Changes from 1876 to 1994 in a Forest Ecosystem Near Walnut Canyon, Northern Arizona

Jody P. Menzel
W. Wallace Covington

School of Forestry
Northern Arizona University
NAU Box 15018
Flagstaff, Arizona 86011

Abstract. A central concept in adaptive ecosystem management is the use of the range of natural variability as a reference for developing and assessing management objectives and strategies. Using the range of variability as a reference requires that the conditions which prevailed prior to Euro-American settlement, which commenced in the mid- to late-19th century in the West, be described and quantified. We used dendroecological techniques to estimate changes in forest structure since Euro-American disruption of the natural disturbance regime in a *Pinus ponderosa-Quercus gambelii* woodland on the northern rim of Walnut Canyon in northern Arizona. The reconstruction of the 1876 stand structure showed an increase in density of trees greater than 10 cm diameter at breast height (dbh), or greater than 10 cm diameter at root collar (drc) for nontimber species, from 72 stems/ha in 1876 to 333 stems/ha in 1994. Total basal area for trees larger than 10 cm increased from 9.0 m^2/ha in 1876 to 19.1 m^2/ha in 1994, primarily due to a greater number of trees in smaller size classes. Overstory composition also changed since 1876. At that time *Pinus ponderosa* stems represented an estimated 80% of the basal area of all trees larger than 10 cm, a proportion which decreased to 68% in 1994. *Quercus gambelii* increased from less than 5% of total basal area in 1876 to over 15% in 1994, *Pinus edulis* increased from 2.5% to nearly 5%, and *Juniperus* spp. increased from 12.7% to 15%.

Changes in forest structure associated with Euro-American settlement previously have been documented in pure and mixed western pine ecosystems. Results from the Walnut Canyon area demonstrate that similar changes also occurred on marginally productive limestone soils near and within the ecotone between ponderosa pine forests and pinyon-juniper woodlands.

Key words: Ecosystem management, Euro-American settlement, fire suppression, pine-oak woodland, presettlement, range of natural variability.

Research Objectives

Although humans have had considerable impacts on the interior forests and woodlands of western North America for millennia (Kay 1995), ecosystem changes since the mid-19th century Euro-American settlement of the interior western U.S. are unprecedented within such a relatively brief period of time. Livestock grazing, fire suppression, timber and other resource extraction, and landscape modification are perhaps the most significant of the Euro-American activities which caused these changes in interior western ecosystems. Changes since Euro-American settlement include a greater number of trees in smaller size classes, shifts in species composition, and tree invasions into historically unforested areas. A few of the actual and potential adverse effects associated with these changes are increases in the risk and intensity of wildfires, increases in the incidence and severity of forest pathogen outbreaks, decreases in stream flow, and shifts in habitat quality (Covington et al. 1994). Resource managers are increasingly concerned with mitigating or reversing the adverse environmental impacts of Euro-American settlement as these problems become manifest (U.S. Forest Service 1993, Kaufmann et al. 1994).

Ideally, resource managers would mitigate adverse effects associated with anthropogenic impacts by instituting management practices based on a comprehensive understanding of the systems and interactions involved. In reality, the complexity of ecosystems precludes such an approach. In the absence of a comprehensive understanding of ecosystem functions, a proposed approach is to use the environmental conditions which prevailed in an area prior to significant anthropogenic impact as a reference with which to design and assess management goals and strategies (Bonnicksen and Stone 1985, Monnig and Byler 1992, Kaufmann et al. 1994). An approach based on this range of natural variability, or RNV (Swanson et al. 1994), is propitious because: (1) native species, including those listed under Endangered Species Act of 1973, have evolved in concert with the RNV, and (2) many forest health problems, such as unnatural insect and disease outbreaks and the risk of increasingly destructive fire, are due to post-settlement departures from the RNV (Covington et al. 1994, Harvey 1994).

Before management practices or goals which use the RNV as reference conditions can be instituted, managers must know what constituted the RNV over the spectrum of ecosystems (Covington and Moore 1994a, Morgan et al. 1994). The research described here directly addresses this problem. The purposes of this research are to: (1) estimate the pre-Euro-American settlement forest structure of a ponderosa pine (*Pinus ponderosa*)-Gambel oak (*Quercus gambelii*) woodland near Flagstaff, Arizona, in terms of tree composition and size distributions; (2) quantify the changes which have occurred in the area since Euro-American settlement; and (3) compare changes with regard to different management histories in the area. Our discussion of the research results will explore management implications suggested by the study.

Ponderosa Pine Forest Ecology

In northern Arizona, ponderosa forests have been well established for at least the past 4,000 years (Cole 1990). Regional climate changes, including more frequent lightning strikes and ignitions coincident with the advent of the Arizona monsoon weather pattern, likely contributed to the ascendancy of fire-resistant ponderosa pine on the montane Colorado Plateau (Anderson 1989). Packrat midden macrofossils from within Walnut Canyon suggest that the vegetative composition of our study area has changed little in the past 5,000 years (Murdock 1994).

Native Americans undoubtedly influenced the character of forest and woodland ecosystems, but the magnitude of their impact is subject to debate (Kay 1995). Aboriginal broadcast burns, cultivation, and construction had at least localized ecosystem effects. For example, the appearance of yucca (*Yucca* spp.) macrofossils in packrat middens only after Sinagua colonization of Walnut Canyon may reflect an aboriginal modification of the local vegetation (Murdock 1994). The direct impacts of aboriginal settlement in the Walnut Canyon area ceased with the abandonment of the Walnut Canyon cliffhouses about 700 years ago (Short 1988), but some Native American impacts, such as fire ignitions, may have continued sporadically (see, e.g., Cline 1976). For our purposes, we accept a definition of the RNV which incorporates the influence of Native Americans prior to Euro-American settlement (cf., Parsons et al. 1986, Bonnicksen 1994).

Empirical and historical evidence suggests that the presettlement ponderosa forest landscape was dominated by groups of old-growth pines with few seedlings, saplings, and poles. Cooper (1960) summarizes numerous early descriptions of the Arizona pine forest as follows: "The forest was decidedly open and park like. Reproduction was present but not abundant, and in many areas was markedly deficient. Grass was abundant, but not universal." Recent quantitative reconstructions of presettlement ponderosa pine forest structure corroborate early qualitative descriptions (Covington and Moore 1994a,b).

Relatively frequent surface fires maintained the open forests dominated by older trees which characterized the presettlement landscape. Early disruption of this disturbance pattern was primarily due to livestock grazing and the corresponding reduction in fine fuels rather than to active fire suppression (Harrington and Sackett 1992). Several fire disturbance history studies in the Southwest show a marked decrease in fire frequency around the turn of the century, coincident with increasing Euro-American livestock introductions (Swetnam 1990). Studies in northern Arizona reflect the relatively frequent fires in the area prior to Euro-American settlement. In the years 1785–1876 the average fire return interval was 2.5 years, with a maximum interval of 8 years, at Chimney Springs north of Flagstaff (Dieterich 1980a). In 1750–1898 the average fire return interval was 2.9 years, with a maximum interval of 10 years, at Limestone Flats south of

Flagstaff (Dieterich 1980b). Dated fire-scar samples from the Walnut Canyon area suggest that its ponderosa pine forests experienced fire return intervals similar to others in the region prior to 1900 (Swetnam et al. 1990).

Study Area

Physical Description

The study area consists of six contiguous sections of approximately 259 ha (640 acres) each on the north rim of Walnut Canyon in northern Arizona (Fig. 1). These sections are numbered 21, 22, 23, 26, 27, and 28, Gila and Salt River Baseline and Meridian. Within this study area, the U.S. Forest Service manages public lands within sections 21, 23, and parts of 26 and 27. The State of Arizona Land Department manages sections 22 and 28, and the U.S. Park Service manages the southern portion of section 26.

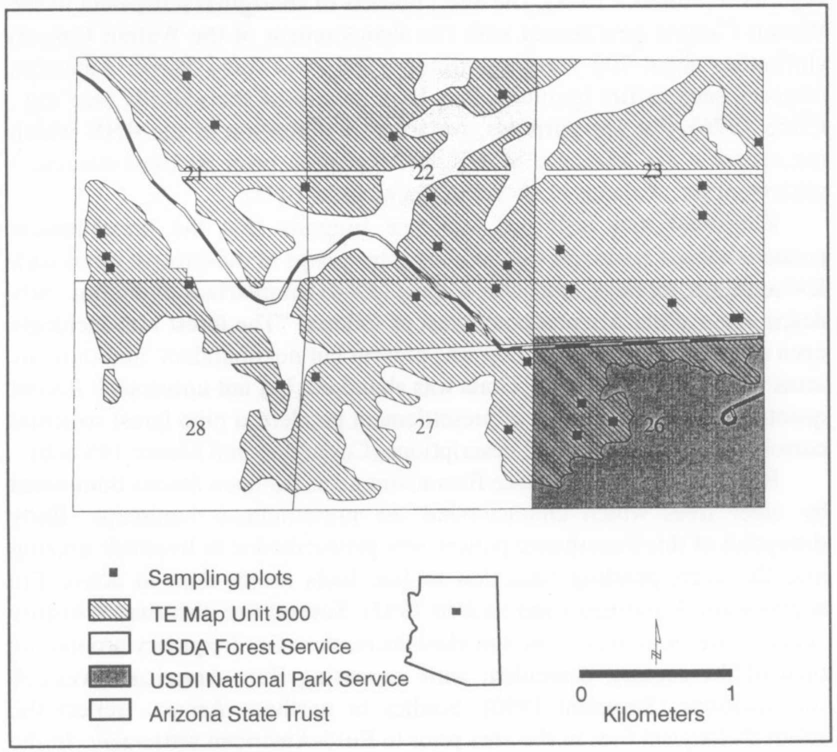

Fig. 1. Map of study area near Walnut Canyon National Monument, northern Arizona. The numbers 21–23 and 26–28 correspond to section numbers. Diagonal hatching represents land within the U.S. Forest Service's TE map unit 500 classification.

Sample plots were located within an elevational range of about 2,000 m to 2,150 m above sea level. Soils are shallow, well-drained derivatives of the Kaibab Limestone formation, with some sandstone components. Average annual precipitation at Walnut Canyon National Monument is 45 cm, with about 16 cm in the form of winter snowfall; average daily temperatures range from 11° C to 30° C in the summer and -8° C to 7° C in the winter. Summer precipitation falls mostly during July, August, and September, when thunderstorms develop almost daily. Winter precipitation is extremely variable, with most snow falling between late November and early March (U.S. Soil Conservation Service 1975). Average annual snowfall is 140 cm (U.S. Park Service 1992). The growing season in Walnut Canyon National Monument is 150 days (Short 1988).

Study plots were located within the *Pinus ponderosa-Poa fendleriana-Quercus gambelii* biotic community, and within the ecotone representing the gradation of this community into the *Pinus edulis-Juniperus monosperma-Bouteloua gracilis* biotic community (Brown 1982) as elevations drop to the north and east within the study area. Gambel oak is common throughout the area, but is replaced by pinyon pine and junipers in the ecotone marking the transition from ponderosa pine forest to pinyon-juniper woodlands. Juniper species found in the area, in order of their present-day occurrence in the sample plots, are Utah juniper (*J. osteosperma*), alligator juniper (*J. deppeana*), one-seed juniper (*J. monosperma*), and Rocky Mountain juniper (*J. scopulorum*).

Local Land Use History

Local changes in forest structure reflect changes in the patterns and relative impacts of human land use, so a history of those uses is instructive. The San Francisco Peaks area of northern Arizona has been visited or occupied by Native Americans sporadically since at least 4000 B.C. From about A.D. 1125 to A.D. 1250 a community of Native Americans of the Sinagua culture group lived in cliff dwellings within Walnut Canyon. The cliff dwelling community was relatively small, occupying at most 300 rooms within the 87 sites in the canyon, and they left the area entirely by about 1,300 (Short 1988). Native Americans continued to travel in the area following the Sinagua abandonment, and explorers and missionaries of European descent occasionally forayed through northern Arizona in the three centuries following Coronado's expedition in 1540 (Cline 1976). Human impact was minimal until the 1850s, however, when about 551,000 sheep were driven from New Mexico to California. One of the two major driveways during this decade passed through the Flagstaff area along the route of the Beale wagon road, which passed within 3 km of the Walnut Canyon study area (Haskett 1936). In the decades after Beale's last expedition in 1859, the wagon road was used by hundreds of Euro-Americans.

The first Euro-American to permanently settle in the Flagstaff area was a sheep rancher, Thomas Forsythe McMillan, who arrived no later than May 1876. This also was the year in which the flag was raised which gave the community its name (Cline 1976). It was the last year marked by frequent fires in the Walnut Canyon area (Swetnam et al. 1990), and it coincides with Dieterich's (1980a) evidence for the last fire at Chimney Spring. Thus, 1876 is an appropriate year with which to define the advent of Euro-American settlement in the area.

Livestock husbandry, primarily sheep ranching, was the primary Euro-American activity in the Flagstaff area until the establishment of the Ayer Lumber Company in 1882 (Cline 1976). By 1891 there were about 110,000 head of cattle and 9,000 horses competing with 270,000 sheep in the Flagstaff area (Cline 1994). In 1904, Leiburg et al. described the range around Flagstaff as "eaten or sheeped out," and reported that the grazing value of the township containing the study area was "yet moderate, but [it] will not last many years longer. Some of the northern sections... now chiefly produce coarse weeds."

Sheep were replaced by cattle in the Walnut Canyon area in the mid–1950s. In 1991, 1,160 cattle were permitted within two extensive allotments which extend into portions of the study area outside Walnut Canyon National Monument. Range conditions in the study area in 1991 were rated fair to good, with a static or upward trend (U.S. Forest Service 1991).

All the land within the study area, with the exception of lands patented under the Preemption or Homestead Acts, was public domain administered by the Department of the Interior until the Atlantic and Pacific Railroad was granted the odd-numbered sections in the 1880s. As public domain, the land generally was closed to timber harvest. Timber trespass by early settlers and loggers probably was frequent to the point of being commonplace, however (Matheny 1975). Many of the oldest stumps in the study area, some of which are axe-hewn, probably date to unregulated cutting by early settlers and loggers prior to the large-scale commercial harvests which commenced with the establishment of the Ayer Lumber Company in 1882.

The Arizona Lumber Company, successor to the Ayer Lumber Company, purchased by 1889 all timber on all 868 odd-numbered sections owned by the Atlantic and Pacific Railroad, including timber within sections 21, 23, and 27 of the study area. In 1890 the even-numbered sections in the area, with the exception of section 26, were granted to the State of Arizona under the Lieu Lands Provision of the Territorial Enabling Act of 1863.

The odd-numbered railroad grant sections had been heavily harvested by 1902. Less than 2,000 board feet per acre remained in sections 21 and 27, and section 23 had been clearcut. In contrast, between 2,000 and 5,000 board feet per acre remained within the unharvested sections 22, 26, and 28 (Leiburg et al. 1904).

In 1902, the Atchison, Topeka and Santa Fe Railroad (formerly the Atlantic and Pacific Railroad) began to exchange its odd-numbered sections within the San Francisco Peaks Forest Reserve for land outside the Reserve under the lieu lands provision of the 1897 Organic Act. Sections 21, 23, and 27 were revested in 1904 and came under the management of the U.S. Department of Agriculture's Bureau of Forestry, which became the U.S. Forest Service in 1905.

Walnut Canyon was established as a National Monument in 1915 under the management of the U.S. Forest Service. It came under U.S. Park Service management in 1934. Scattered ponderosa pine stumps within its boundaries attest to unregulated cutting and timber trespass prior to the protection afforded by Monument status, and stumps of other species reflect illegal fuelwood gathering, which was curtailed with the completion of an effective boundary fence in 1977. The fence also eliminated the common problem of trespass grazing within the Monument.

The state-managed sections 22 and 28 were harvested in 1914–1916 by what had become known as the Arizona Lumber and Timber Company. After then, timber and fuelwood harvests in the area were relatively light. Selected declining trees were harvested on both state and U.S. Forest Service-managed lands in the area in the early 1970s, and an oak fuelwood sale was conducted in state-managed Section 22 in 1988. Other management activities within the study area include some small (less than 4 ha) prescribed burns within Walnut Canyon National Monument in the 1980s, followed by a more aggressive prescribed burning program of 8 ha and greater annually within the Monument beginning in 1995. During this century, suppression has extremely confined the occurrence, areal extent, and environmental effects of wildfires in the area (Swetnam et al. 1990). Due in part to its proximity to Flagstaff, the area is much used by hikers, bicyclists, equestrians, and recreational motorized vehicle enthusiasts, as well as by illegal trash dumpers and firewood gatherers. Local advocates for protection of the area, organized as the Friends of Walnut Canyon, influenced a 1991 decision to withdraw sawtimber harvests scheduled for 1996 on the U.S. Forest Service-managed sections in favor of a management alternative which emphasized scenic, recreation, and wildlife values.

On 12 November 1996 President William Jefferson Clinton signed into law the Omnibus Parks and Public Lands Management Act, which expanded Walnut Canyon National Monument by 539 ha. About 65 ha of this transferred land, the SE 1/4 of section 27, is within the study area. This expansion will challenge the Monument's land managers to devise management strategies reflecting the NPSs preservation mandate in an area formerly governed by the U.S. Forest Service's multiple-use mandate.

Methods

We used classifications from the U.S. Forest Service Terrestrial Ecosystem Survey (TES) (U.S. Forest Service 1986) to exclude gross site differences between sample points while sampling within a large proportion of the greater study area (cf. Covington and Moore 1994a,b). This classification system represents a coarse-filter approach (*sensu* Kaufmann et al. 1994); it describes ecosystem attributes at a level of detail which incorporates considerable variation while still retaining definitive similarities. The TES classifies ecosystems with similar soil, vegetation, and slope properties into similar Terrestrial Ecosystem (TE) map units. TE map unit 500 is characterized by Mollic or Lithic Eutroboralfs, or Udic Ustochrepts soils; limestone bedrock; a High Sun Cold climate classification; overstory vegetation dominated by ponderosa pine, with pinyon pine, juniper, and Gambel oak secondary; and slopes ranging from 0 to 15%. We randomly located 30 sampling locations within TE map unit 500, the most extensive unit within the study area, by assigning numbers to all potential sampling locations and choosing for sampling those locations whose numbers appeared first on the random number generator of an HP-71 scientific calculator.

In order to quantify differences in forest structure between management units, we ensured that the number of sampling locations in each management unit was proportional to the area of TE map unit 500 within each management unit. Thus, 20 plots were located on U.S. Forest Service-managed land, seven were located on Arizona state land and three within Walnut Canyon National Monument.

At each sampling location, we established a 40 m x 40 m plot to measure presettlement forest structure and a 20 m x 20 m nested subplot to measure present forest conditions. The northeast 20 m x 20 m quadrat within each 40 m x 40 m plot represented the current-conditions subplot. Within the current-conditions subplots, we recorded the species and location of all live trees, snags, stumps, and fallen trees. For ponderosa pine, diameter was measured at breast height (dbh = 1.37 m). Diameter was measured at root collar for species other than ponderosa pine (see Born 1985). Increment cores were taken at 20 cm above ground level from all live trees with a dbh or drc of 10 cm or greater.

We classified standing trees into one of seven snag condition stages according to characteristics described in Maser et al. (1979). Snag decomposition stages and their associated characteristics are: Stage 1 (healthy live trees), Stage 2 (declining live trees), Stage 3 (recently dead trees), Stage 4 (loose bark), Stage 5 (clean), Stage 6 (broken), and Stage 7 (decomposed). We also used five condition classes described by Maser et al. (1979) to classify fallen dead material, based on log characteristics such as the amount of bark present, the presence or absence of small (< 3 cm) twigs, the texture of the wood, the cross-sectional shape (round or oval) of the log, the color of the wood, and the portion of the log resting on the ground. Stumps were classified according to the snag criteria.

Sampling procedures on the remaining three-fourths of the 40 m x 40 m plots were identical to those used on the 20 m x 20 m present conditions subplots, with the exception that only those trees, living and dead, which appeared to have established during or before 1876 were measured. A living tree was judged presettlement according to criteria modified from White (1985), i.e., all ponderosa pine trees greater than 37 cm dbh, and all ponderosa pine trees smaller than 37 cm but exhibiting yellow bark, were measured. Living trees of other species were measured if diameter at root collar was equal to or greater than 25 cm; this criterion was based on field examinations of increment cores, which indicated that trees which had established during or before 1876 would rarely fail to reach 25 cm drc in 1994. We adjusted the diameter criteria for establishing whether a tree was presettlement or not upward or downward if field examination of several increment cores suggested it was prudent to do so. The minimum size criteria for determining whether or not to measure dead material within the presettlement subplots were the same as the diameter criteria for live trees (37 cm for ponderosa pine, 25 cm for other species). However, since it was usually impossible to determine presettlement origin in the field, we subjectively but conservatively measured any and all material which we considered could have been of presettlement origin based on its degree of decomposition and diameter.

We mounted and surfaced the increment cores and counted annual rings on all samples under a microscope to estimate tree age and measure the 1876–1994 radial increment, if present. All ponderosa pine tree samples were cross-dated (Stokes and Smiley 1968) by comparing them to a tree-ring width chronology from the International Tree-Ring Data Bank at the National Geophysical Data Center in Boulder, Colorado, developed by Graybill and Rose (1989) for the Walnut Canyon area.

We determined current (1994) forest structure and species composition directly from the diameter measurements and counts of live trees within the 20 m x 20 m subplots, extrapolated to a per-ha basis. We used less straightforward dendrological techniques and mathematical models to determine the 1876 forest structure and composition.

For ponderosa pines, if an 1876 growth increment existed and the tree pith was present or its location could be estimated from the increment core, we measured the diameter from the pith to this 1876 increment. We then used a regression equation developed by Hann (1976) to correct this measurement from 1876 diameter inside bark at stump height (dsh) to 1876 diameter outside bark at breast height.

Determining the 1876 dbh of ponderosa pines with incomplete cores was more complicated. These were ponderosa pine cores for which the location of an absent center pith could not be estimated from the increment core. To estimate 1876 dbh of possible presettlement ponderosa pines smaller than 37 cm dbh with incomplete cores, we used the ponderosa pine diameter mean annual increment (DMAI) as calculated from all sampled trees with complete cores, and subtracted this value 118 times from 1994 dbh. For ponderosa pine trees 37 cm dbh and larger with incomplete cores, we used measurements from complete cores to develop a regression equation which estimated the expected value of 1876 dbh based on 1994 dbh.

When we had complete cores from oak and juniper trees of obvious presettlement origin, we determined whether an 1876 growth increment was present by counting rings. We were unable to develop a predictive 1876-1994 BAI model for these species because of the small number of complete presettlement core samples, the uncertainty of the presettlement radial diameter measurements for complete cores, and the lack of species-specific formulae to correct from diameter at root collar outside bark to diameter at stump height inside bark. Instead we used annual growth estimates from Rogers et al. (1984) to estimate 1876 drc or, for those species for which Rogers et al. (1984) did not provide annual growth estimates, we used the DMAI as calculated from our data set.

To determine the 1876 dbh of dead material, we first estimated the year in which the tree had died, then subtracted modeled growth between 1876 and the year of death. We used both published decomposition rates and harvest dates to estimate year of death for dead material. Rogers et al. (1984) provided locally calibrated estimates of the rates at which standing dead trees move from one snag condition stage to another, based on data from the Fort Valley area about 20 km northwest of the Walnut Canyon study area. Cunningham et al. (1980) provided descriptions of snags and their ages from the same general area as that of the Rogers et al. (1984) data; we used the Cunningham et al. (1980) descriptions to estimate ages of recently dead trees.

Year of death for stumps was inferred from harvest records. Where records were unavailable, death year was estimated using the snag decomposition rates. Ponderosa pine stumps in snag condition stages 3 and 4 were assigned a 1970 harvest date. Ponderosa pine stumps in snag condition stages 6 and 7 in what are now state land sections were assigned a harvest year of 1915, while those in what are now U.S. Forest Service-managed sections were assigned a harvest date of 1901. Gambel oak stumps within state land sections and in snag decomposition stages 3 or 4 were assigned a 1988 harvest date. Finally, we included a stump decomposition stage in the field which did not correspond to any of the snag condition stages in Maser et al. (1979), representing stumps in a state of decomposition more advanced than those which we otherwise would have classified as stage 7 stumps. These "stage 8" stumps were sometimes marginally identifiable as stumps at all, and sometimes showed evidence of being ax-hewn. We conservatively assigned these ancient stumps a harvest year of 1890, prior to the known commercial harvest dates but within the period of accelerating European-American settlement which followed the arrival of the railroad in 1882.

We estimated years of death for fallen trees by applying decomposition rates in Rogers et al. (1984) and to logs in decomposition classes described in Maser et al. (1979).

Results

Comparison of 1876 and 1994 Forests

Our research shows the following changes in forest structure and composition for trees larger than 10 cm diameter since 1876, our base comparison year: (1) increases in density (stems/ha) for all species in the area, (2) a shift in structure toward trees in smaller diameter classes, and (3) a shift in composition toward nontimber species.

Tree density increased from 72 stems/ha in 1876 to 333 stems/ha in 1994 (Fig. 2). Virtually all of this increase is in diameter classes less than 40 cm. Note that Fig. 2 reflects no trees larger than 80 cm in 1994. Although none of these larger trees were observed in the current-conditions subplots, they do still occur in the area.

Changes in basal area for trees larger than 10 cm follow a similar pattern (Fig. 3). Average basal area increased from 9.0 m^2/ha in 1876 to 19.1 m^2/ha in 1994. Increases in basal area primarily are in the smaller size classes, with a slight increase in the 60–79.9 diameter class. Again, no trees greater than 80 cm were observed in the current-conditions subplots.

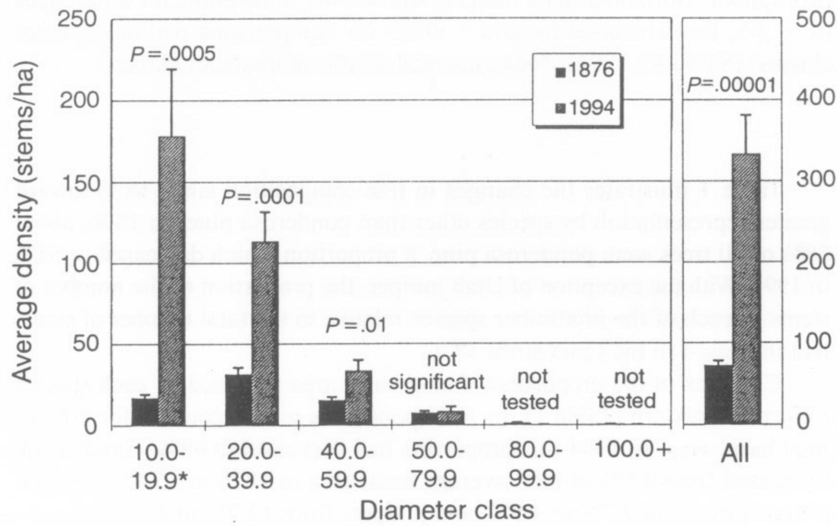

Fig. 2. Average density per 20 cm diameter class in 1876 and 1994, all species combined. Error bars are one SE of the mean. Probabilities are from two-sample separate variance *t*-tests with n = 30 throughout. Horizontal bars indicate statistically nonsignificant differences (a = .05; Bonferroni-adjusted a = .0125 for comparisons within diameter classes) (SYSTAT 1992). *Note unequal widths of diameter classes.

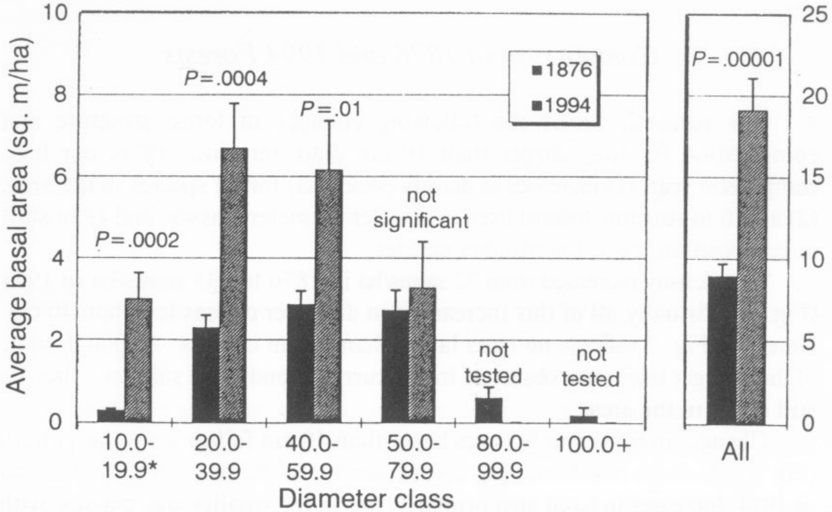

Fig. 3. Average basal area at breast height/root collar per 20 cm diameter class in 1876 and 1994, all species combined. Error bars are one SE of the mean. Probabilities are from two-sample separate-variance *t*-tests with $n = 30$ throughout. Horizontal bars indicate statistically nonsignificant differences ($a = .05$; Bonferroni-adjusted $a = .0125$ for comparisons within diameter classes) (SYSTAT 1992). *Note unequal widths of diameter classes.

Table 1 illustrates the changes in tree composition since 1876 toward greater representation by species other than ponderosa pine. In 1876, about 68% of all trees were ponderosa pine, a proportion which decreased to 55% in 1994. With the exception of Utah juniper, the proportion of the number of stems of each of the nontimber species relative to the total number of stems had increased in the years since 1876.

Changes in the proportion of total basal area occupied by each species reflect this pattern (Table 1). In 1876 ponderosa pine accounted for 80% of total basal area. In 1994 this proportion had decreased to 68%. Gambel oak increased from 4.6% of total average basal area in 1876 to 15.4% in 1994, pinyon pine from 2.5% to 4.9%, and junipers from 12.7% to 15%.

Differences in Magnitude of Changes Across Management Units

The magnitude of changes in forest structure since 1876 differed between lands managed by the three resource management agencies in the area, suggesting that different management practices over the years have had a measurable effect on forest attributes. Generally, changes since 1876 on lands now managed by the Arizona State Lands Department were less pronounced than those on lands now managed by the U.S. Forest Service, while lands now managed by the U.S. Park Service experienced the greatest amount of change in density and basal area.

Table 1. Proportions of density and basal area of trees 10 cm and greater by species in 1876 and 1994.

	Average density			
	1876		1994	
Species	Average stems/ha	Percent of total	Average stems/ha	Percent of total
Ponderosa pine	54.79	67.8	250.83	54.7
Gambel oak	14.58	18.0	109.16	23.8
Pinyon pine	3.54	4.4	35.00	7.6
Utah juniper	4.79	5.9	24.16	5.3
Alligator juniper	2.91	3.6	23.30	5.1
One-seed juniper	0.21	0.2	8.33	1.8
Rocky Mountain juniper	0.00	0.0	7.50	1.6

	Average basal area			
	1876		1994	
Species	Average m^2/ha	Percent of total	Average m^2/ha	Percent of total
Ponderosa pine	7.24	80.2	12.8	67.8
Gambel oak	0.42	4.6	3.05	15.4
Pinyon pine	0.23	2.5	.98	4.9
Utah juniper	0.67	7.4	1.13	5.7
Alligator juniper	0.46	5.3	0.91	4.6
One-seed juniper	0.01	0.01	0.35	1.8
Rocky Mountain juniper	0.00	0.0	0.57	2.9

In 1876, average density per ha for all species combined did not differ significantly across areas now managed by the U.S. Forest Service, the Arizona State Land Department, and Walnut Canyon National Monument (Fig. 4). Increases in density since 1876 of trees larger than 10 cm in diameter were statistically significant on lands managed by the U.S. Forest Service and the U.S. Park Service, but not for Arizona State Trust lands. Agency differences were less pronounced for ponderosa pine taken alone, but the same pattern of change among the agencies is apparent. Also, although differences between ponderosa pine average densities were not statistically significant across the agencies in 1876, it is perhaps significant that Walnut Canyon National Monument, compared to the other agencies, had a smaller proportion of ponderosa pine at that time (Fig. 5). This suggests that initial species composition, combined with the differences in timber and fuelwood harvest events, could account for some of the present differences in forest attributes across the management units.

Differences in average basal area among the three management areas mirror the average density pattern, except statistical significance is lost for 1994 differences across agencies for ponderosa pine exclusive of other species (Fig. 5). The trend across the agencies is still apparent, however. Lands managed by the State of Arizona Land Department again had the least change in 1876–1994.

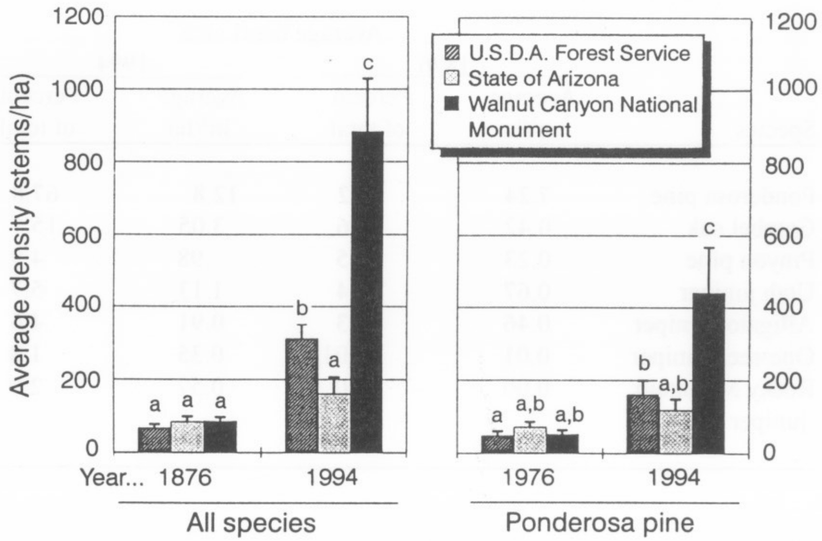

Fig. 4. Comparison of changes in average density across management agencies in 1876 and 1994. Error bars represent one SE of the mean. Same letters indicate nonsignificant differences between agencies both within and across years (a = .05, ANOVA weighted means model with n = 20 for U.S. Forest Service, n = 7 for Arizona State Trust, and n = 3 for Walnut Canyon National Monument) (SYSTAT 1992).

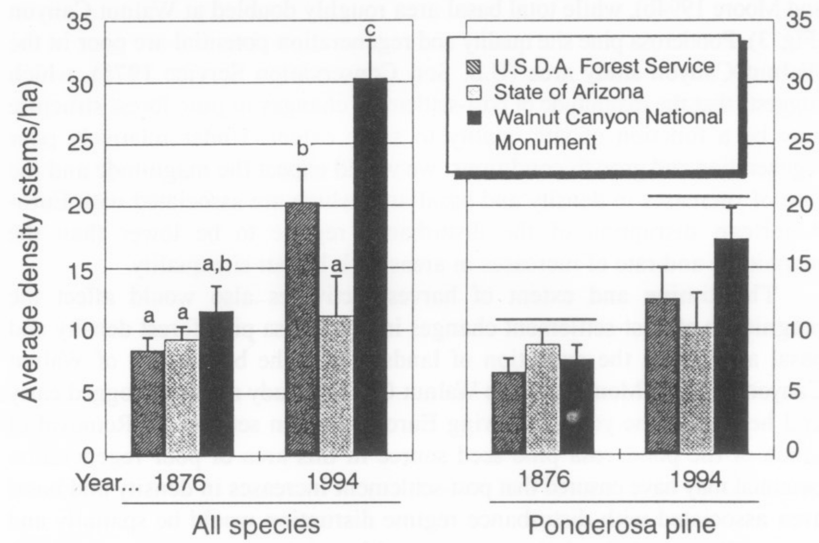

Fig. 5. Comparison of changes in average basal area across management agencies in 1876 and 1994. Error bars represent one SE of the mean. Same letters indicate nonsignificant differences between agencies both within and across years (a = .05, ANOVA weighted means model with n = 10 for U.S. Forest Service, n = 7 for Arizona State Trust, and n = 3 for Walnut Canyon National Monument). Horizontal bars indicate statistically nonsignificant differences (a = .05, ANOVA weighted means model) (SYSTAT 1992).

Discussion

Changes in Forest Structure and Composition since 1876

Our results suggest that the forests and woodlands on the northern rim of Walnut Canyon in 1876 were similar in appearance to ponderosa pine-type forests in other areas at that time (cf. Cooper 1960, Covington and Moore 1994a). The forests in the study area were relatively open compared to their present-day appearance, with a proportionately greater contingent of larger trees. Moreover, in 1876 most trees in all size classes were ponderosa pine. While ponderosa pine is still the dominant species in terms of basal area and sheer numbers, its dominance has diminished in the past 120 years (Table).

The magnitude of changes since Euro-American settlement are not as great in the Walnut Canyon area as those measured elsewhere in northern Arizona. Basal area increased nearly six-fold since Euro-American settlement at Bar-M Canyon and about fourfold on the North Kaibab Plateau (Covington and Moore 1994b), while total basal area roughly doubled at Walnut Canyon (Fig. 3). Ponderosa pine site quality and regeneration potential are poor in the Walnut Canyon study area (U.S. Soil Conservation Service 1975), which suggests that the magnitude of post-settlement changes in pine forest structure may be a function of site quality to some extent. Under relatively poor regeneration and growth conditions, we would expect the magnitude and the rate of increases in density and basal area which are associated with Euro-American disruption of the disturbance regime to be lower than the magnitude and rate of increases in areas with higher site quality.

The timing and extent of harvest activities also would affect the magnitude of post-settlement changes in ponderosa pine forest density and basal area. With the exception of lands within the boundaries of Walnut Canyon National Monument, the Walnut Canyon study area was logged early and heavily in the years following Euro-American settlement. Removal of much of the ponderosa pine seed source in this area of poor regeneration potential may have ensured that post-settlement increases in density and basal area associated with disturbance regime disruption would be spatially and temporally retarded relative to areas with greater regeneration potential. Differences in the magnitude of the changes in forest attributes across management unit boundaries since 1876 in the Walnut Canyon area (Figs. 4 and 5) suggest that different land-use histories and management philosophies have modulated the effects of Euro-American activities across boundaries of lands managed by the three agencies. The most pronounced of these changes are within Walnut Canyon National Monument. Although the possible influence of inherent site differences cannot entirely be ruled out, the heavier sawtimber and fuelwood harvests on Arizona state- and U.S. Forest Service-managed lands likely were most responsible for the relatively greater magnitude of change since 1876 in Walnut Canyon National Monument. The heavy harvesting of ponderosa pine overstory trees outside the Monument in the early-1900s would leave a relatively greater number of these trees within the Monument, which would result in a relatively greater seed rain. This in turn would increase the number of smaller trees within the Monument relative to other areas.

Different harvest histories can explain other differences in forest structure and composition across lands managed by the three agencies in the area. For example, sections now managed by the U.S. Forest Service have had more time to recover since the last sawtimber harvest in the early 1900s relative to Arizona state lands, which were harvested in 1914–1916. Trees which germinated in the 15 or so years between these harvest events may account for some of the differences between the U.S. Forest Service-managed lands and the Arizona state-managed lands. Also, the removal of many larger-diameter Gambel oak stems from state-managed section 22 may have moderated increases in both basal area and density since 1876 on lands managed by this agency.

Management Implications

Management practices designed to restore to some degree the presettlement attributes of the landscape in the Walnut Canyon area have much to recommend themselves. Perhaps most saliently, restoration of these attributes could inhibit or ameliorate potential adverse effects of post-settlement departures from the RNV, such as increases in the incidence and severity of wildfires and forest pathogens.

In addition, the proximity of the area to the city of Flagstaff and its popularity as a recreation destination provide an ideal opportunity to educate visitors of the value and qualities of the presettlement forest, as well as of the merits of applying management tools to restore those values and qualities. The fragmentation of the area in terms of management units provides not only a challenge in coordinating efforts between agencies, but also an opportunity to test the feasibility of such coordination of strategies and goals across jurisdictional boundaries.

Oliver et al. (1994) suggested an 8-step systematic approach to achieving forest health. Step 1 was to describe the range of natural variability in order to establish a reference for assessing current forest conditions and desired future conditions. Step 2 was to assess current departures from the range of variability. These two steps represent the focus of the research described here. Oliver et al.'s (1994) remaining steps are: (3) involve scientists, managers, landowners, and the public in determining an acceptable range of variability, using the natural range of variability as a reference; (4) involve all partners in developing management strategies to return the trajectories of forest change within the defined acceptable range of variability; (5) use large areas to demonstrate alternative strategies; (6) use adaptive management strategies, i.e. remain flexible and receptive as new information becomes available; (7) highlight the consequences of alternative management actions; and (8) conduct education and awareness programs, internally and externally. Using Oliver et al.'s (1994) systematic approach as a framework, our research suggests several management strategies aimed at restoring to some extent the presettlement structure and composition of the study area.

First, since frequent, low-intensity forest fires were the most instrumental of the processes which maintained the relatively open, large ponderosa pine-dominated presettlement forest, restoring this process would perhaps be the most accessible management practice towards restoring presettlement forest attributes. Walnut Canyon National Monument already has instituted a prescribed fire program toward this goal. An aggressive prescribed fire program across agency boundaries would be difficult to implement in the area, given its proximity to the Flagstaff urban-wildland interface, local and governmental restrictions, the existence of more high-priority candidate areas for prescribed fire, and the necessity of close interagency cooperation. Nevertheless, recreating some semblance of the presettlement fire regime represents a worthwhile, perhaps an integral, step toward restoring attributes of the presettlement forest.

Other considerations urge caution before a program of frequent, low-intensity prescribed fire is instituted over the entire area. First, it is unknown to what extent a modern prescribed fire would mimic the burn pattern of presettlement fires. Prior to modern fire exclusion, fires were fed by fine fuels, primarily grasses (Cooper 1960). Over a century of livestock grazing in the area likely has reduced the extent and biomass of the herbaceous understory. Without the grassy understory, prescribed fires in the area may not spread sufficiently to achieve the areal extent of presettlement fires. Also, the possibility of larger trees succumbing to fire is greater than it was during the presettlement era, due to over a century of fuel buildup beneath the larger trees. Removal of the duff beneath exceptional trees may be desirable before igniting prescribed fires in the area.

Second, restoring the herbaceous understory is essential towards recreating the presettlement ecosystem structure and maintaining frequent, low-intensity surface fires. The area should be reseeded or planted with native grasses, shrubs, and forbs if natural regeneration is inadequate. Determining the composition and biomass of the herbaceous understory prior to Euro-American settlement was beyond the scope of our research, but it represents a valuable direction for future research in the area (see Fisher et al. [1987] for an example of an approach to this type of research).

Third, excluding herbivores from the area, at least temporarily, may be necessary in order to allow an herbaceous understory to develop which is sufficient to carry frequent, low-intensity surface fires. Livestock use is not heavy in the area, but undomesticated herbivores, especially elk, may consume some or all of the forage made available by excluding livestock. The area is much used by elk (personal observation 1994), probably because most of the study area is within either the Flagstaff city limits or Walnut Canyon National Monument and thus is closed to hunting.

Fourth, although average density in the area has not increased to the extent observed at other locations (Covington and Moore 1994a,b), dense clumps of ponderosa pine and Gambel oak saplings and poles are scattered throughout the area. These clumps are likely to become more common, more dense, and more extensive in the absence of frequent fires. Mechanically thinning these clumps to an approximation of their presettlement densities and occurrences is essential, because prescribed fire alone may be inadequate to restore the presettlement forest structure (Bonnicksen and Stone 1985).

Fifth, restoration treatments will require community support. They also represent an opportunity to educate Flagstaff-area residents and visitors about ponderosa pine ecosystems. Interpretive signs and exhibits, workshops, tours, and other approaches toward raising community interest, knowledge, and support should accompany any program aimed at restoring presettlement attributes in the area.

Sixth, restoration treatments should proceed with increased cooperation across agency jurisdictions. Each of the managing agencies in the area--U.S. Forest Service, U.S. Park Service, and the State of Arizona Land Department--has different missions, management philosophies, and goals. Identifying common goals and incorporating them into a strategy aimed at restoring desirable presettlement attributes over the entire study area would ensure that the largest potential area will benefit from restoration treatments. It also would preclude one agency's activities from interfering with the goals of another; for example, in the event that a prescribed fire on U.S. Forest Service-managed land inadvertently crossed into state-managed land. Other agencies and groups which have an interest in the area, such as the City of Flagstaff, the Friends of Walnut Canyon citizens' group, and adjacent landowners, also should share in developing restoration strategies and goals.

Finally, research into presettlement forest structure, such as that described here, should be accelerated while evidence of presettlement conditions still exists. One of the ironies of presettlement research is that management practices suggested by the research, especially prescribed fire, destroy the stumps, snags, and other evidence which the researcher relies upon to make recommendations. Ultimately, however, over time, virtually all evidence of the nature of presettlement forests will be destroyed. Combining presettlement research with adaptive ecosystem management (Kaufmann et al. 1994) represents the most promising approach towards improving forest health and supplying human needs. Under adaptive ecosystem management, treatments such as prescribed fire are considered experiments; the effects of management treatments represent experimental results which are incorporated into later management efforts. Thus, research is continuous, and strategies are continuously refined in order to manage ecosystems as efficiently and intelligently as is possible. Adaptive ecosystem management, guided by presettlement forest conditions research, will ensure that land managers and the public can work to restore the health of forests to the best of their abilities, while simultaneously furthering our knowledge of ecosystem dynamics.

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