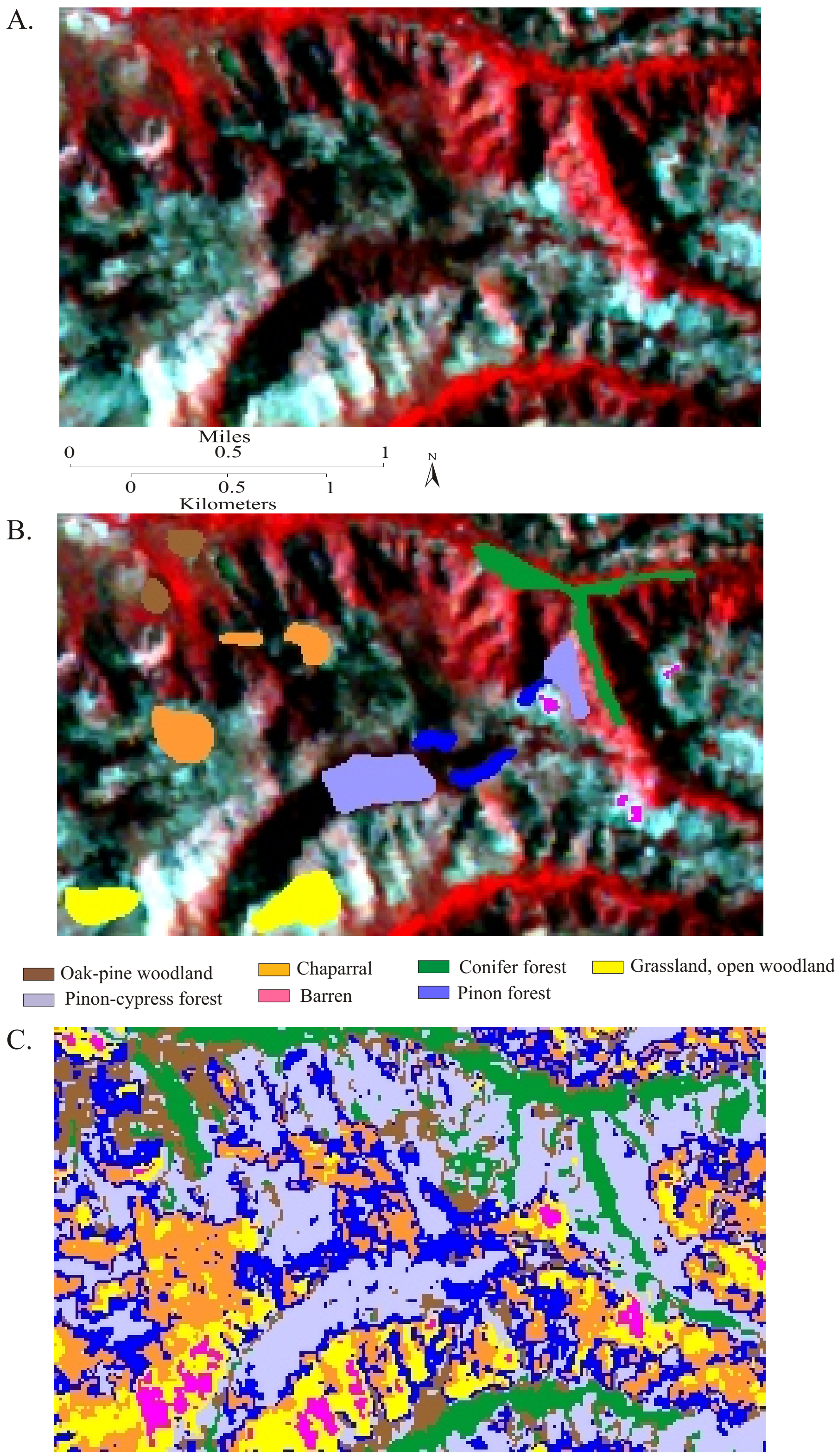
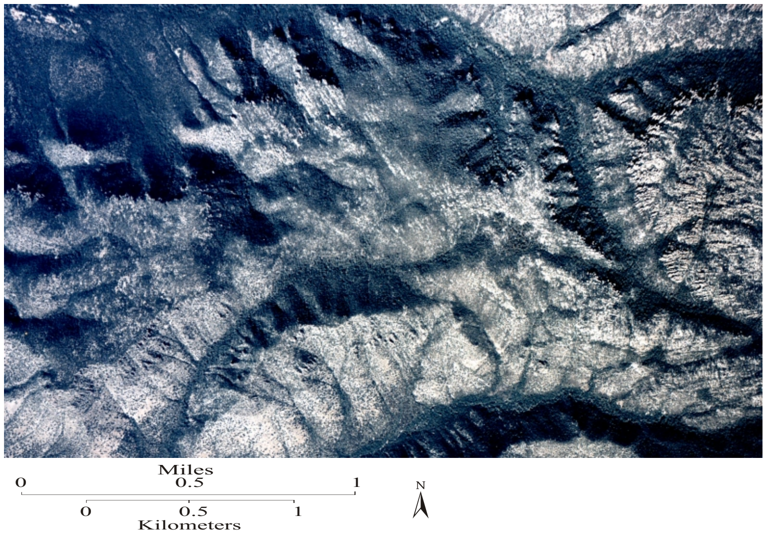
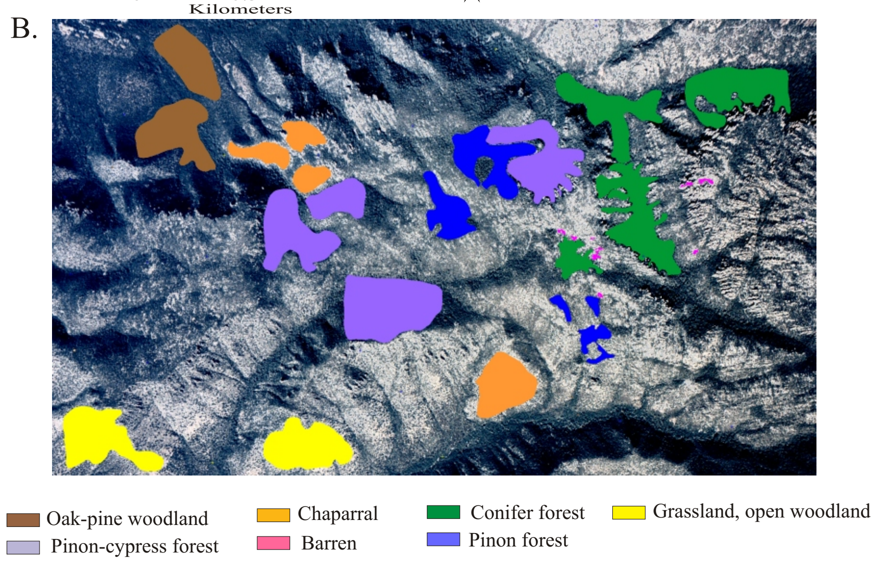


Figure 13. Classification of a satellite TM image (30m resolution) by maximum likelihood algorithm. Representative areas were chosen based on aerial photography and field reconnaissance to perform the supervised classification. (A.) Base image; (B.) Training areas; (C.) Classified image.

A.



B.



C.

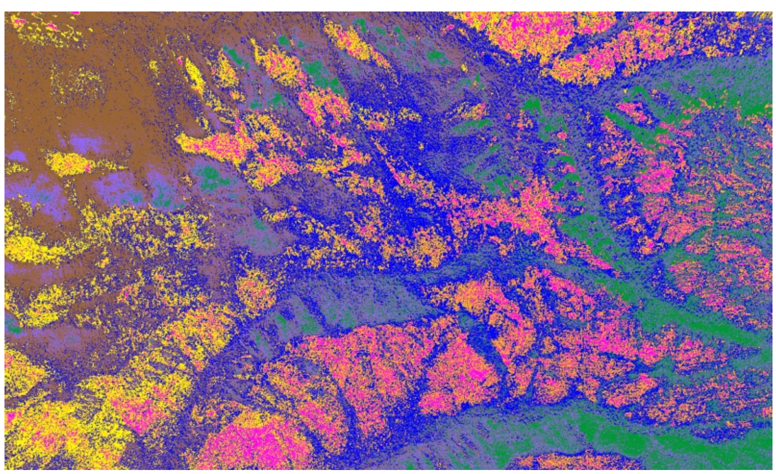


Figure 14. Classification of a color aerial photo (~1m resolution) by maximum likelihood algorithm. Representative areas were chosen based on aerial photography and field reconnaissance to perform the supervised classification. (A.) Base image; (B.) Training areas; (C.) Classified image.

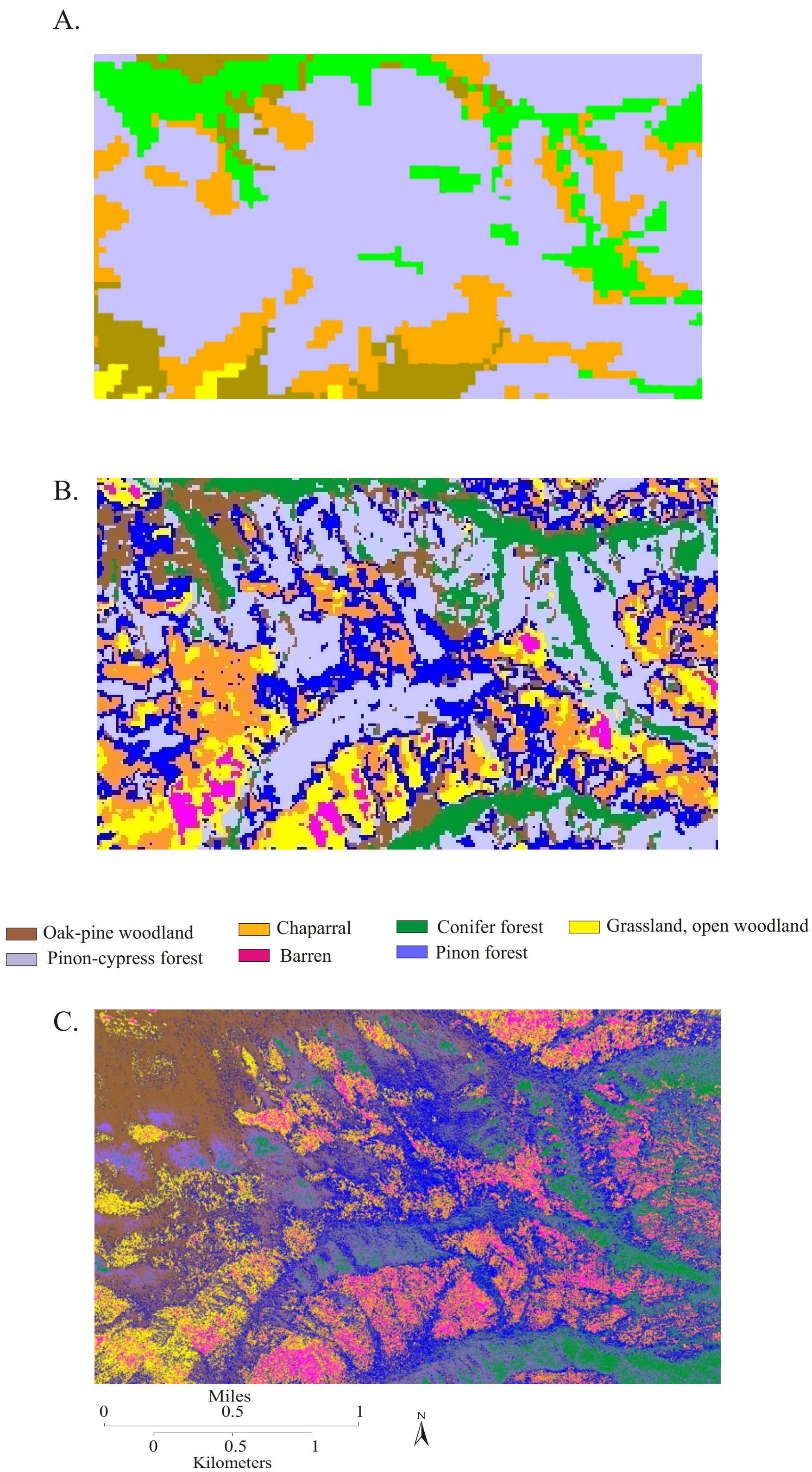


Figure 15. Comparison of the three classifications, coarse to fine scale. (A.) Roseberry and Dole. (B.) TM scene. (C.) Aerial photo

Image Analysis

The aerial photography and satellite imagery was utilized via GIS software to produce maps of estimated vegetation type (Figures 13 and 14). These were then compared to the digitized version of the Roseberry and Dole map (Figure 15). Classification accuracy for the classification models vs the training areas is presented in Table 8.

Table 8. Classification accuracy.

Region	Color	Veg. Type	% Accuracy (TM*)	% Accuracy (AP**)
1	brown	pine/oak woodland	85	83
2	orange	chaparral	78	29
3	blue	pinon forest	90	65
4	yellow	grassland	68	44
5	violet	pinon/cypress forest	92	34
6	magenta	rock/barren	93	87
7	green	pine/fir forest	95	33
		Overall	84	44
		Kappa	0.82	0.37

* Thematic Mapper satellite image.
** Color aerial photo.

While the TM classification appears to be reasonably accurate, averaging 84% for all vegetation classes, this is misleading, as is the apparent poor accuracy of the aerial photo classification. The resolution of the satellite image is $900m^2$/pixel compared to approximately $1m^2$ for the aerial photography. Given that the training areas are relatively large, and assumed by definition to be homogeneous, it is not surprising that the model for the aerial photography appears to perform so poorly. The actual vegetation is highly variable with plant species intermixed in variable associations at a fine scale. The training areas used to produce the classification model are not, in fact, homogeneous at this resolution. The generalized model developed from the coarse resolution satellite image is a better match for the class averaging in the training areas, thus appearing more accurate. None the less, the TM classification contains systematic errors of mis-assignment. Barren rock is confused with grassland. Tall-canopy coniferous forest cannot be reliably segregated into cypress-dominated forest vs pine/douglas-fir forest. While this classification is generally correct, it is not specifically correct in many cases. The classification of the aerial photo comes much closer to capturing the actual vegetation

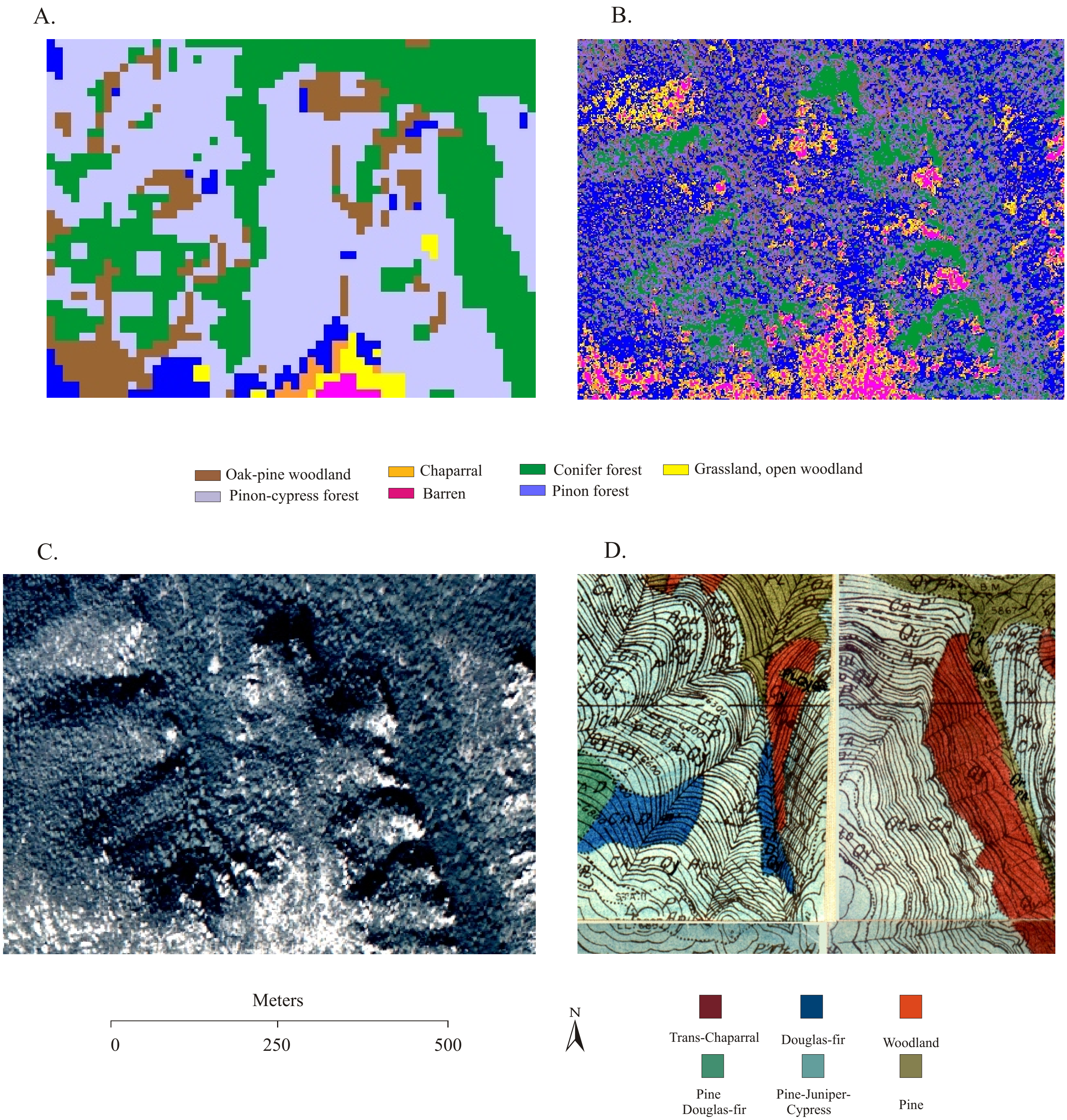


Figure 16. Detail comparison of the classification result of similar areas. (A.) Classified TM image. (B.) Classified color aerial photo. (C.) Original color aerial image. (D.) Hand mapped.

complexity (Figures 14 and 16), however, issues such as shadowing produce artifacts in this model as well. Tall canopy forest is characterized by shadows, as are steep canyon walls regardless of their vegetation cover.

The map produced by Roseberry and Dole is similar in resolution to the TM classification. This can be seen in the comparison of the classification results presented in Figure 15. While it too contains some inaccuracies, they do not appear to be systematic in nature. Rather, the investigators probably did not visit and field check all areas mapped, some mistakes of assignment were not corrected. Specifically, we recognized in the course of field reconnaissance that a few areas mapped as Douglas fir forest are dominated by tall canopy cypress. Additionally, many brushy areas along the western and southern Monument boundaries mapped as Trans-chaparral are probably former grassland invaded by woody shrubs.

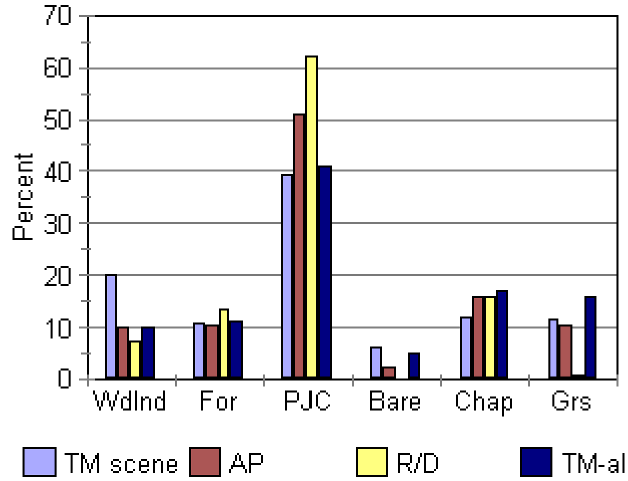


Figure 17. Percent cover type for each of the different mapping techniques. The first three bars compare the area of the clipped image (Figure 14) and the fourth is for the Monument as a whole based on the TM image (Figure 18). TM = Thematic Mapper satellite image, AP = aerial photograph, R/D = Roseberry and Dole. Wdlnd = woodland, For = forest, PJC = pinon juniper cypress, Bare = barren, Chap = Chaparral, Grs = grassland.

Despite these issues of class assignment, the percent cover for each mapped class did not vary by a large amount when the different mapping techniques are compared for the clipped image (Figure 17). Additionally, a classification of the entire Monument based on the TM image (Figure 18) shows a similar ratio of cover types when compared to this smaller area.

Given the difficulties in producing a reliable classification based on image modeling alone it would appear that a revision of the Roseberry and Dole map based on aerial photography and field recognizance should produce the most reasonable vegetation cover map product at a resolution that is useful for fire management decisions. While the true complexity of the vegetation communities in CHIR can be shown with a mapping model based on color aerial photos, the utility of such a complex map for fire management is questionable. Basic fire regime differences can be adequately described with a relatively coarse resolution cover type map. However, as an objective tool for change detection and tracking trends in vegetation cover, use of remote imagery of various types and resolutions has great promise. High resolution infra-red aerial photography, when it becomes available has the potential to provide an improved base for remote vegetation mapping.

A.

B.

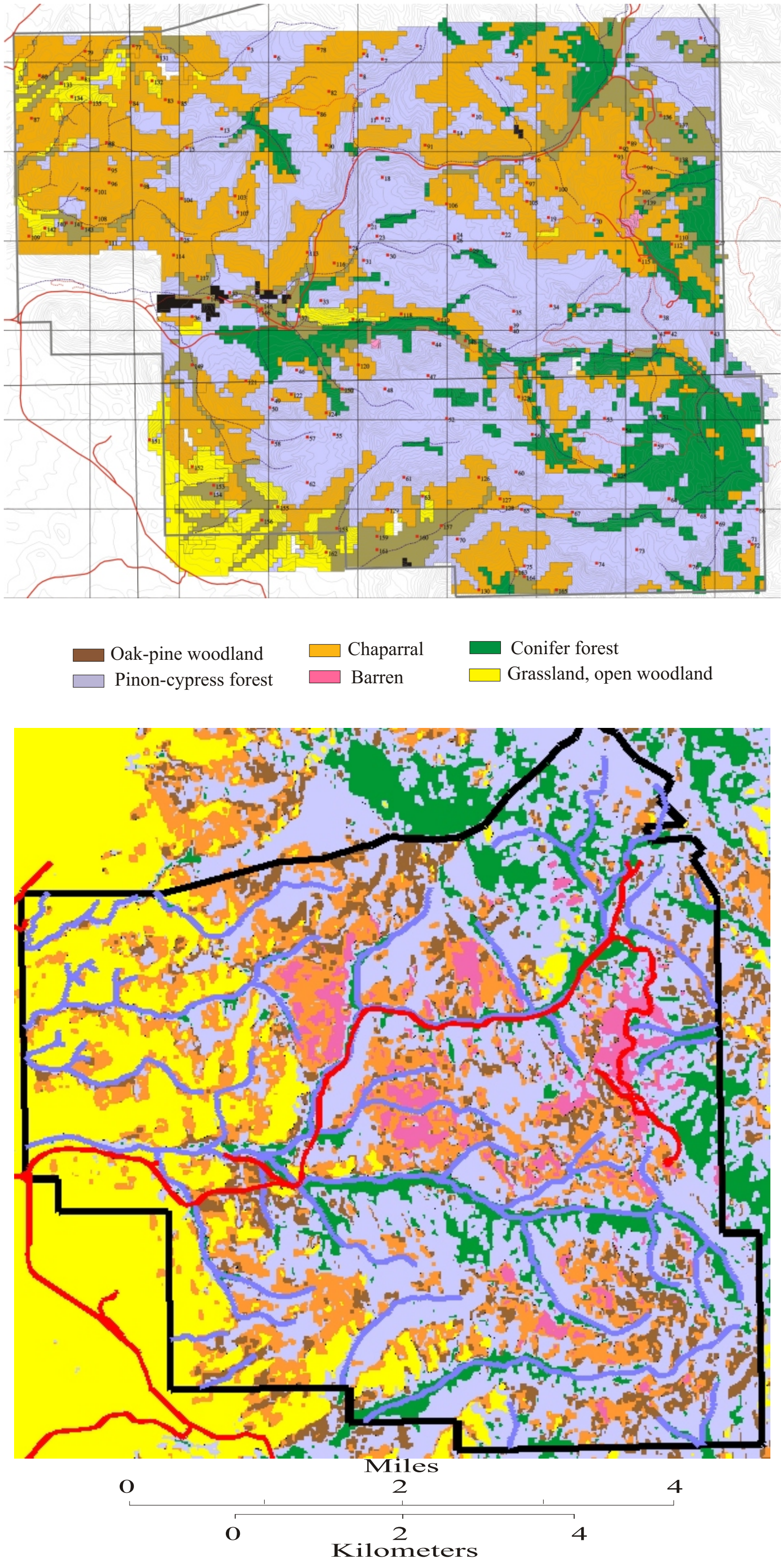


Figure 18. Modified Rosberry and Dole vegetation map (A) and classified TM image (B).

SUMMARY

- All cover types within Chiricahua National Monument have experienced fires in the past. Direct evidence of past fire was observed in approximately 1/3 of all sampling plots in all cover types.

- Fire frequency, intensity, and spatial extent was highly variable with these characteristics generally, but not exclusively, related to cover type. The approximate relationship of fire intensity to cover type from low to high was grassland and open woodland (2-15 years) < conifer forest and canyon woodland (2-15 years) < trans chaparral (20-100 years) < piñon-juniper-cypress woodland and forest (80->400 years).

- Spreading surface fires, recurring at intervals of 1 to 19 years, were an integral component of the dynamics shaping the vegetation within the major canyon systems and adjacent forested areas over at least the past five centuries. Spatial patterns of fire derived from fire scars suggest that many of these fires may have spread from areas outside current monument boundaries. This indicates that fire management strategies should include management ignitions. Additionally, interagency cooperation to develop an integrated plan for, perhaps, the northern Chiricahuas may be a more appropriate scale at which to manage fire in this area.

- The surface fire regime influenced a variety of plant associations along an elevational gradient from grassland, oak-conifer woodland, montane conifer gallery forest, to upland pine forest by encouraging fire tolerant species at the expense of fire intolerants and maintaining open stand conditions. Open stands dry out more readily and provide better conditions for grasses and herbaceous cover which, in turn, encourage the spread of subsequent fires in a positive feedback loop.

- Based on fire scar position, these fires occurred predominantly during the spring and early summer months. While this suggests the opportune window for effective fire spread, current management objectives may dictate fire ignitions during other seasons. Burning is possible throughout the year depending on antecedent weather conditions.

- High intensity fires, or surface fires with a high intensity component probably played a role in all cover types, but were more typical in transition chaparral and piñon-juniper-cypress woodland and forest. The interval between such fires was highly variable (e.g. decades to centuries) and dependant on the chance co-occurrence of necessary pre-conditions of ignition, weather, fuel continuity, and fuel abundance. Given the long intervals between such events it may not be necessary to specifically require high intensity fire as part of a management plan or at some particular interval. Should such an event occur, however, it probably should be treated as part of the normal behavior of the system. Management planning should acknowledge this possibility and plan appropriate responses should it occur.

- While fire has historically been a feature of pinon-juniper-cypress communities it's irregular occurrence and the long intervals between fires in some stands suggest that post-settlement changes have been less pronounced or absent in this cover type. Specifically targeting PJC for management ignited fire may not be necessary. Should fires naturally occur within PJC or spread to this type from adjacent areas, however, this could be considered part of the normal fire regime.

- At least one high-intensity fire appears to have occurred in the pine and mixed-conifer forest within portions of Rhyolite Canyon (approximately 400 years ago, perhaps in 1591). Like debris flows, such events were uncommon and do not characterize "typical" system behavior. Yet they have significant and persistent effects on the landscape lasting decades to centuries and are an important part of the longer term variability of the area.

- The abundance of woody plants, particularly fire intolerant species, has increased over the past century in most cover types. This change affects fire behavior, leading to increased intensities and spread potential by changing fuel structure composition and continuity. Return of fire to the landscape should be expected to affect woody plant abundance. In particular, the abundance and spatial configuration of the transition chaparral cover type could be strongly affected.

- Geomorphic processes (floods and debris flows) interacted with the fire regime within canyons. Flooding removes soil and organic material and deposits sand and gravel along the stream course potentially limiting or redirecting fire spread. Debris flows deposit large amounts of unsorted sand, gravel and boulders, striped from slopes and canyon sides, in vegetation-free berms that could also be expected to affect fire spread patterns. Flooding while unpredictable, may occur several times per decade. Debris flows, on the other hand, occur at intervals of centuries. They are more common following severe fires that remove vegetation from slopes making slope failure more likely during subsequent rains, however fire is not a necessary prerequisite.

- A revised, coarse-grained vegetation map based on the work by Roseberry and Dole may prove the most useful management tool for planning fire management strategy for CHIR. A geo-referenced digital version already exists and a revised map could correct some errors present in the original version. Field data from randomly placed points collected for this project largely corroborated it's general accuracy. While the map is somewhat general in nature it's coarse resolution is probably reasonably matched to a scale appropriate for resource management. The four generalized cover types (canyon woodland and mixed-conifer or pine forest, grassland and open woodland, piñon-juniper-cypress forest and woodland, and transition chaparral) embody distinct fire regimes and thus can provide a useful starting point for fire management planning. Community boundaries should be expected to fluctuate over time, particularly as fire is reintroduced to the landscape. Thus any vegetation map should be treated as a useful tool, not a rigid template or fixed entity.

- High resolution color aerial, and color infra-red photography if it becomes available, can be used to assist in ground truth and correction of the existing vegetation map as well as to document change and trend within plant communities. Currently available photography will also undoubtably prove helpful to track vegetation change and verify map accuracy and field observations.

ACKNOWLEDGMENTS

This research was funded by the National Park Service. Logistical support and general encouragement was provided by Chiricahua National Monument staff and management. The USFS Rocky Mountain Research Station contributed equipment for the field effort. Shelly Danzer developed the vegetation sampling procedure and contributed substantially to the field work. The Advanced Resources Technology Lab at the University of Arizona provided data layers used for some of the maps and analysis. Additionally, Gary Christopherson, James Riser, Bob Czaja, Matt Rollins provided assistance with field work, mapping and photo analysis portions of the project. Kathy Davis of NPS SOAR provided helpful reviews of this report and her devotion to Park management based on science has supported this and many other studies.

The efforts of many additional people over more than a decade contributed to this work as well. These include Jorge Alzega, Dick Anderson, Peter Brown, Tony Caprio, Thomas Harlan, Matt Riser, Robert Shay, Marv Stokes, Tom Swetnam, and Ramzi Touchan.

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Appendix II

Historical documentation.

Fire documentation from Ft. Bowie Military Post records - microfilm, sent by Larry Ludwig 4-23-98. Font approximates original hand.

Camp Emmet Crawford at 6. P. M. June 21st, 1886
Acting Assistant Adjutant? General
District of Bowie
Fort Bowie Az.

Sir,

The mail courier has just returned and reports it impossible (on account of fires) to cross to Captain Baldwin's camp on either the Whitetail or Dunn trails. And I send this by the road to Fort Bowie.

Very Respectfully
Your obedient servant
Geo. H. Evans
1st Lieutenant 10th Calvary
Commanding.

Camp Bowie Arizona Territory June 3rd 1868

Capt. St. j. Ripley
32nd Infantry USU
Commanding Post

Sir -

I have the honor to report that in compliance with past Order No. 25 dated Camp Bowie A.T. May 29th 1868 — on the morning of the 30th ?? I left camp with a scout consisting of thirty (30) men of Co. "D" 32nd US Infantry and two (2) citizens who were employed as guides and (volunteers) ?? ?? And went directly to the place where the Overland Mail Coach was captured by Indians on the 26th of May—

There I found the trail which the Indians made when they went back to the mountains — Following it about five (5) miles in a southernly direction it led into a deep Cañon, about eight (8) miles distant from the post. Here was plenty of water and in a ?nearby? second place a deserted Rancheria which had recently been abandoned. From all appearances the place has been for a long time, a general rendezvous for marauding bands of Indians that committed depredations in the vicinity of the Post.

I found the place where they had killed and eaten one of the captured mules and shortly after a place where they had eaten one of their own horses—

Continuing the search we found a place where the captives had been kept. This was the final ?house? of the missing men that had been discovered.

Shortly after we came to a huge ?flat? ?mark? from which the men had been tortured and suffered such a death as only an Apache Indian can invent.

Two of the men only were found Private? Rubent? King and George Knowles of Co. "D" 32nd US Infantry. Xx??xxx?? (some verbiage about those still missing)

After burying the remains of these men, and taking a short rest - I again took to the trail and followed it through deep narrow Cañons and mountain passes until nightfall, when it being impractical to keep it any longer bivouacked for the night - The general direction of today's march was a little South of East and distance from the post about 25 miles.

Early the next morning the march was continued, but with many difficulties as the country was very rough and the Indians had begun to divide into small parties, and leave the trail making it very uncertain which direction the main party had taken. But with the skill and excellent judgement of the guide succeeded in keeping the right trail. About noon we arrived at a clean running stream in the vicinity of the Rio Ancho where we went into camp. The whole country and surrounding mountains for miles around was in a sheet of flame, having been set on fire by the Indians the day before our arrival, and it was only with a great deal of labor that a general? camping ground was secured by putting out the fire in the Cañon in which we found the water. The distance traveled today was about twenty (20) miles and nearly in the same direction as yesterday.

The stream up which were encamped we called the Rio Seco from the fact that it dried up entirely before 3P.M. and the water did not return until about that hour the next morning — On this stream there are traces of ancient ruins pottery similar to those found on the Rio Gila.

Finding that the remaining Indians had scattered in every direction from this place I deemed it useless to continue the search any further, and after a rest of twenty-four (24) hours started back following a different route through the San Simon Valley keeping clear of the mountains—

The scout arrived at Camp Bowie on the morning of the 2nd of June 1868 without anything further of interest taking place—

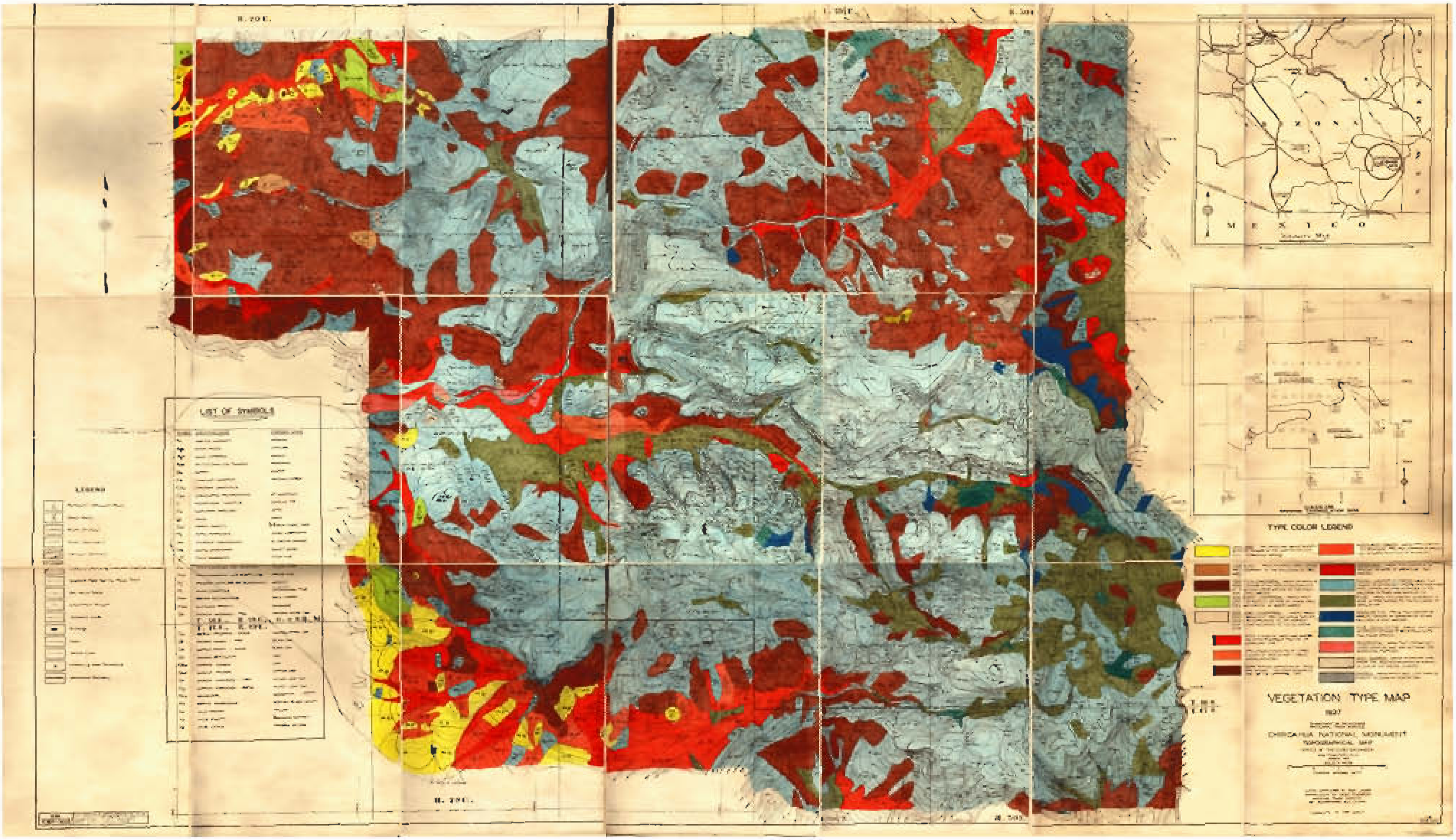
I am under many obligations to A.A. Suiyam? V.P. Wielney? U.S.W. for the many valuable services rendered in this expedition— and also to Messers Abrahm Lynn and Thomas Harris for their invaluable services were? accompanied the scout—

I have the honor....

Very Respectfully Your Obedient Servant

Edward B. ?????

2nd Lieut. 32nd U.S. Infantry - - - -


LIST OF SYMBOLS
LEGEND
TYPE COLOR LEGEND
M E X I C O
VEGETATION TYPE MAP
CHIRICAHUA NATIONAL MONUMENT
TOPOGRAPHICAL MAP