CHANGES IN PONDEROSA PINE FORESTS OF THE MT. LOGAN WILDERNESS

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Mt. Logan Wilderness, Mohave County, Arizona (Photo: Marcy DeMillion)

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ABSTRACT

Ponderosa pine forests in the Mt. Logan Wilderness on the Arizona Strip have become dense with young trees and highly susceptible to catastrophic wildfire due to exclusion of the natural frequent-fire regime and the effects of livestock grazing and logging associated with Euro-American land use practices. As part of a broader regional ecological restoration study, the Mt. Logan Wilderness was sampled for fire scarred trees, vegetation, and fuels between 1995 and 1997. Reconstructed fire histories show that fires recurred about every 5-6 years prior to settlement, with larger fires burning every 9-12 years. Frequent fires ceased after 1869-1879 in the Mt. Logan Wilderness, coincident with the time of Euro-American settlement, beginning a fire-free period that has lasted up to the present except for a few fires in the 1930's. Current forests are dense, ranging from approximately 700 to 3,000 trees/ha, and dominated by small trees. At both unthinned and thinned sites on basalt soils within the wilderness, tree canopy cover is over 50% and tree basal area is high, 39-40 m^2/ha. Understory cover and species diversity are generally low, but slightly higher on cinder soils where shrubs form an important understory community and where tree density is somewhat reduced. Living and dead fuels, including plants, woody debris, and the forest floor , will easily support high-intensity wildfires. In contrast, the presettlement forest was relatively open, with tree densities ranging from approximately 80-100 trees/ha and basal areas ranging from 10-15 m^2/ha, dominated by large ponderosa pine trees. In ecological terms, prospects are good for restoring the Mt. Logan Wilderness to emulate the ecological structure and fire disturbance regime of the presettlement reference condition. The current forest is similar to nearby ecosystems where thinning, burning, and fuel treatments are being implemented. However, ecological information is only one component contributing to the debate over appropriate management values and practices in wilderness areas on public lands.

INTRODUCTION

Over the last century, western ponderosa pine forests have undergone deleterious changes due to human-initiated disruption of the natural structural and disturbance patterns under which these ecosystems evolved. Land use practices introduced by Euro-American settlers, including heavy livestock grazing, harvesting of old trees, and suppression of surface fires, have led to dense forests composed primarily of small, young trees, with greatly reduced herbaceous and shrub productivity. Many ponderosa pine forests are not sustainable in their degraded current conditions: densely growing trees are increasingly susceptible to infestation by insect and disease pathogens and deep forest floors and extensive horizontal and vertical continuity of fuels now support stand-replacing wildfires (Cooper 1960, Covington et al. 1994, Kolb et al. 1994).

The effort to restore ecosystem health in southwestern forests is a multidisciplinary endeavor aimed at averting catastrophic ecological change and restoring ecosystem conditions characteristic of the evolutionary environment (Covington et al. 1995). The Mt. Trumbull Resource Conservation Area, managed by the Bureau of Land Management, is the largest operational restoration site in the Southwest. In cooperation with Northern Arizona University (NAU) and the Arizona Game and Fish Department, the Arizona Strip District of the BLM has undertaken adaptive ecosystem restoration of southwestern ponderosa pine ecosystems to their pre Euro-American settlement conditions: open forest stands dominated by large, old trees above a rich, diverse understory of native grasses and wildflowers, maintained by frequent, low-intensity fires. Beginning in 1995, researchers with the NAU Ecological Restoration Program have established a broad series of studies to measure and monitor ecological conditions within the Mt. Trumbull project area.

The Mt. Logan and Mt. Trumbull wilderness areas are the southern and northern borders, respectively, of the restoration project area. Although these wilderness areas are presently managed primarily for their natural qualities and wilderness character, forests within their boundaries have been affected by the past land use practices. While ecological restoration practices may be particularly valuable to recover natural values in wilderness and park lands, wilderness management regulations and philosophy often appear incompatible with active restorative work. Within the broader Mt. Trumbull restoration project, several lines of research are addressing the role of ecological restoration in wilderness. First, the current and presettlement conditions of ecosystem structure and fire disturbance regime have been measured. This report documents these conditions for the ponderosa forest areas of the Mt. Logan Wilderness. Second, social perceptions of Mt. Logan Wilderness restoration are being assessed in a local survey (M. DeMillion, M. Lee, and W.W. Covington, personal communication, 1998). Finally, potential restoration treatments which may be suitable for wilderness are being tested in nearby areas (A. Kaufmann and W.W. Covington, personal communication, 1998).

METHODS

STUDY AREA

The Mt. Logan Wilderness is located in the Uinkaret Mountains on the Arizona Strip, north of the Colorado River and west of the Kaibab Plateau (latitude 36°20'N, longitude 113°12'W). The study area, comprising the ponderosa pine forest in the northern and northeastern edge of the wilderness, is shown in Figure 1. Mt. Logan is the highest peak (2,398 m). Other prominent peaks are Petty Knoll (2,295 m) and Slide Mountain (2,307 m). The lowest elevation in the forested study area was 2079 m. Soils are derived from volcanic substrates; soils are described under "Analysis Areas" below. Annual precipitation at Mt. Trumbull (elevation 2,448 m, approximately 6.8 km NE of Mt. Logan) averaged 50.59 cm between 1977 and 1997; precipitation averaged slightly less, 48.21 cm/year, between 1975 and 1997 at Nixon Spring (elevation 1,982 m, approximately 6 km NE of Mt. Logan). Most precipitation occurs in winter and during the summer monsoon; spring and fall are relatively dry. Vegetation communities in the study area include ponderosa pine (*Pinus ponderosa*)--Gambel oak (*Quercus gambelii*) forest. Utah juniper (*Juniperus osteosperma*) and pinyon (*Pinus edulis*) occur sporadically within the pine-oak forest; these species dominate the south-facing slopes. New Mexican locust (*Robinia neomexicana*) and a number of shrub species are also interspersed in the pine-oak forest, especially on cinder soils. Scientific names and authors of all species are listed in Appendix A. English-metric conversions are given in Appendix B.

Prehistory and history of the Arizona Strip, including the study area, are reviewed in Altschul and Fairley (1989). Although much of the Arizona Strip has had only limited archeological survey, evidence of Native American presence dates back to the early Archaic period (beginning approximately 8000 years Before Present [B.P.]). The Strip was populated throughout the Formative period (approximately 1800 B.P. through 1250 A.D.);the later portion (Pueblo II period, 1000-1150 A.D.) was characterized by the construction of large, multiroom pueblos, extensive agriculture

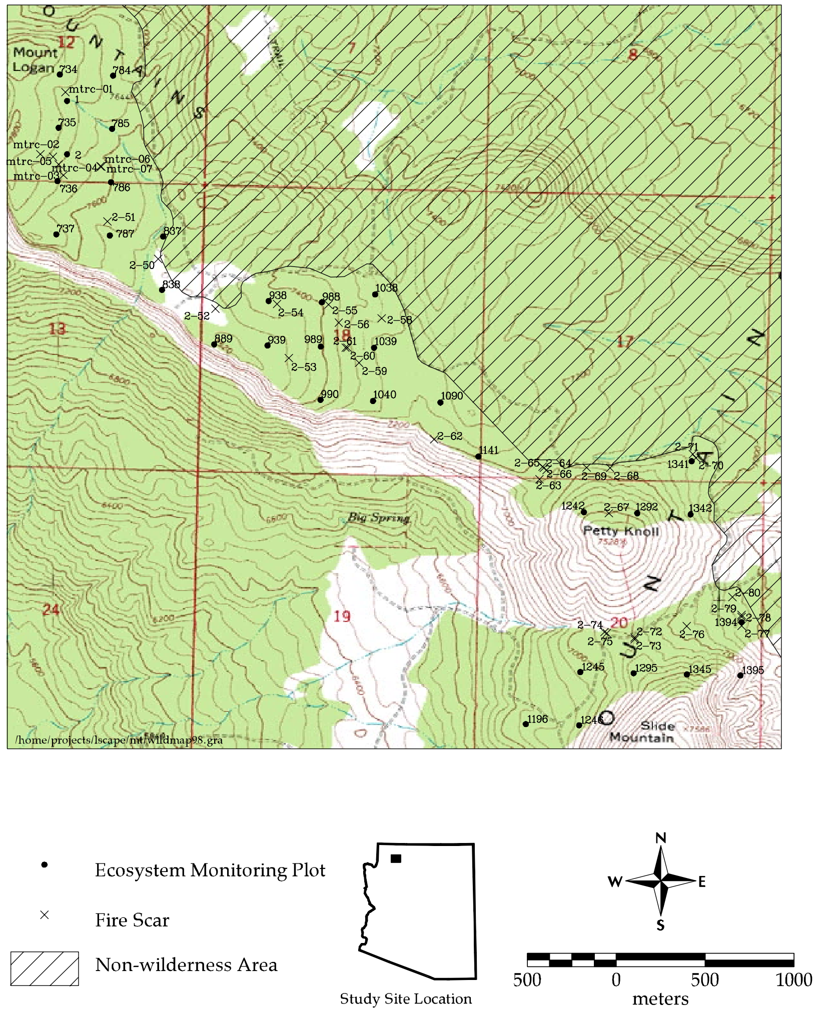

Figure 1. Mount Logan Wilderness Area ecosystem monitoring plot and fire scar sample locations.

including corn and lowland cotton cultivation, and broad trade networks. Upland areas, such as the study area, may have been utilized primarily in the warm season. However, much of the Mt. Trumbull region may have been low enough in elevation for year-round occupancy (Altschul and Fairley 1989:136). Most sites on the Arizona Strip were abandoned in the thirteeenth century. A number of possible reasons, ranging from environmental to social factors, have been suggested to explain the change in settlement patterns. Southern Paiutes were present on the Arizona Strip at least by 1285 A.D. and possibly earlier (Altschul and Fairley 1989:144,147). Ethnographic studies of land use practices by Southern Paiute bands suggest that upland areas were occupied primarily in summer and fall for hunting and gathering of pinyon seeds, berries, and other resources, together with limited seasonal cultivation of corn and squash; "intimate knowledge of plant resources" permitted successful planning of harvest schedules and sites (Altschul and Fairley 1989:149).

The first Europeans on the Arizona Strip were the Spanish members of the Domínguez-Escalante expedition seeking a route to California in 1776 (Altshul and Fairley 1989). The Strip remained unpopulated by Euro-Americans until the 1850's, except for other brief traverses by Spanish, Mexican, and American travelers. However, Southern Paiute bands were affected as early as the beginning of the nineteenth century by European diseases and raiding by other Native American and Euro-American groups. Euro-American settlers, members of the Church of Jesus Christ of Latter-day Saints (Mormons), arrived in southern Utah in 1854 and began to explore the Arizona Strip region. Permanent Euro-American settlements on the Strip were first established in 1862 (Short Creek) and 1863 (Pipe Springs). However, hostility between the Mormons and a Paiute-Navajo alliance kept Euro-American influences away from the Mt. Trumbull region until the conflict was resolved in 1870 (Altshul and Fairley 1989). Meanwhile, expeditions led by Major John Wesley Powell in 1869 and 1871 were instrumental in bringing the Grand Canyon region to the attention of the American public for the first time (Stegner 1954).

Euro-American settlement of much of the Arizona Strip, including Mt. Trumbull, began in 1870. Several ranches were established around Mt. Logan at Oak Spring and Whitmore [Big] Spring by 1872 (Altschul and Fairley 1989:187). Much of the Strip was overgrazed in the 1870's, a dry period, leading to severe degradation of grasslands (Altschul and Fairley 1989:192). To provide timber for construction of a Mormon temple in St. George, Utah, timber harvesting began in the Mt. Trumbull forests around 1872. Sawmills were erected in 1872 and the "Temple Trail" to St. George was built in 1874 (Altschul and Fairley 1989). A sawmill was built north of Mt. Logan in 1890 (BLM 1990:3) and commercial logging continued in the Mt. Trumbull region until the mid-twentieth century. The Mt. Trumbull forest was included in the Dixie (later Kaibab) Forest Reserve, although many lands were released for homesteading after 1916. In 1974, the Forest Service lands in the Mt. Trumbull region were transferred to the Bureau of Land Management (Public Land Order 5413) and a thinning treatment was initiated by the BLM on Mt. Logan. Mt. Logan and Mt. Trumbull were designated wilderness areas under the Arizona Wilderness Act on August 28, 1984 (BLM 1990:4).

Current management of the Mt. Logan Wilderness follows the 1964 Wilderness Act guidelines to maintain "a natural ecological landscape essentially free from man-induced contrast" (BLM 1990:5). Regulations include prohibitions on natural resource extraction (except for hunting and allotted livestock grazing) and require a minimum-tool management approach (BLM 1990). Prescribed fire has been applied since 1994 to reduce unnaturally hazardous fuel loads.

ANALYSIS AREAS

A total of 34 plots, covering approximately 310 ha, was established in the ponderosa pine forest of the Mt. Logan Wilderness between 1995 and 1997 (Figure 1). The forest covers two main soil types: (1) the basalt-derived soils of the Mt. Logan rim and (2) the cinder soils of Petty Knoll and Slide Mountain. Complete soil survey information is not available (Soil Conservation Service 1974), but the wilderness management plan authors (BLM 1990) inferred from incomplete data that the basalt soils were probably Siesta very cobbly clay loam and the cinder soils were probably Wukoki

Variant--Lomaki Cold Variant complex. Plots on the two soil types, 23 on basalt soils and 11 on cinders, were analyzed separately. Within the basalt soil type, over 100 ha were heavily thinned around 1974 (BLM 1990). The 12 thinned plots and the 11 unthinned plots were analyzed separately. Representative scenes from the analysis areas are shown in Appendix C.

Throughout the analysis, comparisons were drawn between (1) soil types (cinder soils vs. basalt [unthinned] soils); and (2) past management history (thinned vs. unthinned, basalt soils only). These categories and the plot numbers in each are summarized in Table 1.

The data for the Mt. Logan Wilderness have been summarized and presented here to support other research projects related to wilderness restoration issues, as described above. However, sample sizes for the Mt. Logan Wilderness analysis are low, probably contributing to relatively high variability and some anomalous results (e.g., see the discussion of stumps in the diameter distribution results below).

Table 1. Analysis areas in the Mt. Logan Wilderness based on soil type and past management history. Plot ID numbers correspond to plot numbers in Figure 1.

Plot ID	Soil	Thin	Plot ID	Soil	Thin	Plot ID	Soil	Thin
786	Basalt	No	1	Basalt	Yes	1345	Cinder	No
938	Basalt	No	734	Basalt	Yes	1342	Cinder	No
1090	Basalt	No	889	Basalt	Yes	1341	Cinder	No
1141	Basalt	No	939	Basalt	Yes	1295	Cinder	No
787	Basalt	No	837	Basalt	Yes	1246	Cinder	No
785	Basalt	No	1038	Basalt	Yes	1242	Cinder	No
737	Basalt	No	1039	Basalt	Yes	1196	Cinder	No
736	Basalt	No	1040	Basalt	Yes	1395	Cinder	No
735	Basalt	No	989	Basalt	Yes	1292	Cinder	No
2	Basalt	No	988	Basalt	Yes	1245	Cinder	No
838	Basalt	No	990	Basalt	Yes	1394	Cinder	No
			784	Basalt	Yes			
Total Basalt Unthinned: 11			Total Basalt Thinned: 12			Total Cinder Unthinned: 11		

FIRE SCAR SAMPLING

FIELD METHODS

Partial cross-sections of catfaces (fire-scarred injuries on the lower boles of trees) were collected from living trees, snags, and downed logs across the study sites. Each site was thoroughly checked for fire scars and the trees which appeared to record the oldest and/or greatest number of fires were selected for sampling.

LABORATORY METHODS

Fire-scarred samples were mounted, surfaced, and crossdated (Stokes and Smiley 1968). All dates were independently checked by another dendrochronologist. Ring widths of all samples were also measured and dating was checked with the COFECHA program (Grissino-Mayer and Holmes 1993). Some samples collected from dead trees could not be initially crossdated. These samples were measured as floating chronologies and dated with the assistance of COFECHA output; dates were then confirmed visually on the samples.

Fire scars were dated to the year and season of occurrence depending on the position of the fire lesion within the annual ring. Seasonal categories were assigned following the procedure of Baisan and Swetnam (1990): EE (early earlywood), ME (middle earlywood), LE (late earlywood), L (latewood), and D (dormant). Dormant scars are generally considered to represent early season fires in the Southwest. Phenological data exist for ponderosa pine in southern Arizona, permitting calendar dates to be assigned to these within-ring positions (Baisan and Swetnam 1990). Because we do not have this information for the Mt. Trumbull region, fires were divided only into "spring" (D + EE) and "summer" (ME + LE + L) groups.

Fire history data were analyzed with the FHX2 software (Grissino-Mayer 1995). Analysis at each site began with the first year with an adequate sample depth (Grissino-Mayer et al. 1994), defined as the first fire year with at least three recording trees at each site. "Recording" trees are those with open fire scars or other injuries (e.g., lightning scars, bark peels), leaving them susceptible to repeated scarring by fire (Swetnam and Baisan 1996). The disruption of the presettlement fire regime, identified by the cessation of frequent fires, was evident at all sites. A number of postsettlement fires were also recorded, however. Fire return intervals were analyzed statistically in two different sub-categories. First, all fire years, even those represented by a single scar, were considered. Second, only those fire years were included in which 25% or more of the recording samples were scarred. The 25%-scarred category reflects 'widespread' fires which were probably larger in area and possibly more intense (Grissino-Mayer 1995). An intermediate 10%-scarred category was not included because the sample sizes were not >> 10 per site. The statistical analysis of fire return intervals includes several measures of central tendency: the mean fire interval (MFI, average number of years between fires), the median, and the Weibull median probability interval (WMPI). The latter statistic is a central measure in the Weibull distribution, used to model asymmetric fire interval distributions and to express fire return intervals in probabilistic terms (Grissino-Mayer et al. 1994, Swetnam and Baisan 1996). Since fire return intervals are rarely normally distributed, the WMPI is preferred over the MFI, although the values are often numerically similar.

Temporal homogeneity in fire return intervals and percentage of scarring was examined by dividing the fire record prior to recent fire exclusion in half at each study site. There was no evidence of changing climate (D'Arrigo and Jacoby 1991, Meko et al. 1995) or other ecological factor in the pre-exclusion period which would provide an alternative date for testing temporal change. The all-scar, 10%-scar, and 25%-scar distributions in these temporally distinct periods were tested for significantly different means (t-test), variances (F-test), and distributions (Kolmogorov-Smirnov test). Alpha level for all tests was 0.05. In addition, the spatial homogeneity of fires in adjacent study sites was investigated by testing the synchroneity of fire years (chi-square test, 2 X 2 and 2 X 1 contingency tables [Grissino-Mayer 1995]). Additional information on fire research procedures is presented by Swetnam and Baisan (1996) and Grissino-Mayer (1995).

ECOSYSTEM MEASUREMENT AND MONITORING PLOTS

FIELD METHODS

Permanent plots were used to measure current conditions of vegetation and fuels, and to collect dendroecological data for reconstruction of past forest structure. A plot design adapted from the National Park Service's Fire Monitoring protocol (NPS 1992, Reeberg 1995) was selected for consistent data collection across the Mt. Trumbull project area as well as at related sites. The plot design was chosen for the following reasons: (1) integrated and comprehensive plot design incorporating well-established measurement procedures for overstory and understory vegetation, forest floor and woody debris, and photo documentation; (2) the large plot size (0.1 ha) is appropriate for capturing presettlement tree groups in southwestern ponderosa pine (White 1985); (3) suitability of the plot system for future re-measurements in ongoing monitoring of treatment and control areas; (4) support for the protocol within the Interior Department land management agencies, including training (e.g., RX-80 "Preburn inventory techniques" course) and software. Adaptations to the Fire Monitoring protocol are noted below.

Plot origins were located from a systematic 300 meter grid placed over the sampling site (Figure 1). This procedure is different from the random sampling specified in the NPS (1992) guidelines. Gridpoints were located in the field by pace and compass (plots 1 and 2) or by taping and compass (all other plots) from mapped reference points, such as road junctions or section corners. Every gridpoint that fell within the suitable ponderosa pine forest type was used as a plot origin. When a gridpoint fell in an unsuitable location (e.g., road, meadow, or archeological site), the points 50 m N, E, W, and S were checked for suitability. If none were acceptable, the gridpoint was discarded. Suitable forest type (equivalent to the NPS [1992] "monitoring type") was defined as at least 10% ponderosa pine forest cover in 1870 based on the presence of presettlement-era trees, snags, stumps, or logs. In mixed species stands, ponderosa pine must have been a dominant tree in the stand with old individuals (or remnants) present. This intentionally broad definition included ponderosa pine types ranging from the pinyon-juniper interface to mixed conifer forests.

Plots were 50 X 20 m (0.1ha) with permanent markers to serve as a long-term monitoring unit. Rebar stakes and rock cairns marked the center (origin) and the four outer corners to ensure identical setup in subsequent surveys. Plots were oriented with the 50 m sides parallel to the slope azimuth (i.e., uphill-downhill) to maximize sampling of variability along the elevational gradient and to permit correction of the plot area for slope.

Plots were divided into four quadrants All trees greater than 15 cm diameter at breast height (dbh) were measured on the entire plot (1000 m^2). Trees between 2.5-15 cm dbh were measured on quadrant one (250 m^2). Each tree over 2.5 cm dbh was tagged with an aluminum label at breast height and the following data was recorded: diameter at breast height, crown code (dominant, co-dominant, intermediate or sub-canopy), damage, and condition class (1. live; 2. declining; 3. recent snag; 4. loose bark snag; 5. clean snag; 6. snag broken above breast height; 7. snag broken below breast height; 8. downed dead tree; and 9. cut stump). The condition class categories were derived from snag decomposition studies (Maser et al. 1979, Thomas et al. 1979) and were an expansion upon the "live/dead" categories in the NPS (1992) protocol. All living and dead trees potentially old and/or large enough to have become established prior to Euro-American settlement (circa 1870) were identified as potentially presettlement trees in the field. Ponderosa pines with dbh > 37.5 cm or ponderosa of any size with yellowed bark (White 1985), as well as all oaks, junipers, and pinyon trees > 17 cm (Barger and Ffolliott 1972) were considered potentially presettlement trees. All living potentially presettlement trees and 10% of all post-settlement live trees were cored for determination of age and past size. The presettlement identification and coring procedures were additions to the NPS (1992) protocol.

Seedling trees, those below 2.5 cm dbh, were tallied by species, condition, and height class in a 10 X 5 m area of quadrant one. Species, condition and height codes (1. < 15 cm; 2. 15.1-30; 3. 30.1-60; 4. 60.1-100; 5. 100.1 cm-2 m; 6. 2.001-3; 7. 3.001-4; 8. 4.001-5; 9. 5.001-6; 10. 6.001-7; 11. 7.001-8; 12. 8.001-9; and 13. 9.001+ m) were recorded for each seedling.

Herbaceous plants and brush were measured along two 50-m point intercept transects along the outer 50 m sides of each plot. Species, species height and substrate (e.g., soil, litter, rock) were recorded every 30 cm, for a total of 166 points per transect and 332 points per plot. A 5-m swath around each transect was surveyed after the point intercept measurements to note additional species not encountered on the transects. If the plot was located in a brushy area (e.g., sagebrush), a belt transect was created by widening the herbaceous transect to 1 m and tallying all shrubs, living and dead, by maturity state (seedling, resprout, mature).

Canopy cover measured by vertical projection was recorded at each of the 332 point intercept locations along the herbaceous transects. The measurement of canopy cover was an addition to the NPS (1992) protocol. Forest floor and woody debris were measured along four 50-ft. planar intersect transects (Brown 1974) originating in random directions every 10 m. Woody debris was recorded by size/timelag classes: 1, 10, 100, and 1000-hour (sound and rotten) fuels. Litter and duff were measured every five feet along each transect. Eight photopoints were established at each plot from the corners and quarter-corners. A board showing the plot number and photo position was included in each photograph. Finally, at each plot a reference presettlement tree was tagged near ground level with the distance and bearing to the plot origin in case the rebar markers were lost or difficult to find after time.

LABORATORY METHODS

Plot areas were corrected for slope. Sample collections of plants were brought back to NAU, unknown species were identified, and representatives of all species were mounted on herbarium sheets and prepared for storage. Mounted specimens were provided to the BLM AZ Strip District and to the NAU Deaver Herbarium. Tree increment cores were surfaced and crossdated (Stokes and Smiley 1968) with local tree-ring chronologies. Rings were counted on cores which could not be crossdated, especially younger trees. Additional years to the center were estimated with a pith locator (concentric circles matched to the curvature and density of the inner rings) for cores which missed the pith. Fuels loadings were calculated from the planar transect data using methods in Brown (1974) and constants from Sackett (1980).

Presettlement forest structure was reconstructed in 1870, the year in which Euro-American land use practices were introduced to the Mt. Logan area and an approximate date for the cessation of frequent, low-intensity fires in the region (range 1869-1879, see below and P.Z. Fulé and others, unpublished data). Reconstruction of forest structure at an earlier date would have presented greater uncertainty because the frequent fires during this era probably consumed much rotten woody material.

The field determination of presettlement or postsettlement tree status was confirmed or rejected using the age data. For each cored presettlement tree, the radial growth increment from 1870 to collection date was measured on the core and the exclusion year diameter calculated. Species-specific equations developed by Myers (1963) and Hann (1976) in the Southwest were used to estimate bark thickness and to predict dbh based on the inside-bark diameter of stumps. Site-specific regressions were developed from the data set to predict diameter at breast height (dbh) from diameter at stump height (dsh, coring height) for all species.

The year of death of presettlement snags and logs was estimated based on tree diameter and condition class. Dead trees representing the range of condition classes are being crossdated in this and other companion studies in northern Arizona. At the Gus Pearson Natural Area, all dead wood classified in the field as 'presettlement' based on size and decay was of presettlement origin (Mast et al., in press). However, direct determination of death date was precluded by sapwood rot on almost all of those samples. The harvest date for large stumps (dsh ≥ 40 cm) was assumed to be 1890, corresponding to the historic timber cutting period in the Mt. Trumbull area (Altschul and Fairley 1989), and the date for smaller stumps was assumed to be 1974, corresponding to more recent thinning under Forest Service and BLM management (BLM 1990).

Rates of snagfall and movement through tree decay condition classes were summarized by Rogers et al. (1984). They combined data from Cunningham et al. (1980) and Avery et al. (1976) to calibrate for northern Arizona the tree decomposition model developed by Thomas et al. (1979). Because of high variability among substrates and environmental conditions, as well as the extremely long time span required for research, the dynamics of tree decomposition are poorly understood (Harmon et al. 1985) and mathematical models based on observed decomposition classes are likely to be highly imprecise. To assess the effect of such variability on the presettlement forest reconstruction, we carried out a sensitivity analysis by using three different decomposition rate percentiles, 25%, 50%, and 75%, to examine the effect of slower or faster decomposition on the estimates of death date and ecosystem structure at the date of fire exclusion. Presettlement forest structure based on each of the three percentiles were calculated to determine the relative effect of model imprecision.

To determine the presettlement diameter of dead trees, growth estimates for the period from fire exclusion to death date were subtracted from the measured diameter, adjusted for the loss of bark where appropriate. Site-specific predictive regression relationships between diameter and basal area increment were developed for presettlement ponderosa pine, Gambel oak, and pinyon trees, where an adequate sample size was collected. For Utah juniper, published diameter-dependent growth regression equations were applied to determine presettlement diameter (Barger and Ffolliott 1972).

A potential source of error in this reconstruction approach is missing presettlement-era woody material, which would lead to an underestimate of presettlement forest density. Fire consumption of wood was controlled as much as possible by selecting the year of the last widespread fires in the Mt. Trumbull region as the reconstruction year (although later fires also occurred in parts of the study area, as described below). Complete decomposition of resinous woody material in the absence of fire is likely to take longer than the fire exclusion period due to the very slow decomposition rate in arid southwestern forests (Jenny et al. 1949, Hart et al. 1992). Because small-diameter pines rot quickly (Harmon et al. 1985, Arno et al. 1995), it could be argued that small trees or even doghair thickets which were alive in the settlement year but died soon thereafter would be missed. However, there is no evidence in historical accounts, photographs (see 1870 illustration of Mt. Trumbull in Powell [1961:288]), or early inventories for the existence of numerous small trees in presettlement northern Arizona--quite the contrary (Cooper 1960). Nor does it seem likely that such thickets could have become established under frequent fire regimes (White 1985). Finally, there is no reason to believe that such trees would have died in high numbers following fire exclusion, especially in light of the remarkable persistence of small trees in stressed postsettlement doghair thickets (Schubert 1974, Avery et al. 1976, White 1985). The possible underestimation of some small presettlement trees that left no trace cannot be dismissed but such trees are unlikely to have formed a substantial component of presettlement forest structure.

RESULTS

FIRE HISTORY

The fire history data for the Mt. Logan Wilderness is summarized in Table 2. A total of 200 fire scars were dated from 32 sample trees, within the periods of adequate sampling depth for the wilderness study sites. These periods ranged from 312 to 365 years, with the earliest fire date in 1632 and the ending fire history year in 1996. Additional fires were dated prior to the beginning year in each site, but were not included in the statistical analysis due to limited sample depth.

Table 2. Summary of fire history data collection.

Site	Number of samples	Number of fire scars	Beginning year*	Ending year	Length of fire history (years)	Fire regime disruption date
Logan	14	78	1632	1996	365	1879
Petty Knoll	8	70	1670	1996	326	1869
Slide Mountain	10	52	1684	1996	312	1871

* Beginning year is the first fire year with adequate sample depth (at least 3 recording trees).

Each fire-scarred sample appears as a horizontal line in the fire charts shown for each study site in Figure 2. The vertical bars mark the occurrence of fire scars, with the bottom composite axis of each chart indicating the fire years. A number of fires were recorded in consecutive years, especially in the Mt. Logan study site where fires occurred every year between 1732 and 1735. These fires were probably relatively small, however, scarring only one or two sample trees. The Mt. Logan study site is long and thin, delineated by the wilderness border and the rim of the mountain (Figure 1), making it likely that presettlement fires under prevailing winds would have often burned to the NE out of the wilderness. In contrast, the more compact areas included in the Petty Knoll and Slide Mountain study sites show more evidence of large-scale fires crossing each site. For example, fires scarred most of the samples across the Petty Knoll site in 1670, 1686, 1703, and 1782. These sites also recorded fewer consecutive-year fires.

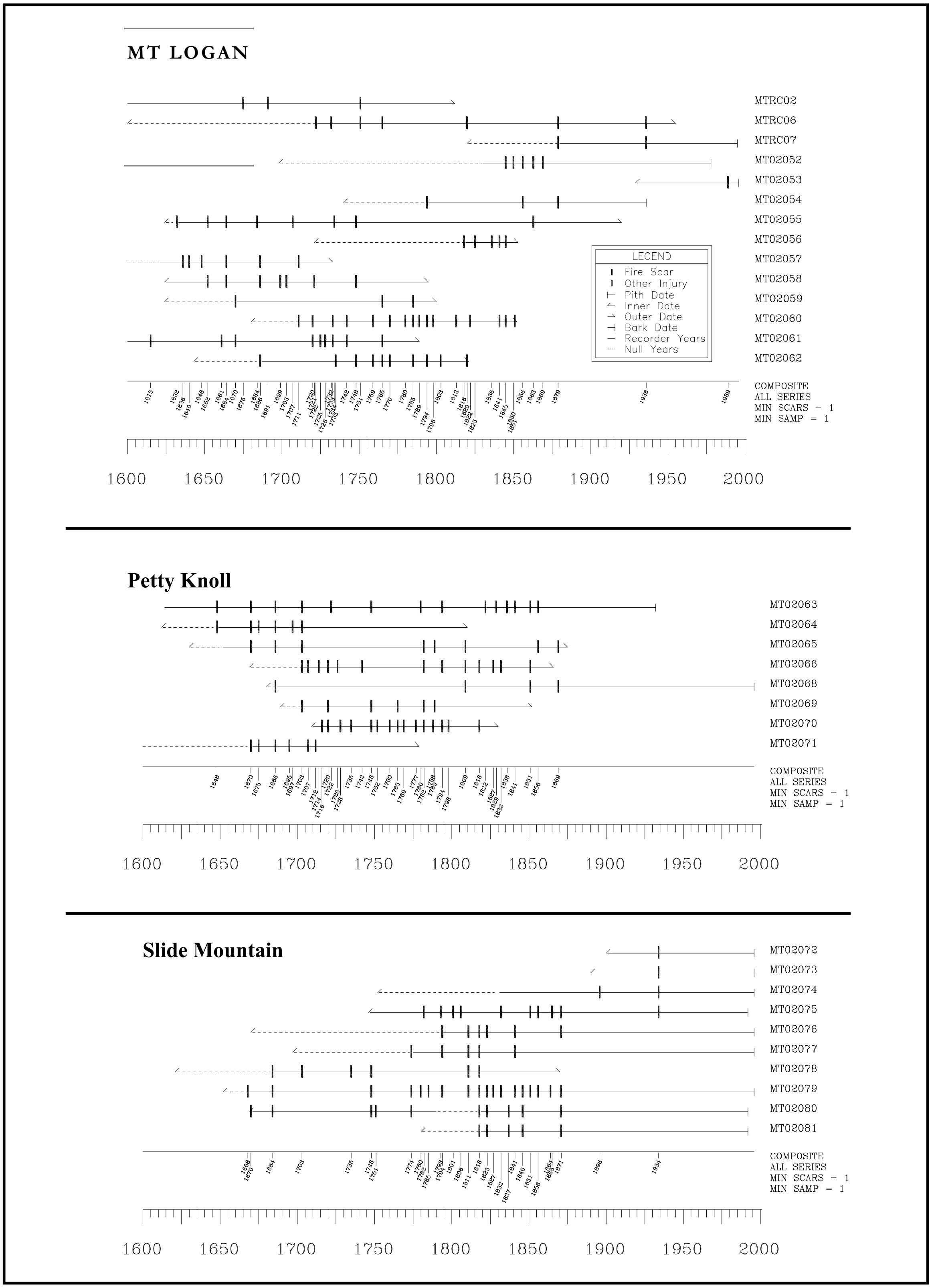

Figure 2. Composite fire charts for the study areas within the Mt. Logan Wilderness: (Top) Mt. Logan; (Middle) Petty Knoll; (Bottom) Slide Mountain.

Fires burned frequently in the Mt. Logan Wilderness until frequent fire regimes were disrupted between 1869 and 1879 (Table 2, Figure 2), coinciding with Euro-American settlement of the Mt. Trumbull area (Altschul and Fairley 1989). Presettlement fire return intervals (WMPI) ranged from 4.5 to 6 years, including all scars, and about twice as long—10 to 12 years—including only fires scarring 25% or more of the sample trees (Table 2). The mean fire interval (MFI) and WMPI values were similar, indicating that the fire interval distributions were not highly skewed. The minimum time between fires was one year at all sites (up to 3-4 years for the 25%-scarred distributions) and the maximum fire-free periods were 11-32 years (26-32 years for the 25%-scarred distributions). The 32-year period between 1703 and 1735 at Slide Mountain was the longest presettlement period without any evidence of fire at any of the sites.

Table 3. Presettlement fire return intervals (years) at the study sites. Statistical analysis was carried out in two categories: (1) all fire years, including those represented by a single fire scar; and (2) fire years in which 25% or more of the recording sample trees were scarred. The period of analysis at each site covered the beginning date through the fire disruption date, as noted in Table 1.

Site Scar category	Number of fire intervals	Mean (MFI)	Median	Standard deviation	Min	Max	WMPI*
Mt. Logan							
All scars	49	4.84	5	2.60	1	11	4.52
25%-scarred	20	10.85	9	6.70	3	26	10.02
Petty Knoll							
All scars	38	5.24	5	2.92	1	13	4.91
25%-scarred	15	13.27	13	8.47	4	33	12.12
Slide Mountain							
All scars	25	7.48	5	7.18	1	32	6.02
25%-scarred	18	10.39	6.5	8.19	1	32	8.75

* WMPI = Weibull median probability interval.

No statistically significant temporal changes in the presettlement fire regimes were found at any site. Some evidence of spatial differences in fire interval distributions, as well as synchroneity between adjacent sites was observed, but the sample sizes were small and different tests gave contradictory results. Therefore, analysis of spatial patterns will be deferred until complete fire history data are available.

Fires occurred predominantly in the summer, accounting for 52% to 76% of the fire years (Table 4). However, the season could not be determined on approximately 1/3 to 1/2 of the fire scars, usually because of narrow rings or decay in the scarred area.

Table 4. Seasonal distribution (number and percent) of fires at the three study sites based on the position of the fire injury within each scarred tree ring.

	Mt. Logan	Petty Knoll	Slide Mountain
Season determined	50 (64%)	33 (47.1%)	34 (59.6%)
Season undetermined	38 (36%)	37 (52.9%)	23 (40.4%)
Dormant	12 (24%)	2 (6.1%)	8 (23.5%)
Early earlywood	12 (24%)	6 (18.2%)	5 (14.7%)
Middle earlywood	22 (44%)	21 (63.6%)	19 (55.9%)
Late earlywood	4 (8%)	4 (12.1%)	2 (5.9%)
Latewood	0	0	0
Dormant + Early (= spring fires)	24 (48%)	8 (24.2%)	13 (38.2%)
Middle through Latewood (= summer fires)	23 (52%)	25 (75.8%)	21 (61.8%)

No fires were recorded after 1869 at the Petty Knoll site (although the sample size was only 2 recording trees), but postsettlement fires occurred at the other sites. The Mt. Logan site had fires in 1936 (scarring two of five samples) and 1989 (one of two samples). At Slide Mountain, fire was recorded in 1896 (one of eight samples) and 1934 (four of nine samples, in the NW portion of the site).

CONTEMPORARY FOREST CONDITIONS

CONTEMPORARY HERBACEOUS COMPOSITION AND DENSITY

Substrate cover along the herbaceous transects is presented in Figure 3. Plant material accounted for only 8% of the ground cover, while about 70% was litter. Bare mineral soil, wood, rock and duff were also present, representing the remaining 18%-20% ground cover. Comparing substrate frequency across soil types, cinder soils had the highest plant cover, at 16%. Basalt soils had only 7% plant cover. The lowest plant cover was found in the thinned plots on basalt soils, with only 2% cover.

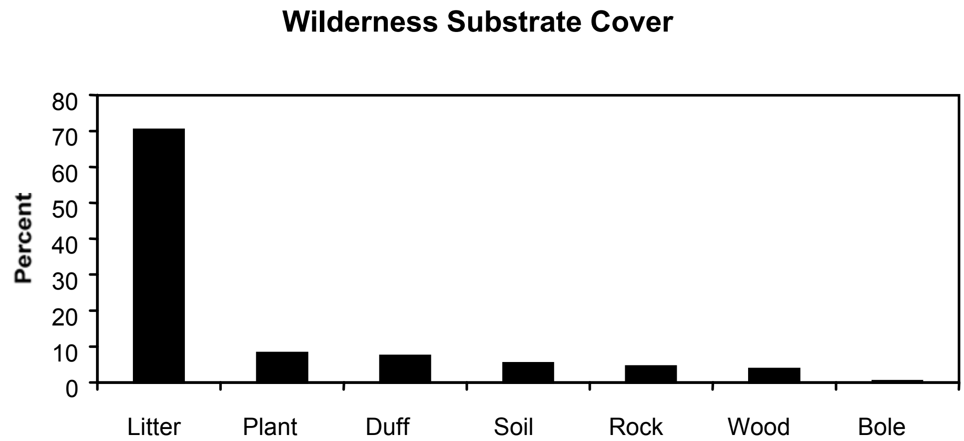

Figure 3. Substrate cover on herbaceous transects.

Differences in plant species diversity (Table 2) parallel those in substrate cover, above, with highest diversity found on cinder soil plots and lowest diversity found on thinned basalt soils plots. Plant frequency was relatively low: the 20 most frequent plants in each analysis area are listed in Tables 3. Sagebrush (*Artemisia tridentata*) was one of the most frequent plants, found on around 2% of the landscape. Higher frequencies of plants occurred on the cinder plots and a larger proportion were shrub species, including *Amelancheir utahensis*, *Artemesia tridentata*, *Ptelia trifoliata*, *Ribes cereum*, *Rhus trilobata*, *Ceanothus spp.*, *Quercus turbinella*, and *Arctostapholus pungens*. Approximately 10% of the cinder landscape was covered by these shrubs. In contrast, only 2.5% of the basalt landscape was covered by shrub species and less than 1% shrub cover was found on thinned basalt plots.

Native plant species were predominant in the understory but several species of the most frequent taxonomic groups were exotics (*Bromus tectorum*, *Poa pratensis*, *Verbascum thapsus*, and some species of *Agropyron*.). The cinder plots supported the highest percentage of native plant cover (94%). Unthinned basalt plots had 81% native plant cover and thinned basalt plots had 77% native plant cover. A complete species list, by family, is provided in Appendix A.

Table 5. Species diversity of herbaceous plants and shrubs.

	Unthinned Plots	Thinned Plots
Basalt Soil Plots	4.1	2.3
Cinder Soil Plots	8.5	N/A

Table 6a. Plant frequency: cinder soil.

Species	Native	Percent Frequency
Amelanchier utahensis	native	5.3
Artemisia tridentata	native	3.7
Sitanion hystrix	native	1.0
Lupinus argenteus	native	0.7
Ptelia trifoliata	native	0.6
Carex occidentalis	native	0.5
Verbascum thapsus	exotic	0.4
Ribes sp.	native*	0.3
Thalictrum fendleri	native	0.3
Rhus trilobata	native	0.3
Ceanothus sp.	native*	0.2
Penstemon barbatus	native	0.2
Quercus turbinella	native	0.2
Penstemon rostriflora	native	0.2
Frasera speciosa	native	0.2
Arctostaphylos pungens	native	0.1
Erigeron divergens	native	0.1
Bouteloua gracilis	native	0.1
Ribes cereum	native	0.1
Penstemon pachyphyllus	native	0.1

Table 6c. Plant frequency: thinned basalt.

Species	Native	Percent Frequency
Lupinus argenteus	native	0.5
Carex occidentalis	native	0.3
Sitanion hystrix	native	0.2
Poa fendleriana	native	0.1
Solidago velutina	native	0.1
Bromus tectorum	exotic	0.1
Amelanchier utahensis	native	0.05
Lathyrus sp.	native	0.05
Artemisia tridentata	native	0.05
Allium bisceptrum	native	0.03
Lomatium foeniculaceum	native	0.03
Poa spp.	unk.*	0.03
Ribes cereum	Native	0.03

Table 6b. Plant frequency: unthinned basalt.

Species	Native	Percent Frequency
Artemisia tridentata	native	2.3
Sitanion hystrix	native	1.1
Lupinus argenteus	native	1.1
Poa pratensis	exotic	0.6
Carex occidentalis	native	0.5
Poa fendleriana	native	0.3
Bromus inermis	exotic	0.3
Mahonia repens	native	0.2
Solidago velutina	native	0.2
Agropyron spp.	exotic*	0.1
Poa spp.	unk.*	0.1
Lathyrus sp.	native	0.1
Chrysothamnus nauseosus	native	0.1
Allium bisceptrum	native	0.1
Agoseris glauca	native	0.03
Unknown annual	unk*	0.03
Penstemon sp.	native*	0.03
Penstemon pachyphyllus	native	0.03
Lupinus kingii	native	0.03
Astragalus sp.	native*	0.03

*Nativity assignments of taxonomic groups such as Agropyron spp., and unknown species such as Solidago sp. re based on preliminary identifications. Taxonomic group nativity represents the majority of species observed (i.e., the majority of Agropyron species identified were exotic).

CONTEMPORARY FOREST OVERSTORY STRUCTURE

Current forest conditions were dense, with a mean of 1,411 trees/ha in the Mt. Logan Wilderness. About 90% of the trees were ponderosa pine and about 7% were Gambel oak. Basal area is dominated by ponderosa pine. However, differences in forest structure were observed between the basalt and cinder soils. Forest density on basalt soils averaged 2790 trees/ha while density on cinder soils averaged only 696 trees/ha (Table 7) and almost twice as much ponderosa pine basal area occurred on basalt soil plots as on cinder plots (Table 8). The proportions of pines and oaks also differed: while 98% of all basal area on basalt soils was ponderosa pine, only 85% of the total basal area on cinder soils was ponderosa pine. Gambel oak was a more prominent component in the cinder soil stands, comprising 22% of the trees per hectare and 11% of the basal area.

Table 7. Tree density (trees/ha) on basalt vs. cinder soils.

	Basalt Plots, n = 11*		Cinder Plots, n = 11	
Species	Mean	S.E.	Mean	S.E.
Ponderosa pine	2725.2	709.52	475.6	150.49
Gambel oak	42.8	29.60	157.0	106.47
Utah juniper	13.7	5.62	17.5	9.61
Pinyon pine	8.2	7.27	14.8	8.27
New Mexican Locust	0	0	31.4	21.08
Total	2789.9	699.63	696.3	178.91

Table 8. Tree basal area (m^2/ha) on basalt vs. cinder soils.

	Basalt Plots, n = 11*		Cinder Plots, n = 11	
Species	Mean	S.E.	Mean	S.E.
Ponderosa pine	37.0	4.52	19.6	2.97
Gambel oak	1.7	1.24	2.7	1.45
Utah juniper	1.0	0.57	0.5	0.28
Pinyon pine	0.06	0.05	0.05	0.03
New Mexican Locust	0	0	0.2	0.09
Total	39.8	3.85	23.0	3.30

Thinned and unthinned plots difffered greatly in tree density. The thinned plots had 800 trees/ha while the unthinned plots had 2790 trees/ha (Table 9). The thinned plots also had a higher proportion and absolute density of Gambel oak. However, the total basal area from thinned and unthinned plots was almost identical (Table 10) and strongly dominated by ponderosa pine (approximately 92% of the basal area). Although approximately 15 m^2/ha of basal area was removed from the thinned plots around 1974 (BLM 1990), based on the cross-sectional area of stumps measured on the plots, growth of the residual trees has replaced this basal area over the past 23 years.

Table 9. Tree density (trees/ha) on unthinned vs. thinned plots.

	Unthinned Plots, n = 11*		Thinned Plots, n = 12	
Species	Mean	S.E.	Mean	S.E.
Ponderosa pine	2725.2	709.52	703.5	75.99
Gambel oak	42.8	29.60	85.3	57.09
Utah juniper	13.7	5.62	7.5	5.00
Pinyon pine	8.2	7.27	0	0
New Mexican Locust	0	0	3.4	3.35
Total	2789.9	699.63	801.3	64.60

Table 10. Tree basal area (m^2/ha) on unthinned vs. thinned soils.

	Unthinned Plots, n = 11*		Thinned Plots, n = 12	
Species	Mean	S.E.	Mean	S.E.
Ponderosa pine	37.0	4.52	35.8	2.51
Gambel oak	1.7	1.24	1.6	1.12
Utah juniper	1.0	0.57	1.5	1.12
Pinyon pine	0.06	0.05	0	0
New Mexican Locust	0	0	0.05	0.05
Total	39.8	3.85	39.0	2.30

Diameter distributions are presented below for trees found on cinder soils (Figure 4), unthinned basalt soils (Figure 5) and thinned basalt soils (Figure 6). The distributions of living trees show that 80% were less than 25 cm dbh. Gambel oak made up a large proportion of the smaller trees, but few large oaks or other non-ponderosa tree species were encountered. Several large living ponderosa pine trees were found (maximum tree diameter was 112 cm), but many of the largest trees had been cut: 7.5 stumps/ha greater than 90 cm were found (maximum stump diameter was 112 cm). Snag distributions were dominated by Gambel oak in the smaller size classes, making up more than 50% of all snags less than 20 cm, but almost all larger snags and downed dead trees were ponderosa pine. The largest non-ponderosa snag was less than 80 cm in diameter while the largest ponderosa pine snag was 147 cm. Distributions of cut stumps reflect the thinning of small trees on the thinned basalt plots (Figure 6) as well as past harvest of large-diameter ponderosa pine trees. By chance, no stumps larger than 30 cm were encountered on the unthinned basalt plots (Figure 5), even though this area had been commercially harvested in the past. The absence of stumps appears to have been due to the variability associated with the small sample size (n = 11 plots).

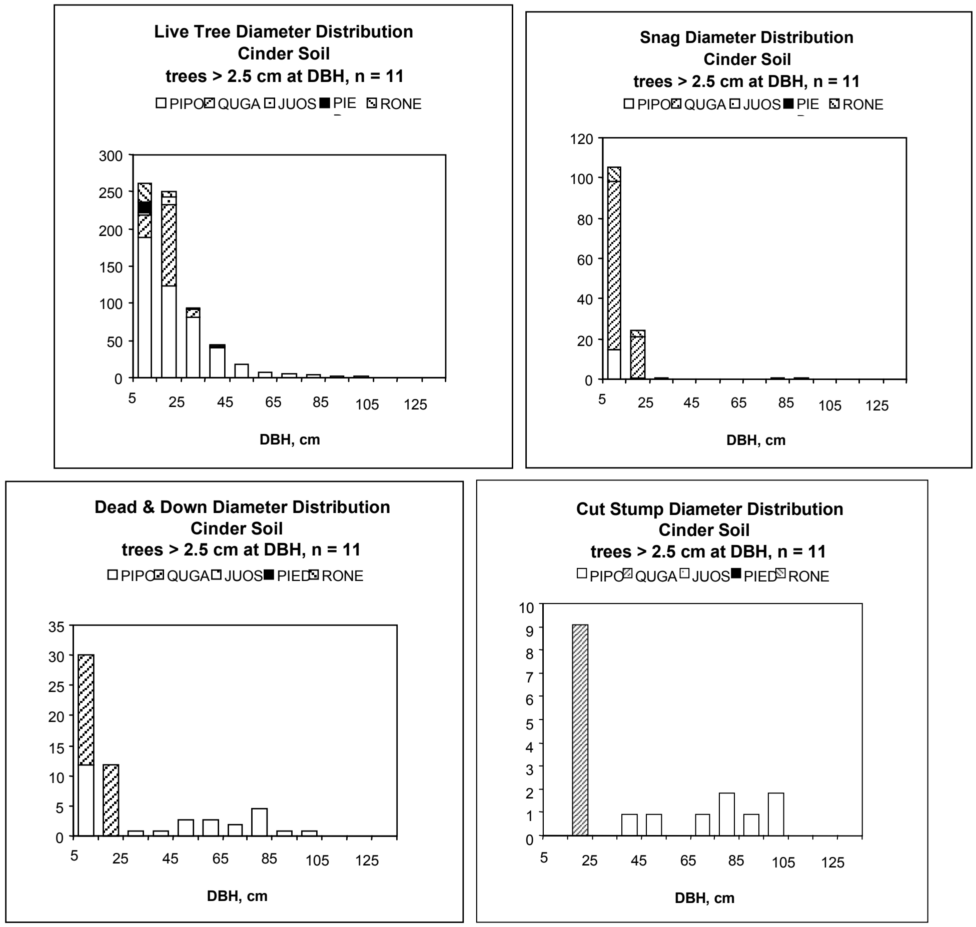

Figure 4. Diameter distributions of trees on cinder soil plots. X-axis is the mid-point of 10-cm diameter classes; y-axis is density (trees/ha).

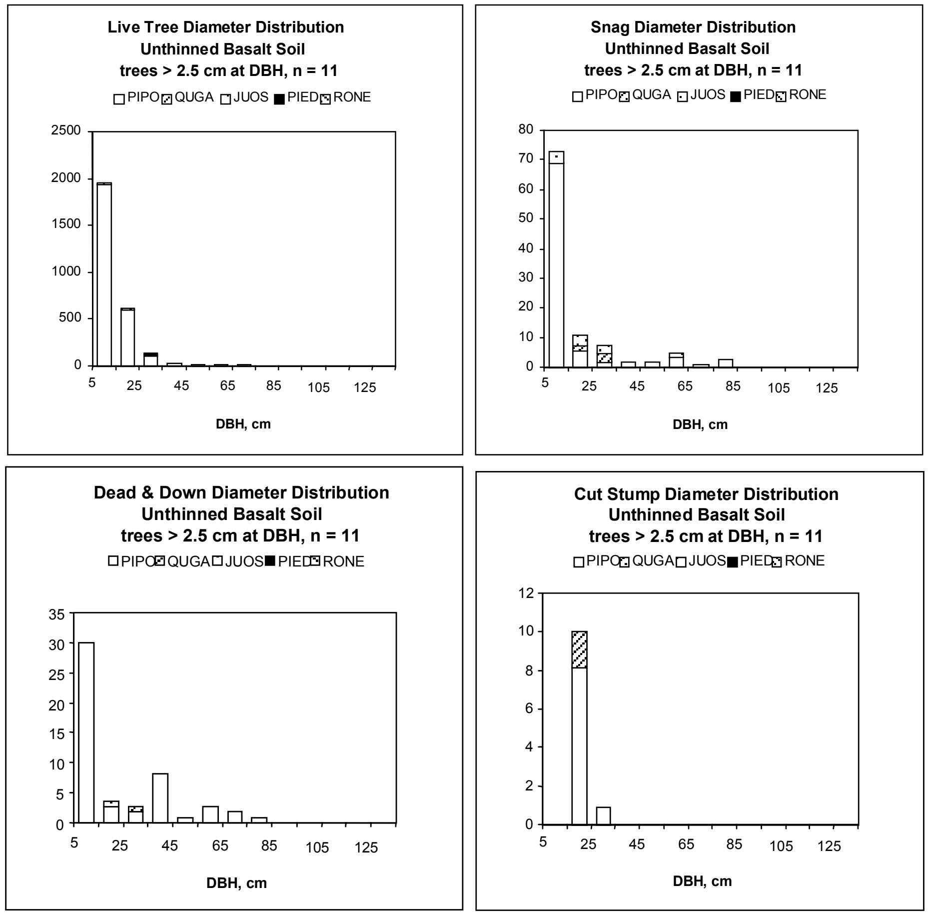

Figure 5. Diameter distributions of trees on unthinned basalt soil plots. X-axis is the mid-point of 10-cm diameter classes; y-axis is density (trees/ha).

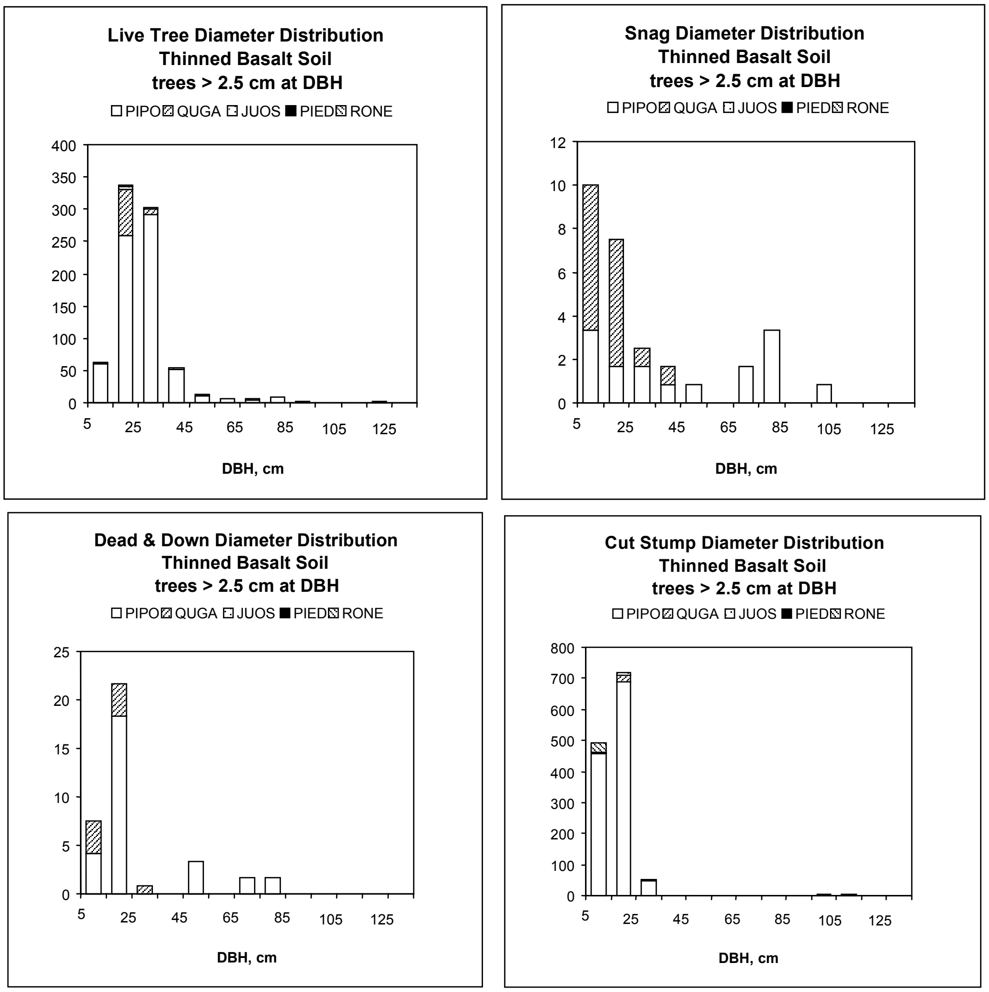

Figure 6. Diameter distributions of trees on thinned basalt soil plots. X-axis is the mid-point of 10-cm diameter classes; y-axis is density (trees/ha).

Tree age distributions (Figure 7) show a range of center dates from 1510 to 1995 at the 40-cm sampling height. Large pulses of Gambel oak regeneration appeared in the late 1800's but ponderosa pine regeneration lagged until about 1910.

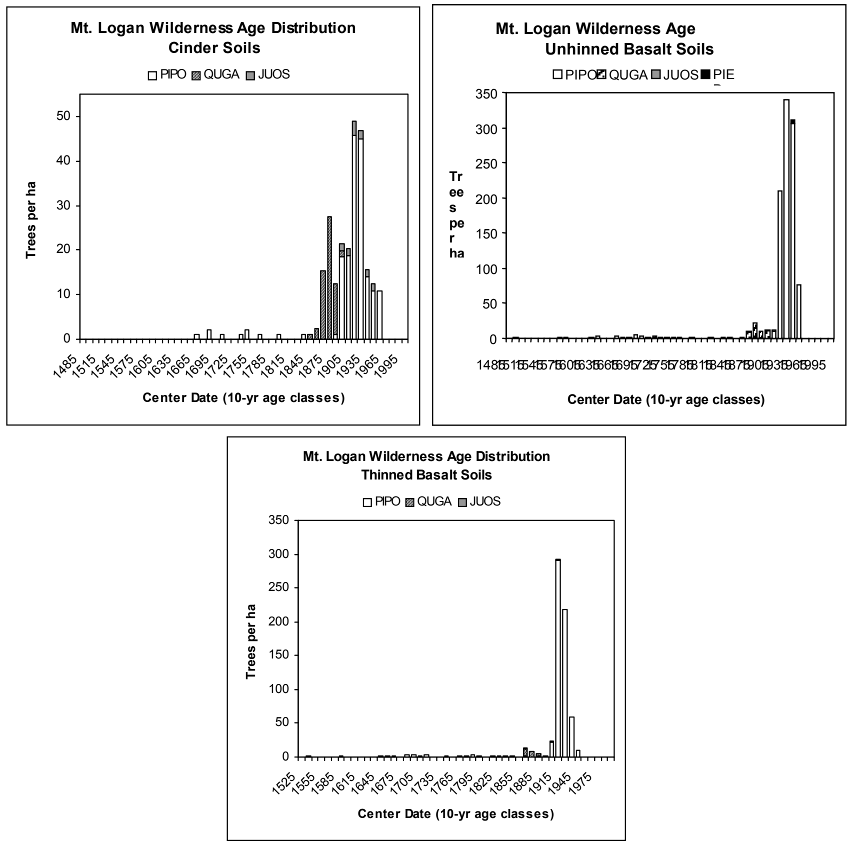

Figure 7. Tree center date distribution; x-axis is the mid-point of 10-year center date classes.

TREE REGENERATION

Tree regeneration data are summarized in Table 11. Gambel oak had the highest regeneration densities, but only on cinder soils. Oak densities declined sharply with succeeding height classes. Ponderosa pine was less abundant but seedling densities declined more slowly with increasing height. The density and diversity of size classes and species in regeneration was greatest on the cinder soil plots and least on the thinned basalt soil plots.

Table 11. Tree regeneration in the Mt. Logan Wilderness analysis areas.

Species	Height Class	Trees/ha
	Cinder (n = 11)	
Pinus ponderosa	1	54
Pinus ponderosa	4	54
Pinus ponderosa	5	73
Pinus ponderosa	6	54
Quercus gambelii	1	1709
Quercus gambelii	2	2236
Quercus gambelii	3	909
Quercus gambelii	4	109
Quercus gambelii	5	18
Robinia neomexicana	5	18
	Basalt, unthinned (n = 11)	
Pinus ponderosa	1	73
Pinus ponderosa	2	109
Pinus ponderosa	3	272
Pinus ponderosa	4	145
Pinus ponderosa	5	91
Pinus ponderosa	6	91
Pinus ponderosa	7	18
	Basalt, thinned (n = 12)	
Pinus ponderosa	1	33
Pinus ponderosa	5	33
Quercus gambelii	1	267
Quercus gambelii	2	16
Robinia neomexicana	2	16

CANOPY COVER

Canopy cover averaged 53% on all plots sampled in the Mt. Logan Wilderness (Table 12). Cinder soils had the lowest canopy cover, corresponding to the lower tree densities found on cinder soils. There was no difference in canopy cover between thinned and unthinned plots on basalt soils.

Table 12. Canopy cover.

	Basalt Soil Plots		Cinder Soil Plots	
	Mean	S.E.	Mean	S.E.
Canopy Cover	57.1%	0.06	46.2%	0.04
	Unthinned Plots		Thinned Plots	
	Mean	S.E.	Mean	S.E.
Canopy Cover	57.1%	0.06	56.2%	0.04

FUELS—COARSE WOODY DEBRIS AND FOREST FLOOR BIOMASS

Average total fuel loadings were 48.67 metric tons/ha on all wilderness plots (Tables 13 and 14). Approximately half of the fuel loading was woody debris; the remainder was forest floor material. The highest fuel loads occurred on the cinder soil plots, due to the high loading of large sound fuels. However, these fuels were also highly variable (coefficient of variation = 305%). On basalt soils, the thinned plots had nearly twice the fuel loading of the unthinned plots, primarily due to higher large woody fuels. These woody fuels appear to consist mainly of the thinned tree stems (P.Z. Fulé, personal observation 1995).

Table 13. Forest floor and woody debris on basalt vs. cinder soil plots.

	Basalt Soil Plots		Cinder Soil Plots	
Woody Fuel Loadings, tons/ha	Mean	S.E.	Mean	S.E.
1 hr. fuels	0.16	0.05	0.18	0.05
10 hr. fuels	1.48	0.38	0.92	0.16
100 hr. fuels	2.73	0.72	2.65	0.38
1000 hr. sound fuels	2.73	0.94	26.68	24.52
1000 hr. rotten fuels	3.36	1.61	7.87	7.87
Sub Total	10.47		38.29	
Duff & litter loading, tons/ha	18.52		24.59	
Total loading: tons/ha	28.98	3.16	62.88	24.52

Duff & Litter Depths, cm	Mean	S.E.	Mean	S.E.
Litter, cm	1.19	0.28	0.74	0.13
Duff, cm	2.34	0.33	3.96	0.69

Table 14. Forest floor and woody debris on unthinned vs. thinned plots.

	Unthinned Plots		Thinned Plots	
Woody Fuel Loadings, tons/ha	Mean	S.E.	Mean	S.E.
1 hr. fuels	0.16	0.05	0.13	0.02
10 hr. fuels	1.48	0.38	1.39	0.27
100 hr. fuels	2.73	0.72	3.34	0.87
1000 hr. sound fuels	2.73	0.94	12.89	4.03
1000 hr. rotten fuels	3.36	1.61	10.87	5.98
Sub Total	10.47		28.62	
Duff & litter loading, tons/ha	18.52		25.04	
Total loading: tons/ha	28.98	3.16	53.69	9.68

Duff & Litter Depth, cm	Mean	S.E.	Mean	S.E.
Litter, cm	1.19	0.28	1.02	0.20
Duff, cm	2.34	0.33	3.76	0.38

PRESETTLEMENT FOREST STRUCTURE

PRESETTLEMENT RECONSTRUCTION

Reconstructed forest density (Table 15) and basal area (Table 16) were substantially lower than current forest values. Density of ponderosa pine increased by at least an order of magnitude since 1870, although increases for other species were less marked. Current conditions for New Mexican locust are included, but no locusts old enough to be of presettlement origin were found on the sampling plots and no estimate of presettlement locust conditions was made (see also Fulé et al. 1997). Ponderosa pine was the predominant tree species at all sites, making up the smallest proportion of tree density on the cinder soil plots (58%) and the highest proportion on the unthinned basalt soil plots (72%). However, due to the larger size of the ponderosa pine trees, the species comprised 93-97% of basal area at all sites. The results reported in Tables 15 and 16 were based on the assumption that dead trees moved at the 50th percentile rate through the condition classes of the snag decomposition model. The sensitivity analysis carried out by altering the decomposition rate percentile from 25% to 75% led to a 1%-16% change in reconstructed density (highest difference on the cinder soils) but only 1%-3% changes in reconstructed basal area.

Table 15. Reconstructed forest density (trees/ha) in 1870 compared with current density.

Species	1870 Forest		Current Forest	
Cinder Soil	Mean	S.E.	Mean	S.E.
Ponderosa pine	43.1	6.43	475.6	150.49
Gambel oak	30.0	13.77	157.0	106.47
Utah juniper	0.9	0.93	17.5	9.61
Pinyon pine	0	0	14.8	8.27
New Mexican Locust			31.4	21.08
Total	73.9	15.79	696.3	178.91
Unthinned Basalt Soil				
Ponderosa pine	73.82	11.24	2725.2	709.52
Gambel oak	18.2	11.68	42.8	29.60
Utah juniper	10.1	5.43	13.7	5.62
Pinyon pine	0.9	0.91	8.2	7.27
New Mexican Locust			0	0
Total	103.0	11.94	2789.9	699.63
Thinned Basalt Soil				
Ponderosa pine	59.5	9.04	703.5	75.99
Gambel oak	19.3	16.71	85.3	57.09
Utah juniper	7.5	4.12	7.5	5
Pinyon pine	0	0	0	0
New Mexican Locust			3.4	3.35
Total	86.2	16.84	801.3	64.60

Table 16. Reconstructed forest basal area (m^2/ha) in 1870 compared with current basal area.

Species	1870 Forest		Current Forest	
Cinder Soil				
Ponderosa pine	10.3	1.80	19.6	2.97
Gambel oak	0.2	0.09	2.7	1.45
Utah juniper	0.02	0.02	0.5	0.28
Pinyon pine	0	0	0.05	0.03
New Mexican Locust			0.2	0.09
Total	10.6	1.80	23.0	3.30
Unthinned Basalt Soils	Mean	S.E.	Mean	S.E.
Ponderosa pine	12.1	1.66	37.0	4.52
Gambel oak	0.1	0.12	1.7	1.24
Utah juniper	0.7	0.35	1.0	0.57
Pinyon pine	0.01	0.01	0.06	0.05
New Mexican Locust			0	0
Total	13.0	1.56	39.8	3.85
Thinned Basalt Plots				
Ponderosa pine	13.6	2.79	35.8	2.51
Gambel oak	0.1	0.13	1.6	1.12
Utah juniper	0.9	0.74	1.5	1.12
Pinyon pine	0	0	0	0
New Mexican Locust			0.05	0.05
Total	14.7	2.62	39.0	2.30

DIAMETER DISTRIBUTION

Ponderosa pine trees followed a relatively unimodal, normal diameter distribution in 1870 (Figure 8), in contrast to the strongly skewed distribution dominated by smaller trees in the current forest (Figures 4-6). Gambel oak trees made up the majority of the smaller size classes.

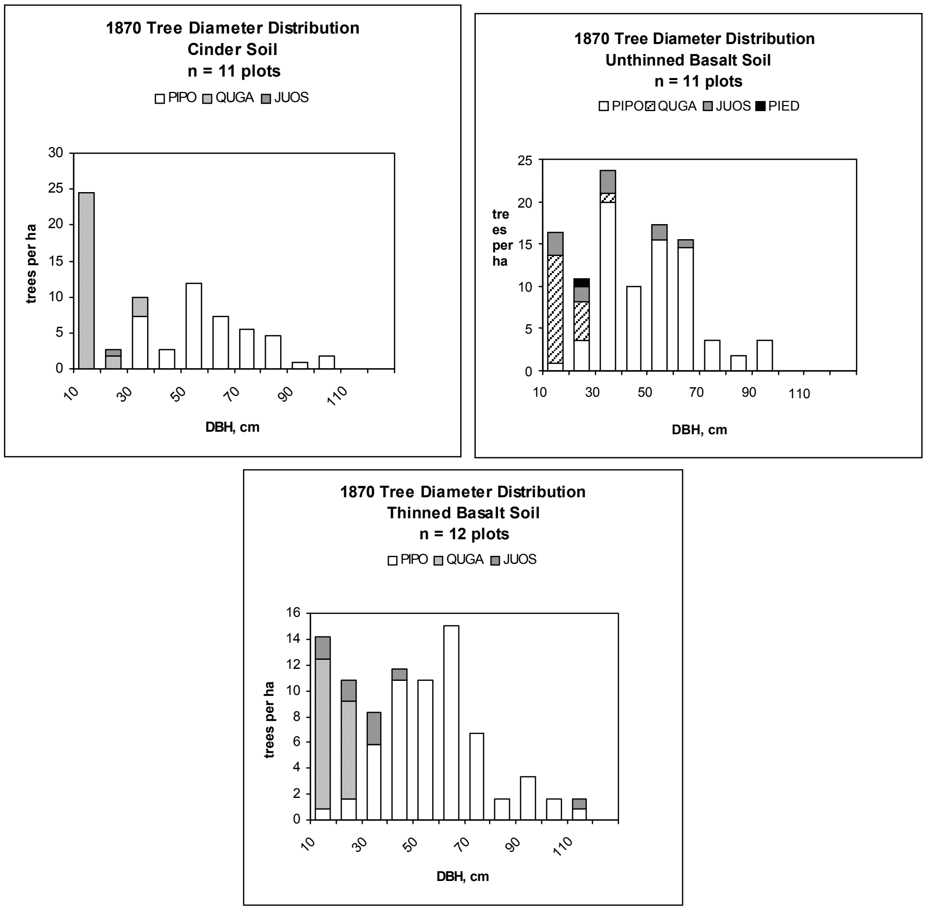

Figure 8. Reconstructed 1870 diameter distributions.

AGE DISTRIBUTION

The age distributions of living presettlement trees are shown in Figure 9. These distributions are not the 1870 age patterns, because mortality, tree harvest, and rot have removed many or most of the trees which were alive in 1870. Usually the oldest trees have either died of natural causes or were preferentially harvested because of their larger size. Current sampling of living presettlement-era trees therefore results in a truncated age distribution. Complete dendrochronological dating of all dead as well as living trees would be required to estimate the age distribution present in 1870 (see Mast et al., in press). The distributions in Figure 9 are identical to the older portion of the current age distributions (Figure 7), except that the old trees can be more clearly distinguished on the y-axis due to the lower presettlement tree density.

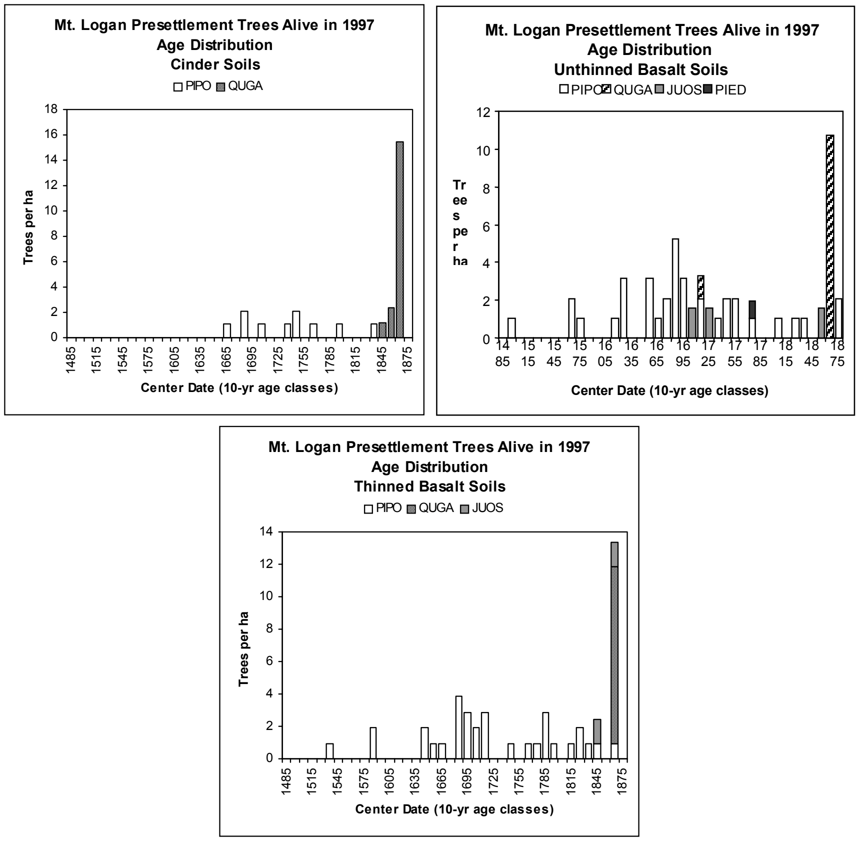

Figure 9. Age distribution of living trees of presettlement origin. These distributions are not equivalent to the presettlement (1870) age distribution.

DISCUSSION

PRESETTLEMENT FOREST CONDITIONS

Prior to Euro-American settlement, fires burned frequently across the Mt. Logan landscape and forest structures were relatively open and dominated by large trees. Tree densities were within the range of approximately 50 to 150 trees/ha found in other reconstruction studies in pine-oak forests (Covington and Moore 1994a, Fulé et al. 1997) and in the range of 7 to 116 ponderosa pines/ha reported in early forest inventories and other studies in northern Arizona (see Covington and Moore 1994b for comparison). Oaks were dominant in the smaller diameter size classes at all three analysis areas (Figure 8); Fulé et al. (1997) suggested that the survival of many of these oak trees might be an artifact of fire exclusion. Oaks probably maintained large numbers of sprouts which were repeatedly thinned by fire and replaced with further sprouting. Had frequent fires continued past the 1869-1879 period, many of the small trees with center dates close to that time (Figure 9) would probably have been killed.

Understory plants were evidently sufficiently abundant to carry presettlement fires, but the cover and species composition of herbaceous plants and shrubs cannot be estimated with the same precision as the tree structure and fire regime. Brown et al. (1974) related herbaceous production to overstory basal area on basalt soils at Beaver Creek, Arizona; their model suggests that the range of average presettlement basal areas on the Mt. Logan sites would produce only about 60-120 kg/ha of herbaceous plants. However, this model and most other contemporary approaches have been based on data collected under twentieth century conditions, usually in forests where trees have been deliberately spaced apart. In the clumpy presettlement forest, gaps between tree clumps would have supported much higher production. At the Gus Pearson Natural Area, near Flagstaff, restored forest plots produced 200-350 kg/ha of grasses and forbs within 2 years of treatment, compared to a control area with 70 kg/ha (Covington et al. 1997 and unpublished data).

After fire exclusion, the sprouting capability of oak appears to have given the species an advantage in establishment (Figure 7). Pines were dependent on seed propagation, requiring a more specific combination of climate conditions (Savage et al. 1997), and pine seed-producing trees may have also been greatly reduced by early logging (Fulé et al. 1997). These factors probably contributed to the lag in pine regeneration between 1870 until the early twentieth century (Figure 7).

CURRENT FOREST CONDITIONS IN THE MT. LOGAN WILDERNESS

Fire has been excluded from most of the ponderosa pine forests of the Mt. Logan Wilderness since 1869-1879. For the broader data set from the Mt. Trumbull region, 1869 or 1870 are the average dates of fire regime disruption (P.Z. Fulé and others, unpublished data), matching the 1870 date of increased resource utilization by Euro-American Mormon settlers (Altschul and Fairley 1989). The only widespread postsettlement fires occurred in the 1930's, when the majority of trees found in the current forest were still very young (Figure 7). The 1934 and 1936 fires may have thinned some trees but apparently did not cause large-scale mortality or substantially check the increase in tree density during the twentieth century. The pattern of relatively abrupt fire exclusion, followed by occasional postsettlement fires, is typical of southwestern ponderosa pine forests (Swetnam and Baisan 1996).

The range of current conditions in the Mt. Logan Wilderness is similar to that of many ponderosa pine forests in northern Arizona. The overstory on basalt soils, with nearly 2,800 trees/ha, is approximately as dense as the unmanaged Gus Pearson Natural Area near Flagstaff (3,098 trees/ha; Covington 1997). The sites are similar not only in density, but also in the mix of scattered large presettlement trees surrounded by dense, "doghair" thickets of postsettlement pines. In the thinned area on basalt soils, the average tree density of approximately 800 trees/ha is close to the Arizona statewide average of 776 trees/ha, calculated by Garrett et al. in 1985. Plots on cinder soils were nearly as dense, close to 700 trees/ha, but had a substantially higher component of non-ponderosa species, especially Gambel oak. Tree density was least variable on the thinned sites (coefficient of variation = 28%), as expected given the management intervention to create a uniform overstory structure. The unthinned basalt and cinder areas had coefficients of variation in tree density of 83% and 85%, respectively.

The thinning carried out on about half of the basalt soil area around 1974 had many ecological impacts on the forest. Approximately 15 m²/ha of tree basal area and nearly 1,200 trees/ha were removed, changing the dense "doghair" forest to an evenly-spaced tree pattern (see Appendix C for contrasting photographs). Growth of the residual trees has been rapid, essentially replacing the thinned basal area within 23 years. The average tree size (quadratic mean diameter), however, is nearly twice as large in the thinned area: 25.5 cm vs. 13.1 cm. Canopy cover is also approximately equal between the thinned and unthinned sites; although the 56%-57% canopy cover may not appear to be high, it is actually typical of dense southwestern ponderosa pine stands when measured by vertical projection, a technique which precisely accounts for small gaps in the tree crowns (see data from Grand Canyon National Park, ERP 1998). Understory cover and diversity are low throughout the basalt plots, but especially in the thinned area, where plant cover was 2% and species diversity averaged only 2.3 species/plot. Overall, the thinning appears to have been highly successful in monopolizing the site resources for tree growth, at the expense of herbaceous plants. An ecological restoration thinning treatment, in contrast, would have retained fewer trees and matched the clumpy presettlement tree pattern (Covington et al. 1997), leaving open areas for understory growth and diversity. Trees would grow even more rapidly under a restoration thinning, but the lower tree density, clumped distribution, and fire control of future regeneration would keep crown closure and canopy fuels relatively low, precluding crownfire.

Understory plants on the cinder soil sites have about twice the cover and species diversity of the basalt sites. Shrubs made up 9 of the 20 most frequent species, possibly reflecting a competitive advantage for deeper-rooted shrubs over grasses and forbs in the well-drained cinders. Many of the shrubs, such as *Ribes*, *Quercus*, and *Ceanothus*, are particularly desirable food sources for animals and humans. Dry cinder sites in the Mt. Trumbull region and elsewhere in northern Arizona seem to be the least affected by the disruption of frequent fires, sometimes with little or no evidence of postsettlement tree population irruptions (e.g., the Sunset Crater volcanic field near Flagstaff). However, in the Mt. Logan Wilderness, fires occurred nearly as frequently in the cinder soil area as in the basalt soil area, where the finer soils may have been better-suited for herbaceous production. It is not clear whether grasses and forbs were in fact more prevalent on the cinders prior to the introduction of heavy livestock grazing, or whether the more scattered shrub, herbaceous, and woody fuels found today are similar to presettlement fuels, with the dry conditions and steep slopes of the cinder hills helping to maintain active fire behavior.

Living and dead fuels are not excessive for contemporary southwestern ponderosa pine forests (Sackett 1979) but on the basalt sites they are clearly sufficient in quantity and continuity to support high-intensity crownfire even in average fire seasons. Trees are more patchily distributed on the cinder sites, but crownfire remains a concern, especially in the denser forests along the lower slopes of Petty Knoll and Slide Mountain.

ECOLOGICAL ISSUES RELATED TO RESTORATION OF THE MT. LOGAN WILDERNESS

Any unique aspects to restoration in the Mt. Logan will most likely center around social decisions regarding the value of management intervention for restorative purposes and the appropriate methods for carrying out treatments. In ecological terms, conditions within the wilderness area are similar to those of non-wilderness ponderosa forests in the Mt. Trumbull region. Appropriate restoration treatments would also be similar: thinning of postsettlement trees to emulate the density and spatial patterns of the presettlement forest, fuel treatments around the bases of presettlement trees, reintroduction of fire in prescription following the pattern of the presettlement fire regime, and ongoing monitoring to track changes and make adjustments as needed (Covington et al. 1997). If natural understory regeneration were inadequate, for example, seeding or planting alternatives could be tried.

Only a few living presettlement trees per ha remain in the Mt. Logan Wilderness, and many appear to suffer from reduced vigor, underscoring the need for rapid intervention even in the absence of catastrophic fire. These residual trees would form the foundation for developing the restored forest structure. Understory plants are very sparse, especially on the basalt soils, but are mostly comprised of native species. Highly stressed old trees and relatively unproductive herbaceous plants under similar circumstances in the Gus Pearson Natural Area, near Flagstaff, have shown a rapid respond to restoration treatments (Covington et al. 1997). Fire is currently being re-introduced to the Mt. Logan Wilderness through prescribed burning over the past several years. Accumulated fuels have been raked from presettlement tree boles prior to burning. These fires will probably contribute to reducing fire hazard, modest improvements in understory condition, and possibly thinning some postsettlement trees. However, the effectiveness of a fire-only treatment is highly limited because the great majority of dense young trees will not be killed under prescribed burning conditions (Sackett et al. 1996).

The effectiveness of restoration treatments can be affected by the presence of exotic species and the absence of extirpated ones. In the plant community, exotics include naturalized species which appear to be relatively innocuous with respect to natural ecosystem function, such as the perennial grasses *Poa pratensis* and *Bomus inermis*. However, two other well-established exotics, *Verbascum thapsus* and *Bromus tectorum*, are aggressive pioneer species which may make native revegetation more difficult. The ability of *Bromus tectorum* to thrive in a frequent fire regime may make this species particularly difficult to control. On the other, as ecosystems are returned to more natural conditions it may be the case that native perennials will demonstrate a high degree of resilience. In the animal community, some species may have been extirpated, especially top predators. Two "semi-native" species, the Abert squirrel (*Sciurus aberti*) and the Merriam turkey (*Meleagris gallopavo*), are common in much of northern Arizona but were introduced to the Mt. Trumbull region in 1971-75 and 1961, respectively (BLM 1990). The roles of these introduced species as well as of native species which are isolated in the "sky island" forest environment of Mt. Trumbull will be of interest as research continues (M. Elson, personal communication, 1998).

Human uses of the Mt. Logan forest are limited under wilderness management guidelines. However, as more is learned about past human influences, possibly including resource management practices such as burning or wildland plant cultivation by Paiute and other residents, the role of modern humans may need to be re-examined (T. Alcoze, personal communication, 1998).

Many of the central ecological issues related to restoration of the Mt. Logan forests in particular, and southwestern ponderosa pine ecosystems in general, are quite straightforward. The relatively short period of anthropogenic ecosystem degradation, the ability to precisely determine many key components of presettlement forest structure and disturbance regimes, and the broad ecological knowledge, research, and experience developed over more than a century of testing and observing treatments such as thinning and burning give scientists and managers powerful tools with which to design restoration treatments. Putting restoration treatments into practice, however, will only be achieved if society perceives real benefits (Higgs 1997). The data assembled in this report are necessary for informing decisions about resource management, but they are only one component in a broader debate over the appropriate goals and methods for managing this wilderness area on public lands.

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APPENDIX A: PLANT SPECIES LIST, MT. TRUMBULL, ARIZONA

Prepared by Judy Springer, Ecological Restoration Program, NAU
All species on this list were updated from Kartesz & Kartesz (1994) and the PLANTS Database based on the Flora of North America Project

Family	Species	Common name	Nat'y[1]	Form[2]	Comments/Synonyms
Aceraceae	*Acer grandidentatum* Nutt.	bigtooth maple	N	T	Wash near EB-4
Amaranthaceae	*Amaranthus albus* L.	prostrate pigweed	I	A	Adventive from tropical America
Anacardiaceae	*Rhus glabra* L.	smooth sumac	N	T	Lava Fire
	Rhus trilobata Nutt.	skunkbush sumac	N	S	
Apiaceae	*Cymopterus multinervatus* (Coult. & Rose) Tidestrom	purplenerve springparsley	N	P	Collected by Cottam, but not NAU
	Cymopterus purpureus S. Wats.	purple springparsley	N	P	Base of MT - p-j zone
	Lomatium foeniculaceum ssp. *macdougalii* (Coult. & Rose) Theobald	MacDougal's biscuitroot	N	P	Mt. Logan overlook
Asclepiadaceae	*Asclepias asperula* (Dcne.) Woods.	spider milkweed	N	P	
	Asclepias subverticillata (Gray) Vail	whorled milkweed	N	P	
Asteraceae	*Ageratina herbaceae* (Gray) King & H.E. Robins.	fragrant snakeroot	N	P	Similar to *Brickellia grandiflora,*EB-4 wash
	Agoseris glauca (Pursh) Raf.	pale agoseris	N	P	
	Artemisia carruthii Wood ex Carruth.	Carruth's sagewort	N	P	
	Artemisia dracunculus L.	wormwood	N	P	Cottam - Uinkaret Plat. (Check NAU plots)
	Artemisia frigida Willd.	fringed sagewort	N	P	Cottam - Mt. Emma
	Artemisia tridentata Nutt.	big sagebrush	N	S	
	Brickellia eupatorioides var. *chlorolepis* (Woot. & Standl.) B.L. Turner	false boneset	N	P	*Brickellia chlorolepis*
	Chaenactis douglasii (Hook.) Hook. & Arn.	Douglas' dustymaiden	N	P	
	Chrysothamnus depressus Nutt.	longflower rabbitbrush	N	S	
	Chrysothamnus viscidiflorus (Hook.) Nutt.	green rabbitbrush	N	S	Cottam - east slope of Mt. Trumbull
	Cirsium wheeleri (Gray) Petrak	Wheeler's thistle	N	P	
	Conyza canadensis (L.) Cronq.	Canadian horseweed	N?	A	Probably introduced
	Erigeron bellidiastrum Nutt.	western daisy fleabane	N	A	Cottam - hill N. of N.S., not coll. by NAU
	Erigeron divergens Torr. & Gray	spreading fleabane	N	P	
	Erigeron flagellaris Gray	trailing fleabane	N	P	
	Erigeron speciosus (Lindl.) DC.	aspen fleabane	N	P	
	Gutierrezia sarothrae (Pursh) Britt. & Rusby	broom snakeweed	N	P	

[1] N = native; I = introduced
[2] A = annual; B = biennial; P = perennial; S = shrub; T = tree

	Helianthus anomalus Blake	western sunflower	N	A	Cottam - Uinkaret Plateau in pipo
	Heliomeris multiflora var. *multiflora* Nutt.	showy goldeneye	N	A/P	*Viguiera multiflora*
	Hymenopappus filifolius Hook.	fineleaf hymenopappus	N	P	
	Hymenoxys cooperi var. *cooperi* (Gray) Cockerell	Cooper's hymenoxys	N	P/B	
	Machaeranthera canescens (Pursh) Gray	hoary aster	N	P	
	Onopordum acanthium L.	Scotch cottonthistle	I	P	
	Sanvitalia abertii Gray	Albert's creeping zinnia	N	A	
	Senecio eremophilus var. *macdougalii* (Heller) Cronq.	Macdougal's groundsel	N	A/P	*Senecio macdougalii*
	Senecio multilobatus Torr. & Gray ex Gray	lobeleaf groundsel	N	P	
	Solidago velutina DC.	threenerve goldenrod	N	P	*Solidago sparsiflora*
	Stephanomeria tenuifolia (Raf.) Hall	narrowleaf wirelettuce	N	P	
	Taraxacum officinale G.H. Weber ex Wiggers	common dandelion	I	P	
	Tetradymia canescens DC.	spineless horsebrush	N	P	
	Tetraneuris acaulis var. *acaulis* (Pursh) Greene (*v. arizonica?*)	stemless hymenoxys	N	P	*Hymenoxys acaulis* - crest of Mt. Logan
	Townsendia incana Nutt.	hoary townsendia	N	P	Cottam?
	Tragopogon dubius Scop.	yellow salsify	I	P	
	Verbesina encelioides (Cav.) Benth. & Hook.f.ex Gray	golden crownbeard	N	A	96-1 after the burn
Berberidaceae	*Mahonia fremontii* (Torr.) Fedde	Fremont's mahonia	N	S	*Berberis fremontii*
	Mahonia repens (Lindl.) G. Don	Oregon-grape	N	S	*Berberis repens*
Boraginaceae	*Cryptantha cinerea* var. *cinerea* (Greene) Cronq.	James's catseye	N	P	
	Lappula occidentalis (S. Wats.) Greene	flatspine stickseed	N?	A	May be introduced
	Mertensia macdougalii Heller	Macdougal's bluebells	N	P	Not enough plant mat'l for positive ID
Brassicaceae	*Arabis fendleri* var. *fendleri* (S. Wats.) Greene	Fendler's rockcress	N	P/B	
	Chorispora tenella (Pallas) DC.	crossflower	I	A	Logan Burn
	Descurainia californica * (Gray) O.E. Schulz	Sierran tansymustard	N?	A/B	Not enough plant mat'l for positive ID
	Descurainia pinnata ssp. *intermedia* (Rydb.) Detling	western tansymustard	N?	A	Introduced?
	Draba sp. L.	whitlowgrass	N	A/B	One spec. in 96-1 after burn, not coll.
	Lepidium densiflorum Schrad.	common pepperweed	N	A	
	Streptanthus cordatus Nutt.	heartleaf twistflower	N	P	Trail up Mt. Trumbull
Capparaceae	*Cleome lutea* Hook.	yellow spiderflower	N	A	
	Cleome serrulata Pursh	Rocky Mtn. bee plant	N	A	
Caprifoliaceae	*Sambucus nigra* ssp. *cerulea* (Raf.) R. Bolli	elderberry	N	T	*Sambucus cerulea*
	Symphoricarpos oreophilus Gray	whortleleaf snowberry	N	S	
Caryophyllaceae	*Arenaria eastwoodiae* Rydb.	Eastwood's sandwort	N	P	

	Arenaria fendleri	Fendler's sandwort	N	P	Crest of Mt. Logan, check author
	Arenaria lanuginosa ssp. *saxosa* (Gray) Maquire	spreading sandwort	N	P	
	Pseudostellaria jamesiana (Torr.) W. A. Weber & R.L. Hartman	tuber starwort	N	P	*Stellaria jamesiana* - EB4 in wash
	Silene scouleri Hook.	Scouler's campion	N	P	NE aspect - Mt. Logan
Chenopodiaceae	*Chenopodium berlandieri* var. *berlandieri* Moq.	Berlandier's goosefoot	N	A	*Chenopodium album var. berlandieri*
	Chenopodium botrys L.	Jerusalem oak goosefoot	I	A	2 spec. in 96-1 after burn, common in seed bank
	Chenopodium graveolens Willd.	fetid goosefoot	N	A	
	*Chenopodium leptophyllu*m (Moq.) Nutt. ex S. Wats.	narrowleaf goosefoot	N	A	
Convolvulaceae	*Convolvulus arvensis* L.	field bindweed	I	P	
Cupressaceae	*Juniperus osteosperma* (Torr.) Little	Utah juniper	N	T	
Cyperaceae	*Carex occidentalis* Bailey	western sedge	N	P	
Ericaceae	*Arctostaphylos patula Greene*	greenleaf manzanita	N	S	Cottam - called it *A. platyphylla*
	Arctostaphylos pungens Kunth	pointleaf manzanita	N	S	
Euphorbiaceae	*Chamaesyce serpyllifolia* var. *serpyllifolia* (Pers.) Small	thymeleaf sandmat	N	A	*Euphorbia serpyllifolia*
	Euphorbia brachycera Engelm.	horned spurge	N	P	
	Euphorbia lurida Engelm.	San Francisco Mtn. spurge	N	P	
Fabaceae	*Astragalus argophyllus* Nutt.	silverleaf milkvetch	N	P	
	Astragalus argophyllus var. *stocksii* Barneby ex Isely	silverleaf milkvetch	N	P	
	Astragalus castaneiformus S. Wats.	chestnut milkvetch	N	P	Cottam - Mt. Emma
	Astragalus oophorus var. *caulescens* (M.E. Jones)	egg milkvetch	N	P	
	Dalea candida var. *oligophylla* (Torr.) Shinners	white prairieclover	N	P	
	Dalea polygonoides Gray	sixweeks prairieclover	N	P	Cottam, but not collected by NAU
	Dalea searlsiae (Gray) Barneby	Searls' prairieclover	N	P	
	Lathyrus laetivirens Greene ex Rydb.	aspen peavine	N	P	
	Lotus humistratus Greene	foothill deervetch	N	A	Check McKee for occurrence, not coll. by NAU
	Lotus utahensis Ottley	Utah birdsfoot trefoil	N	P	
	Lotus wrightii (Gray) Greene	Wright's deervetch	N	P	
	Lupinus argenteus Pursh	silvery lupine	N	P	
	Lupinus formosus var. r*obustus* C.P. Sm.	summer lupine	N	P	Cottam - *L. greenei*, not in AZ per PLANTS
	Lupinus kingii S. Wats.	King's lupine	N	A	
	Medicago sativa L.	alfalfa	I	P	
	Melilotus officinalis (L.) Lem.	yellow sweet-clover	I	P	
	Phaseolus angustissimus Gray	slimleaf bean	N	P	Logan Burn
	Psoralidium tenuiflorum (Pursh.) Rydb.	slimflower scurfpea	N	P	

	Robinia neomexicana Gray	New Mexico locust	N	P	
	Vicia americana Muhl. ex Willd.	American vetch	N	P	
Fagaceae	*Quercus gambelii* Nutt.	Gambel's oak	N	T	
	Quercus gambelii Nutt. x *Quercus turbinella* Greene	hybrid	N	S	
	Quercus turbinella Greene	shrub live oak	N	S	
Fumiariaceae	*Corydalis aurea* Willd.	scrambled eggs	N	A	disturbed areas, fires, 96-1
Garryaceae	*Garrya flavescens* S. Wats.	ashy silktassel	N	P	
Gentianaceae	*Frasera albomarginata* var. *albomarginata* S. Wats.	desert elkweed	N	P	*Swertia albomarginata,* along C.R. 5
	Frasera speciosa Dougl. ex Griseb.	showy frasera	N	P	*Swertia radiata*
Geraniaceae	*Erodium cicutarium* (L.) L'Her. ex Ait.	redstem stork's bill	I	A	
	Geranium caespitosum James	pineywoods geranium	N	P	
	Geranium richardsonii Fisch. & Trautv.	Richardson's geranium	N	P	
Grossulariaceae	*Ribes cereum* Dougl.	wax currant	N	S	
	Ribes sp. L.	currant	N	S	Slide Mtn. - has spines - spec. missing
Hydrophyllaceae	*Nama dichotomum* (Ruiz & Pavon) Choisy	wishbone fiddleleaf	N	A	Looks very similar to *Phlox gracilis*
	Phacelia crenulata var. *corrugata* (A. Nels.) Brand	cleftleaf wild heliotrope	N	P	Cottam
	Phacelia egena (Greene ex Brand) Greene ex J.T. Howell	Kaweah River scorpionweed	N	P	*P. magellanica*
	Phacelia sp.		N	P	Lava Burn, only one, not coll., not flwrng.
Lamiaceae	*Dracocephalum parviflorum* Nutt.	American dragonhead	N	A/B	*Moldavica parviflora*
	Leonurus cardiaca (L.)	common motherwort	I	P	common under oaks
	Marrubium vulgare L.	horehound	I	P	
	Monardella odoratissima Benth.	Pacific monardella	N	P	Lava flows
	Nepeta cataria L.	catnip	I	P	Based on leaf shape, no flowers observed
Liliaceae	*Allium bisceptrum* var. *palmeri* (S. Wats.) Cronq.	aspen onion	N	P	
	Calochortus nuttallii Torr. & Gray	sego lily	N	P	
	Fritillaria atropurpurea Nutt.	spotted missionbells	N	P	
Linaceae	*Linum australe* Heller	southern flax	N	A	Keyed using IMF. *L. aristatum* w/Macdoug.
	Linum lewisii Pursh	prairie flax	N	P	
Loasaceae	*Mentzelia dispersa* S. Wats.	bushy blazingstar	N	A	May be first occurrence in AZ
	Mentzelia pumila Nutt. ex Torr. & Gray	dwarf mentzelia	N	P	
Malvaceae	*Spharalcea parvifolia* A. Nels.	smallflower globemallow	N	P	
Monotropaceae	*Pterospora andromedea* Nutt.	woodland pinedrops	N	P	
Nyctaginaceae	*Mirabilis decipiens* (Standl.) Standl.	broadleaf four o'clock	N	P	
	Mirabilis linearis (Pursh) Heimerl	narrowleaf four o'clock	N	P	

	Mirabilis oxybaphoides (Gray) Gray	smooth spreading four o'clock	N	P	
	Mirabilis pumila? (Standl.) Standl.	dwarf four o'clock	N	P	
Onagraceae	*Epilobium angustifolium* ssp. *angustifolium* L.	fireweed	N	P	Lava flow - EB1
	Gayophytum diffusum Torr. & Gray	spreading groundsmoke	N	A	
	Oenothera caespitosa Nutt.	tufted eveningprimrose	N	P	
	Oenothera coronopifolia Torr. & Gray	crownleaf eveningprimrose	N	P	Roadside - CR 5
	Oenothera flava (A. Nels.)	yellow eveningprimrose	N	P	Sawmill Tank
Orobanchaceae	*Orobanche fasciculata* Nutt	clustered broomrape	N	P	parasitic on ARTR, check current listing status
Papaveraceae	*Argemone munita* Dur. & Hilg.	flatbud pricklypoppy	N	P	
	Eschscholzia californica ssp. *mexicana* (Greene) C. Clark	California poppy	N	A	Cottam
Pinaceae	*Pinus edulis* Engelm.	twoneedle pine	N	T	
	Pinus ponderosa P. & C. Lawson	ponderosa pine	N	T	
Poaceae	*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth	Indian ricegrass	N	P	*Oryzopsis hymenoides*
	Agropyron cristatum (L.) Gaertn.	crested wheatgrass	I	P	
	Aristida purpurea var. *longiseta* (Steud.) Vasey	Fendler threeawn	N	P	
	Bouteloua curtipendula (Michx.) Torr.	sideoats grama	N	P	
	Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths	blue grama	N	P	
	Bromus ciliatus L.	fringed brome	N	P	
	Bromus inermis Leyss.	smooth brome	I	P	
	Bromus marginatus Nees ex Steud.	mountain brome	N	P	Cottam - Mt. Emma
	Bromus tectorum L.	cheatgrass	I	A	
	Elymus elymoides ssp. *elymoides* (Raf.) Swezey	wildrye	N	P	*Sitanion hystrix*
	Elymus trachycaulus ssp. *trachycaulus* (Link) Gould ex Shinners	slender wheatgrass	N	P	
	Elytrigia elongata (Host) Nevski	tall wheatgrass	I	P	*Agropyron elongatum*
	Elytrigia intermedia (Host) Nevski	intermediate wheatgrass	I	P	*A. intermedium* var. *trichophorum*
	Elytrigia intermedia ssp.*intermedia* (Host) Nevski	intermediate wheatgrass	I	P	*A. intermdium* var. *intermedium*
	Eragrostis mexicana (Hornem.) Link	Mexican lovegrass	N	A	Cottam - not collected by NAU
	Festuca arizonica Vasey	Arizona fescue	N	P	Only in Logan burn
	Hesperostipa comata ssp. *comata* (Trin. & Rupr.) Barkworth	ncn	N	P	*Stipa comata*
	Koeleria macrantha (Ledeb.) J.A. Schultes	prairie junegrass	N	P	*K. nitida, K. cristata*
	Leymus cinereus (Scribn. & Men.) A. Love	basin wildrye	N	P	
	Monroa squarrosa (Nutt.) Torr.	false buffalograss	N	A	Logan burn
	Muhlenbergia minutissima (Steud.) Swallen	annual muhly	N	A	
	Muhlenbergia repens (J. Presl.) A. S. Hitchc.	creeping muhly	N	P	

	Muhlenbergia wrightii Vasey ex Coult.	spike muhly	N	P	
	Piptatherum micranthum (Trin. & Rupr.) Barkworth	smilograss	N	P	*Oryzopsis micrantha*
	Poa fendleriana (Steud.) Vasey	muttongrass	N	P	
	Poa pratensis L.	Kentucky bluegrass	I	P	
	Schizachyrium scoparium (Michx.) Nash	little bluestem	N	P	
	Secale cereale L.	cultivated rye	I	A	
	Sporobolus cryptandrus (Torr.) Gray	sand dropseed	N	P	
Polemoniaceae	*Gilia sinuata* Dougl. Ex Benth.	rosy gilia	N	A	Cottam
	Ipomopsis aggregata (Pursh) V. Grant	skyrocket gilia	N	P	
	Ipomopsis arizonica (Greene) Wherry	Arizona skyrocket	N	P	
	Ipomopsis multiflora (Nutt.) V. Grant	manyflowered gilia	N	P	
	Navarretia breweri (Gray) Greene	Brewer's navarretia	N	A	Near Mt. Trumbull 5900' - N. Brian list
	Phlox austromontana Coville	desert phlox	N	P	Nixon Springs pipeline
	Phlox gracilis (Hook.) Greene	slender phlox	N	A	
	Phlox longifolia Nutt.	longleaf phlox	N	P	
Polygonaceae	*Eriogonum alatum* Torr.	winged buckwheat	N	P	C.R. 5
	Eriogonum corymbosum var. *corymbosum* Benth.	crispleaf buckwheat	N	P?	
	Eriogonum cernuum Nutt.	nodding buckwheat	N	A	
	Eriogonum pharnaceoides var. *cervinum* Reveal	wirestem buckwheat	N	A	
	Eriogonum racemosum Nutt.	redroot buckwheat	N	P	
	Eriogonum trichopes Torr.	little deserttrumpet	N	A	Cottam
	Eriogonum umbellatum Torr.	sulphur wildbuckwheat	N	P	
	Eriogonum sp. Michx.	buckwheat	N	A	Slide Mtn. - missing specimens
	Polygonum convolvulus L.	black bindweed	I	A	
	Polygonum douglasii ssp. *johnstonii* (Munz) Hickman	Johnston's knotweed	N?	A	*P. sawatchense*
Polypodiaceae	*Cheilanthes feei* T. Moore	slender lipfern	N	P	Cottam
	Cystopteris fragilis (L.) Bernh.	brittle bladderfern	N	P	
	Woodsia scopulina D. C. Eat.	Rocky Mountain woodsia	N	P	Cottam
Portulacaceae	*Portulaca oleracea* L.	little hogweed	N?	A	May be introduced
Ranunculaceae	*Ceratocephala testiculata* (Crantz) Bess.	curveseed butterwort	I	A	*Ranunculus testiculatus*
	Clematis ligusticifolia Nutt.	western white clematis	N	P	EB4
	Delphinium nuttallianum var. *nuttallianum* Pritz. ex Walp.	Nuttal's larkspur	N	P?	
	Ranunculus oreogenes Greene	Oregon buttercup	N	P	
	Thalictrum fendleri Engelm. ex Gray	Fendler's meadowrue	N	P	

Rhamnaceae	*Ceanothus fendleri* Gray	Fendler's ceanothus	N	S	
	Ceanothus martinii M.E. Jones	Martin's ceanothus	N	S	
Rosaceae	*Amelanchier alnifolia* (Nutt.) ex M. Roemer	Saskatoon serviceberry	N	S/T	
	Amelanchier utahensis Koehne	Utah serviceberry	N	S/T	
	Antennaria sp. Gaertn.	pussytoes	N	P	
	Cercocarpus ledifolius var. *intermontanus* N. Holmgren	curlleaf mountain mahogany	N	S/T	Mt. Logan - Hell's Hole Overlook
	Fallugia paradoxa (D. Don) Endl. ex Torr.	Apacheplume	N	S	
	Petrophyton caespitosum (Nutt.) Rydb.	mat rockspirea	N	P	Cottam
	Prunus emarginata (Dougl. ex Hook.) Walp.	bitter cherry	N	S/T	
	Purshia stansburiana (Torr.) Henrickson	Stansbury cliffrose	N	S	
	Purshia tridentata (Pursh) DC.	antelope bitterbrush	N	S	
	Rosa woodsii var. *ultramontana* (S. Wats.) Jepson	Woods' rose	N	S	
Rubiaceae	*Galium bifolium* S. Wats.	twinleaf bedstraw	N	A	Check current listing status
	Galium sp. L.	bedstraw	N	P	Slide Mtn. - missing specimens
	Galium wrightii Gray	Wright's bedstraw	N	P	
	Kelloggia galioides Torr.	milk kelloggia	N	P	
Rutaceae	*Ptelia trifoliata* ssp. *pallida* (Greene) V. Bailey	common hoptree	N	S/T	
Salicaceae	*Populus tremuloides* Michx.	quaking aspen	N	T	
Santalaceae	*Comandra umbellata* ssp. *pallida* (A. DC.) Piehl	pale bastard toadflax	N	P	
Saxifragaceae	*Heuchera parvifolia* Nutt. Ex Torr. & Gray	littleleaf alumroot	N	P	Cottam - Mt. Emma
	Heuchera rubescens Torr.	pink alumroot	N	P	Check current listing status
Scrophulariaceae	*Castilleja integra* Gray	wholeleaf Indian paintbrush	N	P	
	Castilleja linariifolia Benth.	Wyoming Indian paintbrush	N	P	
	Collinsia parviflora Lindl.	smallflower blue-eyed Mary	N	A	
	Cordylanthus parviflorus (Ferris) Wiggins	purple bird's beak	N	A	
	Mimulus bigelovii var. *bigelovii* (Gray) Gray	Bigelow's monkeyflower	N	A	One spec. in 96-1 after burn, not collected
	*Mimulus rubellu*s Gray	red monkeyflower	N	A	
	Pedicularis centranthera Gray	dwarf lousewort	N	P	
	Penstemon barbatus (Cav.) Roth	beardlip penstemon	N	P	
	Penstemon eatonii Gray	Eaton's penstemon	N	P	N.S. pipeline - side of Mt. Trumbull
	Penstemon linarioides ssp. *sileri* (Gray) Keck	Siler's penstemon	N	P	
	*Penstemon linarioide*s ssp. unknown	mat penstemon	N	P	5 ssp. in AZ - don't have good key yet
	Penstemon ophianthus Pennell	coiled anther penstemon	N	P	Cottam - juniper slopes
	Penstemon pachyphyllus Gray ex Rydb.	thick-leaf beardtongue	N	P	Also have pink phase - expert ID?

	Penstemon pachyphyllus var. *congestus* (M.E.Jones) N. Holmgren	thickleaf beardtongue	N	P	Cottam
	Penstemon palmeri Gray	Palmer's penstemon	N	P	
	Penstemon rostriflorus Kellogg	Bridge penstemon	N	P	P. bridgesii
	Penstemon thompsoniae (Gray) Rydb.	Thompson's beardtongue	N	P	uncommon at MT - not collected
	Verbascum thapsus L.	common mullein	I	B	
Solanaceae	*Datura wrightii* Regel	sacred thornapple	N	P	Logan burn
	Nicotiana attenuata Torr. Ex S. Wats.	coyote tobacco	N	A	
	Physalis hederifolia Gray	ivyleaf ground cherry	N	P	
	Physalis hederifolia var. *palmeri* (Gray) Cronq.	Palmer's groundcherry	N	P	Not in AZ per PLANTS database
	Solanum jamesii Torr.	wild potato	N	P	
	Solanum triflorum Nutt.	cutleaf nightshade	N	A	
Verbenaceae	*Glandularia gooddingii* (Briq.) Solbrig	southwestern mock vervain	N	P	Verbena gooddingii
	Verbena bracteata Laq. & Rodr.	bigbract verbena	N	P	Only in seedbank? Check datasheets
Violaceae	*Viola canadensis* L.	Canadian white violet	N	P	
	Viola nuttallii Pursh	Nuttall's violet	N	P	No AZ specimens in Deaver Herbarium
Viscaceae	*Phoradendron juniperinum* Engelm.	juniper mistletoe	N	P	

APPENDIX B: METRIC—ENGLISH CONVERSIONS

Multiply:	By:	To get:
Number/ha	0.4047	Number/acre
M^2/ha	4.3554	Ft^2/acre
Ha	2.4710	Acres
Cm	2.54	Inches
M	3.2808	Ft
Km	0.6214	Miles
Metric ton/ha	0.4461	English ton/acre

Plot 1341 on cinder soils north of Petty Knoll in 1997. The forest is relatively open, with many shrubs in the understory. Fuels are variable with occasional large woody debris.

Plot 786 on basalt soils near the peak of Mt. Logan in 1996. Dense young ponderosa pine trees dominate the forest. There are few remaining presettlement trees, such as the tree in the right rear of the scene; many have recently died. Understory productivity is extremely low.

Plot mtrc-01 on basalt soils near the peak of Mt. Logan in 1995. The plot falls in the area thinned around 1974. Residual trees have grown rapidly and basal area is approximately equal to that of the adjacent unthinned stands. Understory productivity is extremely low.