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A UNIQUE OLD-GROWTH PONDEROSA PINE FOREST IN NORTHERN ARIZONA

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ABSTRACT

Old-growth ponderosa pine (*Pinus ponderosa*) forests are uncommon in the Southwest, and only one old-growth forest (the Gus Pearson Natural Area [GPNA]) has been researched in the ponderosa pine belt surrounding the city of Flagstaff in northern Arizona. The purpose of this study was to measure soil characteristics, current and pre-Euro-American settlement (1885) tree structure, and understory plant composition in a 6-ha remnant old-growth forest on volcanic, red cinder soils. Soil bulk density was extremely low (0.21 Mg/m^3) in this forest because of high volumetric contents of cinders >2 mm diameter. As a result, volumetric soil moisture, organic C, and total N contents were low, with June gravimetric moisture (0-15 cm) averaging <1%. Despite these seemingly inhospitable soils, the reconstructed ponderosa pine presettlement density of 183/ha is among the highest reported for northern Arizona. Current density of live presettlement-origin trees also is high (104/ha), including 36 trees/ha that established before 1700. On a 1-ha plot, the live tree age structure reconstructed for 1885 suggested that all 29 decades between 1600 and 1890 had at least one tree establish. These temporal establishment patterns are more constant than those reported at the GPNA, but do support GPNA findings of uneven-agedness within tree groups. Plant communities were dominated by mountain muhly (*Muhlenbergia montana*) and other species of xeric affinity. Several ecological properties at this site differed sharply from the GPNA, which occupies moist basalt soils, and the site is a member of a red cinders/*Bahia* ecosystem type that is among the rarest in this region.

INTRODUCTION

Old-growth forests have ecological and human values that frequently differ from younger forests. For example, old trees can represent reservoirs of genetic diversity because they established in a different time period than younger trees (Beckman and Mitton 1984). Old trees also have recorded long climatic records in their tree rings, important for reconstructing past climate in climate change research (Grissino-Mayer et al. 1997). While characteristics of old-growth forests vary both within and among forest types, old forests often provide unique habitat by containing large trees, snags, abundant dead wood, characteristic microclimates and soils, or other features specific to a forest type (Morgan et al. 2002). Humans in North America also have obtained timber from old forests, and increasingly appreciate old forests for aesthetic, ecological, and other values (Davis 1996).

Old trees have declined in density in southwestern United States ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forests because of past timber harvest and also likely from accelerated mortality associated with deleterious ecosystem changes (Mast et al. 1999). Old trees in these forests are typically defined as trees that established before Euro-American settlement ("presettlement") in the late 1800s. Since settlement, old trees and forests have been impacted by surface-fire exclusion, livestock grazing, and irruptions of young, postsettlement trees (Covington et al. 1997, Allen et al. 2002, Abella 2004). These postsettlement changes, together with a historical disturbance regime of frequent fire (Swetnam and Baisan 1996) and successional pattern of individual-tree replacement (White 1985), make it difficult to define old-growth ponderosa pine forests in the Southwest (Covington and Moore 1994).

Despite this uncertainty in precisely defining old growth in ponderosa pine forests, the ~ 5-ha Gus Pearson Natural Area (GPNA) within the Coconino National Forest, 10 km northwest of the city of Flagstaff in northern Arizona, has been identified as old growth (Covington et al. 1997, Stone et al. 1999). Ecologists have viewed the GPNA as old growth because the site is essentially unharvested, while recognizing that it does not match presettlement conditions because of irruptions of postsettlement pine densities, fire exclusion, fuel buildups, and other factors (White 1985, Covington et al. 1997, Mast et al. 1999). The GPNA has served as a valuable reference site for many ecological studies, including those of presettlement tree regeneration and age structure (White 1985, Mast et al. 1999), soil properties (Kaye and Hart 1998), old-tree physiology (Stone et al. 1999), and ecological

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restoration experiments (Covington et al. 1997, Laughlin et al. 2006).

The GPNA occurs on moist, silt loam basalt soils that are among the most productive soils for tree growth and understory plant biomass in the Flagstaff area (Abella and Covington 2006a). There are no known published studies reporting characteristics of old-growth forests on other or drier soil types surrounding Flagstaff. Using a landscape ecosystem framework, Barnes (1989) highlighted the importance of abiotic factors (soils and topography) in influencing the biotic characteristics (e.g., tree sizes, density, and plant composition) of old-growth forests. Understanding this variation is important for several reasons, including when identifying guidelines or ranges of variability for defining old forests (Keddy and Drummond 1996), estimating presettlement reference conditions (Morgan et al. 2002), and for maintaining or restoring old forests (Habeck 1990).

During fieldwork for a landscape ecosystem classification (Abella and Covington 2006a, b), I encountered an essentially unharvested, remnant old-growth forest dominated by presttlement-origin ponderosa pine on dry, red volcanic cinder soils (Fig. 1). The site is located within the Coconino National Forest, 20 km northeast of Flagstaff and 4.5 km west of the western border of Sunset Crater National Monument. The objectives of this study were to: (1) quantify soil characteristics, (2) measure current and reconstruct presettlement tree structure and age distribution, and (3) assess understory plant species composition in this old-growth forest.

METHODS

Study Site

The remnant forest is ~6 ha in size and occupies an upper, northeast-facing (65°) slope of a cinder cone (Universal Transverse Mercator, NAD83, 446730 m E, 3915773 m N, zone 12). Based on clinometer measurements, slope gradients average 43%. Elevation of the site is 2,326 m. Soils are derived from volcanic cinders, and are classified as frigid, ashy-skeletal, Vitrandic Ustochrepts or frigid, cindery, Typic Ustorthents (Miller et al. 1995). Climatic means are available from the nearby Sunset Crater National Monument weather station (1969-2005 records), 5 km east of the study area at 2,128 m elevation (Western Regional Climate Center, Reno, NV). This station recorded an average of 43 cm/yr of total precipitation, 153 cm/yr of snowfall, and average monthly high temperatures ranging from 7°C (January) to 29°C (July). The study site is classified as the 513 Terrestrial Ecosystem Survey type by the U.S. Forest Service (Miller et al. 1995), and as a red cinders/*Bahia* ecosystem type in an ecosystem classification of the Flagstaff area (Abella and Covington 2006a).

Figure 1. *Views of an old-growth ponderosa pine forest on red cinder soils 21 km northeast of Flagstaff. Arizona. Reconstructed 1885 (pre-Euro-American settlement) ponderosa pine density was 183 trees/ha, sharply higher than published densities of other sites in the Flagstaff area. The site contained 104 live pines/ha that established before 1885, 21 of which had evidence of fire scarring (c).*

Environmental Measurements

In June 2003, I established a 100 × 100 m (1 ha) plot in the center of the site and located a 20 × 25 m (0.05 ha) plot near the center of the large plot. At the northeast and southeast corners of the 0.05-ha plot, I dug a soil pit 50 cm deep. I collected soil samples for laboratory analysis from 0-15 and 15-50 cm depths, and composited samples from the two pits separately for each depth. I also examined deeper layers using a bucket auger. Soil samples were air dried, sieved through a 2-mm sieve, and analyzed for $CaCO_3$ equivalent (Goh et al.'s [1993] approximate gravimetric method), texture (hydrometer method), pH (1:2 soil:0.01 M $CaCl_2$), and organic C and total N (elemental C/N analyzer) following Sparks (1996) and Dane and Topp (2002). I measured gravel concentration by sieving as the weight of material >2 mm diameter. I also measured soil color on air-dry samples using Munsell color charts. On 19 June 2004, during the driest period of the year in this region when no precipitation had fallen since April (Western Regional Climate Center, Reno, NV), I collected two soil cores each of 208 cm^3 from a 0-15 cm depth. Using these cores, I measured gravimetric soil moisture by 105 °C oven drying for 24 hr, and bulk density by sieving out gravel >2 mm diameter. I also collected ~250 g of cinders to measure their density with volume computed by water displacement.

Tree Sampling

On the 1-ha plot in 2004, I mapped all live trees and evidence of presettlement trees (snags, fallen logs, and stumps). I selected the year 1885 to represent settlement and initiation of fire exclusion, which has been consistently measured as the mid-1870s to 1880s in the Flagstaff area (Fulé et al. 1997, Mast et al. 1999). Because of relatively slow decomposition in these semi-arid forests and exclusion of fire since settlement, re-location of presettlement structures has been shown to be reliable within 10% (Moore et al. 2004). I recorded the diameter at breast height (DBH; 1.37 m) of live trees and snags, and the diameter at stump height (DSH; 40 cm) of stumps and fallen logs. I also noted the presence or absence of fire scars on snags and live trees.

I collected increment cores at stump height from all live ponderosa pine trees >10 cm DBH, and from 25% of trees <10 cm DBH that I selected to encompass a range of diameter and height. I also collected cores from non-rotten snags. Cores were sanded, mounted, and cross-dated (Stokes and Smiley 1968) using tree-ring chronologies from the Flagstaff area. If the pith was missed in a core, center dates were estimated with a pith locator. Tree center dates correspond to the 40-cm tall coring height, which has been conventionally used in this region as a compromise between accuracy of age and growth measurements (Mast et al. 1999). Radial growth also was measured on cores by decade.

To reconstruct tree DBH in 1885, I estimated DBH from DSH of presettlement-origin stumps and fallen logs using equations in Myers (1963). I estimated DBH in 1885 from radial growth measurements from cores of live presettlement-origin trees and for snags from which complete cores could be obtained. Using a DBH-age regression equation from all trees from which complete cores were obtained ($n=137$, $r^2=0.66$), I estimated ages at the time of death for stumps, fallen logs, and snags that could not be dated. I assumed that stumps were cut near 1885, suggested by their grey color and appearance (Mast et al. 1999). Based on local models of snagfall and decomposition and also on their visual appearance in the field (Rogers et al. 1984), fallen logs and snags that could not be crossdated were most likely live trees in 1885. I compared patterns of tree establishment in 10- and 20-year increments to the Palmer Drought Severity Index (Cook 2000) using Pearson correlation.

Understory Sampling

On the 0.05-ha plot within the 1-ha plot, I categorized areal percent cover of each understory plant species rooted in 15, 1-m^2 (1 × 1 m) subplots. Subplots were systematically centered at 0.5, 5, 12.5, 20, and 24.5 m along the bottom, middle, and top plot axes. Cover was categorized as 0.1, 0.25, 0.5, and 1% up to 1% cover, 1% intervals to 10% cover, and 5% intervals above 10% cover. I also surveyed the whole 0.05-ha plot for species not already detected in subplots, and assigned these species the lowest average cover value of 0.007% (0.1% in 1/15 subplots). I calculated relative cover of each species as the percent of total cover of all species. Sampling occurred in June 2003, and nomenclature and classification of species as native or exotic followed USDA-NRCS (2004).

RESULTS AND DISCUSSION

Environment

Soil texture was sandy loam for both the 0-15 and 15-50 cm depths (Table 1). Gravel concentrations (volcanic cinders) by weight were near 50% (Table 1), which translates to greater concentration by volume because the density of the cinders was only 1.9 g/cm^3. This density is lower than typical rock densities of basalt (3.0 g/cm^3), limestone (2.7 g/cm^3), or sandstone (2.4 g/cm^3) summarized in Hyndman (1985). Bulk density of the 0-15 cm depth

Table 1. Summary of soil properties in an old-growth ponderosa pine forest on red cinder soils, northern Arizona.

	Depth (cm)	
Property	0-15	15-50
Gravel (%)[1]	43	49
Sand (%)	62	54
Silt (%)	27	30
Clay (%)	11	17
Texture	SL[2]	SL
BD (Mg/m^3)[3]	0.21	--
Color	BR[4]	RB
Organic C (%)	2.4	0.7
Total N (%)	0.12	0.05
pH	6.61	6.76
CaCO3 (%)[5]	0	4
Moisture (%)[6]	0.7	--

[1] Percentages are by weight.

[2] SL = sandy loam.

[3] BD = bulk density, calculated as the mass of soil (< 2 mm) contained in a core of known volume, which included gravel volume.

[4] Soil color measured air dry from Munsell color charts. BR = brown (7.5YR 4/3), RB = reddish brown (5YR 5/4).

[5] Calcium carbonate equivalent, estimated following Goh et al. (1993).

[6] Gravimetric soil moisture, measured 19 June 2004.

was extremely low, because most of the soil volume was occupied by cinders and very little by soil particles <2 mm diameter. Bulk density at this site is 4-6 times lower than typical bulk densities of 0.8-1.2 for forest and grassland soils (Brady and Weil 1999), and also is less than a bulk density of 0.9 Mg/m^3 reported for the GPNA on basalt soils (Kaye and Hart 1998). High gravel volumes and correspondingly low bulk densities reduce rooting volume, available water holding capacity, and nutrient contents (Welch and Klemmedson 1975). For example, if concentrations by weight of total N (Table 1) are converted to a volumetric basis using bulk density, 0-15 cm N content is only 378 kg/ha at this site. This is about four times lower than contents of 1,431-1,726 kg N/ha reported for the GPNA (Kaye and Hart 1998). During a precipitation-free period in June, gravimetric soil moisture of the upper 15 cm was only 0.7% by weight and 0.6% by volume. Soil pH was slightly below neutral and is high for the Flagstaff area, comparable to limestone-derived soils near Walnut Canyon National Monument (Abella and Covington 2006a).

While this site occupies a northeastern aspect which tends to be a moist aspect, its upper topographic position and steep slopes may reduce infiltration (Dyer 2002). Inherent soil properties, however, are probably most strongly related to the site's paltry soil moisture (Table 1). While surface soils appear more hospitable for understory plant growth than nearby black cinder soils such as at Sunset Crater National Monument (Hanks et al. 1983), this site does not seem to contain (based on bucket augering) the deep soils often typifying black cinder soils (Abella and Covington 2006a). These deep soils favor root expansion and resource uptake over large soil volumes, often facilitating rapid ponderosa pine diameter growth on black cinder soils, which would not be expected to occur on the shallower soils at this site (Haasis 1921).

Tree Density and Basal Area

Density of live trees in 2004 totaled 190/ha, which included 9 limber pine (*Pinus flexilis* James) and 181 ponderosa pine (Fig. 2). Reconstructed density in 1885 was 183 ponderosa pine/ha, of which 104 were still alive in 2004. This presettlement ponderosa pine density exceeds those previously reported for other sites around Flagstaff and many other areas in northern Arizona. For example, previously reported presettlement densities (ponderosa pine trees/ha) in the Flagstaff area include 54 near Walnut Canyon (Menzel and Covington 1997), 56 at Bar-M-Canyon (Covington and Moore 1994), 60 at the GPNA (Mast et al. 1999), 65 at Camp Navajo (Fulé et al. 1997), and 54-117 at five sites on the Coconino National Forest (Moore et al. 2004). Density at my study site also exceeds those at Mt. Trumbull in northwestern Arizona (14-65 trees/ha; Waltz et al. 2003), and at two Grand Canyon south rim sites (65-72 trees/ha; Fulé et al. 2002). Presettlement density at my site more closely resemble, although are still higher than, north rim sites ranging from 132-156 trees/ha (Fulé et al. 2002). It is unclear why presettlement densities are so high at this site, and it seems particularly unusual because the site's dry soils seem inhospitable to tree establishment (Table 1). Two other sites on red cinder soils near

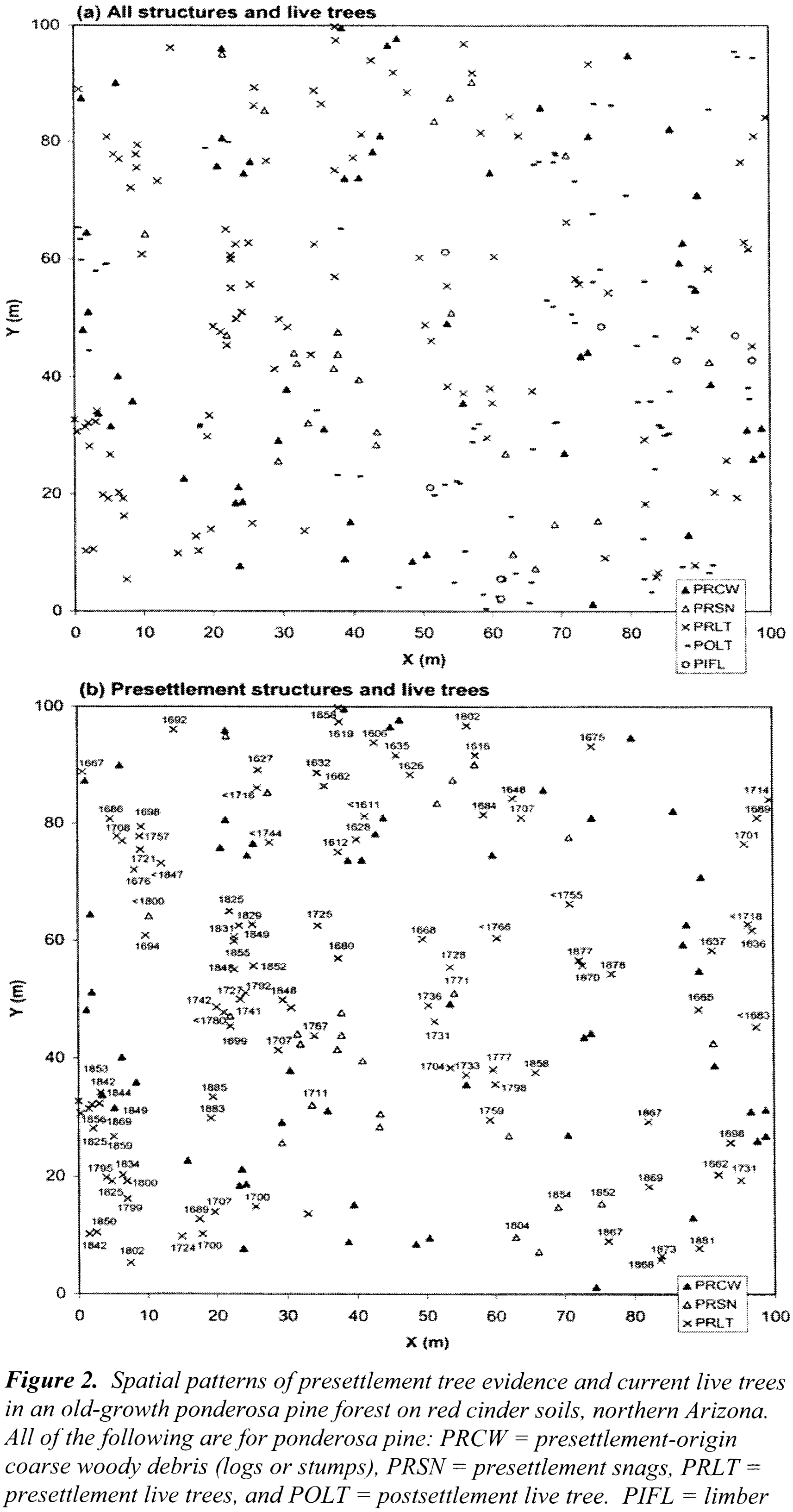

Figure 2. *Spatial patterns of presettlement tree evidence and current live trees in an old-growth ponderosa pine forest on red cinder soils, northern Arizona. All of the following are for ponderosa pine: PRCW = presettlement-origin coarse woody debris (logs or stumps), PRSN = presettlement snags, PRLT = presettlement live trees, and POLT = postsettlement live tree. PIFL = limber pine. In (b), establishment dates are shown for presettlement ponderosa pine snags and live presettlement trees that were able to be dated. Dates correspond to a coring height of 40 cm, and < indicates that a tree established before that date but a complete core could not be obtained.*

Flagstaff had low presettlement densities of 17 and 28/ha (S. R. Abella, unpubl. data).

I encountered only five stumps/ha (Fig. 2), two of which I noted difficulty in determining whether the trees had been cut or had broken off, suggesting that this minimal harvest or snag-felling level is similar to that reported for the GPNA (Covington et al. 1997). It is possible that the site's relatively steep slopes and only small-medium sized trees forestalled tree harvesting. There were an additional 49 fallen logs/ha of probable presettlement origin, and 25 snags/ha of presettlement origin.

Contemporary and reconstructed 1885 basal area both averaged 15 m^2/ha. Density of trees >40 cm DBH increased from 44/ha in 1885 to 51/ha in 2004 (Fig. 3). The largest live tree in 2004 had a DBH of 72 cm, with the largest tree in 1885 having an 80-cm DBH.

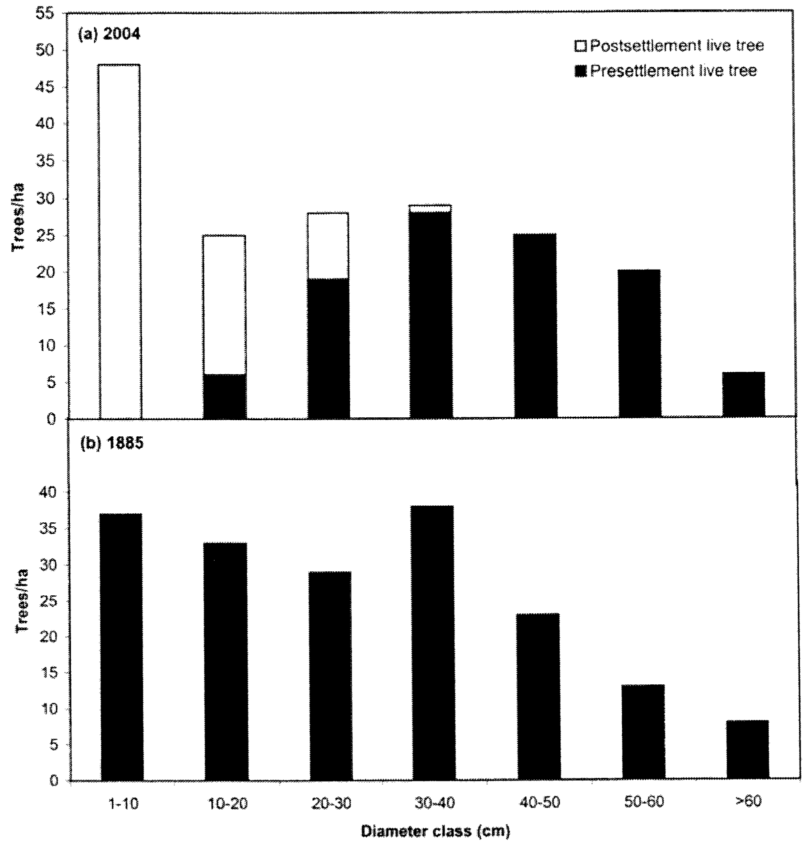

Figure 3. *Diameter distributions in 2004 and reconstructed for 1885 at the time of Euro-American settlement for an old-growth ponderosa pine forest on red cinder soils, northern Arizona. All trees included in the distributions are ponderosa pine.*

Twenty-one live trees of presettlement origin and five snags exhibited fire scarring (Fig. 1c) on the 1-ha plot. While fire-history reconstruction was not undertaken in this study, other research has found that fire-return intervals were generally <15 years in southwestern ponderosa pine forests (Swetnam and Baisan 1996, Fulé et al. 1997). The high density of fire scars on the site, which all occurred on the uphill side of boles, could reflect especially frequent fire possibly due to topography or dry soils, high densities of remaining presettlement live trees and snags, or other factors (Gutsell and Johnson 1996).

Tree Age Structure

Of 152 cored live trees or recent snags, complete cores could be obtained from 137, partial cores to establish minimum ages of 10, and five cores were rotten or otherwise could not be read. Of 104 live presettlement trees, complete cores were obtained from 92, partial from 9, and only 3 trees had unreadable cores. Age structure in 2004 of all live trees indicated that some decades were better represented than others (Fig. 4a). Thirty-six (35%) of the 104 live presettlement trees established before 1700, and 32 (31%) established between 1700 and 1800. The oldest tree able to be dated had a center date of 1606 (age = 399 years) at 40 cm height, and a 72-cm DBH tree had a partial core dated to 1766 and an estimated establishment date using DBH of 1585 (age = 420 years). In their compilation of oldest known conifers, Swetnam and Brown (1992) reported that a ponderosa pine near Littlefield, AZ, was established in 1243 (age = 742 years at the time of sampling).

In both the 2004 and reconstructed 1885 age structures, decades with an absence of trees do not necessarily imply that no trees established during those decades. Trees may have established but were dead in 2004 or 1885 and thus were not part of the live tree age structure. In the reconstructed 1885 age structure, however, 27 of the 29 decades between 1600 and 1890 had dated trees that established (Fig. 4b). Both remaining decades had trees that were estimated to have established based on DBH-age relationships. Presettlement tree establishment at this site was much more prolific with fewer establishment-free periods than was discovered at the GPNA (Mast et al. 1999). At the GPNA, Mast et al. (1999) found that age structure in 1876 contained three decades (midpoints of 1605, 1755, and 1765) from 1600 to 1880 in which no trees established. These researchers also sampled 4.7 ha compared to

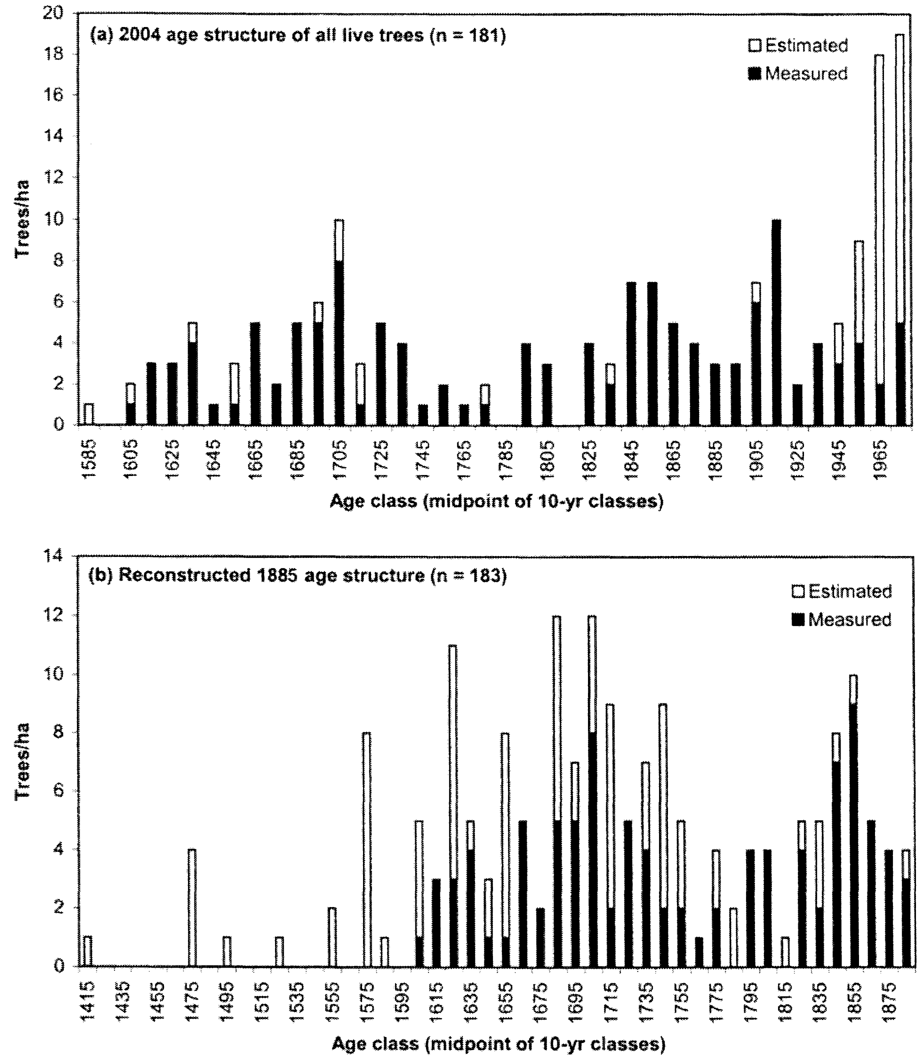

Figure 4. *Age structure in 2004 and reconstructed for 1885 at the time of Euro-American settlement for an old-growth ponderosa pine forest on red cinder soils, northern Arizona. "Measured" indicates trees for which increment cores were collected, and "estimated" indicates trees whose ages were estimated from diameter. Ages represent center dates at the coring height of 40 cm.*

1 ha in my study, amplifying my findings because greater sample area would be expected to increase probabilities of encountering trees establishing in different decades. However, owing to the higher presettlement tree density on my site, the number of trees included in the presettlement age reconstructions are comparable (203 in Mast et al. [1999] and 183 in my study). From the 1550s to 1870s, Mast et al. (1999) reported a maximum establishment of 3.6 trees/ha/decade. The average establishment of 5.2 trees/ha/decade in the 33 decades during this period at my site is higher than the GPNA maximum. However, similar to the GPNA (White 1985, Mast et al. 1999), I found that presettlement trees occurred in uneven-aged groups, often with large differences in establishment dates between nearby trees (Fig. 1b).

Although presettlement establishment density and constancy differed between the GPNA and my site, general peaks of establishment were temporally similar at the two sites. At the GPNA, a peak in establishment occurred between 1680 and 1720 (Mast et al. 1999), which also corresponded with elevated establishment densities at my site (Fig. 4b). However, these regeneration patterns were not easily related to the Palmer Drought Severity Index (Cook 2000), with correlations (Pearson r) of < 0.10 for tree establishment densities in 10- or 20-year increments. This finding is similar to the GPNA results of Mast et al. (1999), who suggested that combining more detailed climatic patterns with fire frequencies and other factors may be needed to explain temporal patterns of presettlement tree

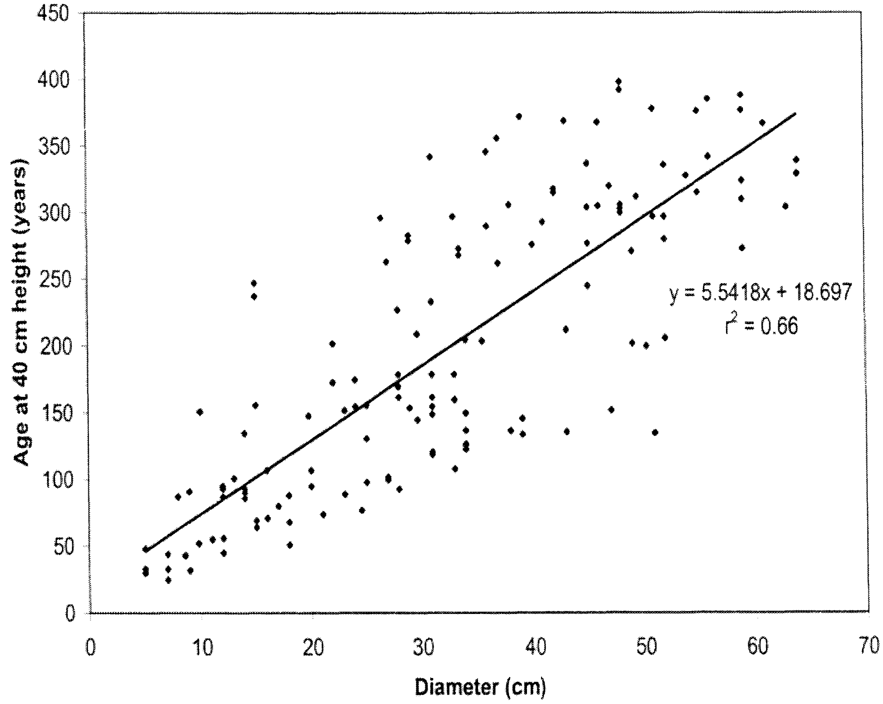

Figure 5. *Diameter-age relationships for 137 trees for which complete cores were obtained in an old-growth ponderosa pine forest on red cinder soils, northern Arizona. Diameters were measured at a height of 1.37 m.*

regeneration. In contrast, Boyden et al. (2005) con cluded that tree establishment was generally related to wet years, as estimated by the Palmer Drought Severity Index, in an old-growth Colorado Front Range ponderosa pine stand.

Tree Growth

DBH-age relationships indicate that tree growth has been slow on this site (Fig. 5), consistent with the site's dry, gravelly soils (Table 1) and possibly with intraspecific competition related to high presettlement tree densities. For example, a 67-cm DBH tree is predicted to be 390 years old at stump height. In comparison, Stone et al. (1999) found that 20 presettlement trees averaging 67-cm DBH averaged only 198 years old on productive soils at the GPNA.

Understory Community

The 0.05-ha sample plot contained 32 plant species, all of which are classified by USDA-NRCS (2004) as native (Table 2). At a finer scale, richness averaged 3.4 species/m^2. This richness is relatively low, with richness averaging 5.9 species/m^2 at other sites of the red cinders/*Bahia* ecosystem and as high as 9.7 species/m^2 in open park grassland ecosystems surrounding Flagstaff (Abella and Covington 2006a). Species composition was dominated by mountain muhly (*Muhlenbergia montana* [Nutt.] A.S. Hitchc.), a C_4 photosynthetic species predicted to thrive on dry sites (Sage and Monson 1999). Other species also frequent in sandy or dry environments in this region typified species composition (Abella and Covington 2006b), such as blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), Fendler's sandmat (*Chamaesyce fendleri* [Torr. & Gray] Small), sand-dune wallflower (*Erysimum capitatum* [Dougl. ex Hook.] Greene), and ragleaf bahia (*Bahia dissecta* [Gray] Britt.).

There was no visual indication during plot sampling of large ungulate grazing at the site, and no known nearby water sources. However, it is unclear how well current plant composition represents presettlement composition for at least two potential reasons. It is possible that past livestock grazing changed species composition (Clary 1975). Additionally, fire exclusion since settlement may have affected composition (Laughlin et al. 2004). Nevertheless, current composition seemingly is consistent with species photosynthetic pathways and tolerances for these dry, infertile soils.

SUMMARY AND CONCLUSION

Several characteristics of this site, such as pre-settlement tree density, soil properties, and understory

Table 2. *Relative cover of understory plant species on a 0.05-ha plot in an old-growth ponderosa pine forest on red cinder soils, northern Arizona.*

Species	RC (%)[1]
Muhlenbergia montana	63
Psoralidium lanceolatum	8
Elymus elymoides	7
Poa fendleriana	5
Stephanomeria spp.	4
Erigeron spp.	3
Bouteloua gracilis	2
Chaetopappa ericoides	2
Chamaesyce fendleri	2
Bahia dissecta	1
Erysimum capitatum	1
Oxytropis lambertii	1
23 others	2

[1] RC = relative cover, summing to 100% for all species on a plot basis. Total plot cover was 12%.

composition, sharply differed from another old-growth site near Flagstaff, the intensively researched GPNA (e.g., Covington et al. 1997, Kaye and Hart 1998, Mast et al. 1999). The site described in this study is unique because it: occupies extremely dry red cinder soils which are rare in the Flagstaff area, contained an exceptionally high ponderosa pine presettlement density (183/ha), exhibited a tree establishment pattern fairly constant over time in presettlement forests, is characterized by unusually slow tree growth rates for this region, currently has an uncommonly high density of live presettlement-origin trees (104/ha) including 36/ha that established before 1700, has a high density (26/ha) of fire-scarred trees or snags, and displays a unique plant species composition with a predominately xeric affinity.

Red cinders/*Bahia* ecosystems, of which this site is a member, historically were rare and are currently rare based on their soils distribution (Abella and Covington 2006a). Soils supporting this ecosystem type occupy <1840 ha (<1.7%) of the north half of the Coconino National Forest (Miller et al. 1995). About 9/32 (28%) of this ecosystem's mapping units (>30% of its area) also have been burned by crown fires since 1950 (Coconino National Forest, Flagstaff, AZ, unpubl. data). Attention could be given to performing restoration or fuel reduction treatments to protect remaining sites from crown fire. Based on the large differences between this old-growth site and the GPNA, sampling other old-growth forests, if and where they exist, on other soil types may facilitate better understanding, definition, and identification of old forests in this region..

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LITERATURE CITED

ABELLA, S. R. 2004. Tree thinning and prescribed burning effects on ground flora in Arizona ponderosa pine forests: A review. *Journal of the Arizona-Nevada Academy of Science* 36:68-76.

ABELLA, S. R., and W. W. COVINGTON. 2006a. Forest ecosystems of an Arizona *Pinus ponderosa* landscape: Multifactor classification and implications for ecological restoration. *Journal of Biogeography* 33:1368-1383.

ABELLA, S. R., and W. W. COVINGTON. 2006b. Vegetation-environment relationships and ecological species groups of an Arizona *Pinus ponderosa* landscape, USA. *Plant Ecology* 185:255-268.

ALLEN, C. D., M. SAVAGE, D. A. FALK, K. F. SUCKLING, T. W. SWETNAM, T. SHULKE, P. B. STACEY, P. MORGAN, M. HOFFMAN, and J. T. KLINGEL. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: A broad perspective. *Ecological Applications* 12:1418-1433.

BARNES, B. V. 1989. Old-growth forests of the northern lake states: A landscape ecosystem perspective. *Natural Areas Journal* 9:45-57.

BECKMAN, J. S., and J. B. MITTON. 1984. Peroxidase allozyme differentiation among successional stands of ponderosa pine. *American Midland Naturalist* 112:43-49.

BOYDEN, S., D. BINKLEY, and W. SHEPPERD. 2005. Spatial and temporal patterns in structure, regeneration, and mortality of an old-growth ponderosa pine forest in the Colorado Front Range. *Forest Ecology and Management* 219:43-55.

BRADY, N.C., and R. R. WEIL. 1999. *The Nature and Properties of Soils.* Prentice Hall, Inc., Upper Saddle River, NJ. 881 pp.

CLARY, W. P. 1975. *Range Management and its Ecological Basis in the Ponderosa Pine Type of Arizona: The Status of Our Knowledge.* Research Paper RM-158, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 35 pp.

COOK, E.R. 2000. *Southwestern USA Drought Index Reconstruction. International Tree-Ring Data Bank.* NOAA/NGDC Paleoclimatology Program, Boulder, CO.

COVINGTON, W. W., and M. M. MOORE. 1994. Postsettlement changes in natural fire regimes and forest structure: Ecological restoration of old-growth ponderosa pine forests. *Journal of Sustainable Forestry* 2:153-181.

COVINGTON, W. W, P. Z. FULÉ, M. M. MOORE, S. C. HART, T. E. KOLB, J. N. MAST, S. S. SACKETT, and M. R. WAGNER. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. *Journal of Forestry* 95:23-29.

DANE, J. H., and G. C. Topp, eds. 2002. *Methods of Soil Analysis. Part 4. Physical Methods.* Soil Science Society of America, Madison, WI. 1692 pp.

DAVIS, M. B., ed. 1996. *Eastern Old-Growth Forests: Prospects for Rediscovery and Recovery.* Island Press, Washington, D.C. 383 pp.

DYER, J. M. 2002. Comparison of moisture scalars and water budget methods to assess vegetation-site relationships. *Physical Geography* 23:245-258.

FULÉ, P. Z., W. W. COVINGTON, and M. M. MOORE. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. *Ecological Applications* 7:895-908.

FULÉ, P. Z., W. W. COVINGTON, M. M. MOORE, T. A. HEINLEIN, and A. E. M. WALTZ. 2002. Natural variability in forests of the Grand Canyon, USA. *Journal of Biogeography* 29:31-47.

GOH, T. B., R. J. ST. ARNAUD, and A. R. MERMUT. 1993. Carbonates. Pp. 177-185 *in* M. R. Carter, ed., *Soil Sampling and Methods of Analysis.* Lewis Publishers, Boca Raton, FL. 823 pp.

GRISSINO-MAYER, H. D., T. W. SWETNAM, and R. K. ADAMS. 1997. The rare, old-aged conifers of El Malpais – their role in understanding climatic change in the American Southwest. *New Mexico Bureau of Mines and Mineral Resources Bulletin* 156:155-161.

GUTSELL, S. L., and E. A. JOHNSON. 1996. How fire scars are formed: Coupling a disturbance process to its ecological effect. *Canadian Journal of Forest Research* 26:166-174.

HAASIS, F. W. 1921. Relations between soil type and root form of western yellow pine seedlings. *Ecology* 2:292-303.

HABECK, J. R. 1990. Old-growth ponderosa pine-western larch forests of western Montana: Ecology and management. *Northwest Environmental Journal* 6:271-292.

HANKS, J. P., E. L. FITZHUGH, and S. R. HANKS. 1983. *A Habitat Type Classification System for Ponderosa Pine Forests of Northern Arizona.* General Technical Report RM-97. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 22 pp.

HYNDMAN, D. H. 1985. *Petrology of Igneous and Metamorphic Rocks.* McGraw-Hill Book Co., New York. 786 pp.

KAYE, J. P., and S. C. HART. 1998. Ecological restoration alters nitrogen transformations in a ponderosa pine-bunchgrass ecosystem. *Ecological Applications* 8:1052-1060.

KEDDY, P. A., and C. G. DRUMMOND. 1996. Ecological properties for the evaluation, management, and restoration of temperate deciduous forest ecosystems. *Ecological Applications* 6:748-762.

LAUGHLIN, D. C., J. D. BAKKER, M. T. STODDARD, M. L. DANIELS, J. D. SPRINGER, C. N. GILDAR, A. M. GREEN, and W. W. COVINGTON. 2004. Toward reference conditions: Wildfire effects on flora in an old-growth ponderosa pine forest. *Forest Ecology and Management* 199:137-152.

LAUGHLIN, D. C., M. M. MOORE, J. D. BAKKER, C. A. CASEY, J. D. SPRINGER, P. Z. FULÉ, and W. W. COVINGTON. 2006. Assessing targets for the restoration of herbaceous vegetation in ponderosa pine forests. *Restoration Ecology* 14:548-560.

MAST, J. N., P. Z. FULÉ, M. M. MOORE, W. W. COVINGTON, and A. E. M. WALTZ. 1999. Restoration of presettlement age structure of an Arizona ponderosa pine forest. *Ecological Applications* 9:228-239.

MENZEL, J. P., and W. W. COVINGTON. 1997. Changes from 1876 to 1994 in a forest ecosystem near Walnut Canyon, northern Arizona. Pp. 151-172 in C. Van Ripler and E. T. Deshler, eds., *Proceedings of the Third Biennial Conference of Research on the Colorado Plateau. Transactions and Proceedings Series NPS/NRNAU/NRTP-97/12,* U.S. Department of the Interior, National Park Service. 256 pp.

MILLER, G., N. AMBOS, P. BONESS, D. REYHER, G. ROBERTSON, K. SCALZONE, R. STEINKE, and T. Subirge. 1995. *Terrestrial Ecosystems Survey of the Coconino National Forest.* USDA Forest Service, Southwestern Region. 405 pp.

MOORE, M. M., D. W. HUFFMAN, P. Z. FULÉ, W. W. COVINGTON, and J. E. CROUSE. 2004. Comparison of historical and contemporary forest struc-

ture and composition on permanent plots in southwestern ponderosa pine forests. *Forest Science* 50:162-176.

MORGAN, T. A., C. E. FIEDLER, and C. WOODALL. 2002. Characteristics of dry site old-growth ponderosa pine in the Bull Mountains of Montana, USA. *Natural Areas Journal* 22:11-19.

MYERS, C. A. 1963. *Estimating past Diameters of Ponderosa Pine in Arizona and New Mexico.* Research Note RM-7. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 4 pp.

ROGERS, J. J., J. M. PROSSER, L. D. GARRETT, and M.G. RYAN. 1984. *ECOSIM: A System for Projecting Multiresource Outputs under Alternative Forest Management Regimes. Administrative Report.* USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 167 pp.

SAGE, R. F., and R. K. MONSON, eds. 1999. *C_4 Plant Biology*. Academic Press, New York. 596 pp.

SPARKS, D. L., ed. 1996. *Methods of Soil Analysis. Part 3. Chemical Methods.* Soil Science Society of America and American Society of Agronomy, Madison, WI. 1390 pp.

STOKES, M. A., and T. L. SMILEY. 1968. *Introduction to Tree-ring Dating.* University of Chicago Press, Chicago, IL. 73 pp.

STONE, J. E., T. E. KOLB, and W. W. COVINGTON. 1999. Effects of restoration thinning on presettlement *Pinus ponderosa* in northern Arizona. *Restoration Ecology* 7:172-182.

SWETNAM, T. W., and C. H. BAISAN. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. Pp. 11-32 *in* C. D. Allen, tech. ed., *Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium.* General Technical Report RM-GTR-286. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 216 pp.

SWETNAM, T. W., and P. M. BROWN. 1992. Oldest known conifers in the southwestern United States: temporal and spatial patterns of maximum age. Pp. 24-38 *in* M. R. Kaufmann, W. H. Moir, and R. L. Bassett, tech. coords., *Old-Growth Forests in the Southwest and Rocky Mountain Regions: Proceedings of a Workshop.* General Technical Report RM-213. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 201 pp.

USDA-NRCS. 2004. *The PLANTS Database, Version 3.5.* National Plant Data Center, Baton Rouge, LA.

WALTZ, A. E. M., P. Z. FULÉ, W. W. COVINGTON, and M. M. MOORE. 2003. Diversity in ponderosa pine forest structure following ecological restoration treatments. *Forest Science* 49:885-900.

WELCH, T. G., and J. O. KLEMMEDSON. 1975. Influence of the biotic factor and parent material on distribution of nitrogen and carbon in ponderosa pine ecosystems. Pp. 159-178 *in* B. Bernier and C. H. Winget, eds., *Forest Soils and Forest Land Management.* Les Presses de l'Universite' Laval, Quebec. 675 pp.

WHITE, A. S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. *Ecology* 66:589-594.