93 Years of Stand Density and Land-Use Legacy Research at the Coulter Ranch Study Site

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Abstract—In 1913, the Fort Valley Experimental Forest initiated an unprecedented case-study experiment to determine the effects of harvesting methods on tree regeneration and growth on a ponderosa pine-Gambel oak forest at Coulter Ranch in northern Arizona. The harvesting methods examined were seed-tree, group selection, and light selection. In addition, the effects of livestock grazing (excluded or not) were examined. We revisited the Coulter Ranch Study Site to examine the effects of these treatments on historical (1913) and contemporary (2003-2006) stand density and tree size. The key finding was that while initial 1913 harvests reduced average pine density by one- to two-thirds, tree densities increased from three to nine times those prior to harvest over the 93-year period. The greatest increase was in the seed-tree method.

Introduction

In 1913, Fort Valley Experimental Forest (FVEF) initiated an experiment to determine the effects of different timber harvesting methods on regeneration and growth of a ponderosa pine (*Pinus ponderosa* Laws. *scopulorum* Engelm.)–Gambel oak (*Quercus gambelii* Nutt.) site in northern Arizona (Krauch 1916, 1937; Pearson 1923). We investigated how three of these harvesting methods influenced tree density and size over a 93-year period. We had four questions: (1) What was stand density like immediately before the 1913 timber harvest? (2) How were stand density and mean tree size affected by each harvest method? (3) How have stand density and mean tree size changed over the long-term, as observed in 2003-2006? (4) How did livestock grazing influence contemporary stand density?

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Methods

Study Site and Plot Description

This study was conducted on a 162-ha (400-ac) site located 21 km south of Flagstaff, Arizona on the Coconino National Forest (Figure 1); latitude 35°0.91' N, longitude 111°36.26' W. Ponderosa pine and Gambel oak are the dominant trees, with scattered New Mexican locust (*Robinia neomexicana* Gray) thickets and single alligator junipers (*Juniperus deppeana* Steud.) occurring throughout the study area. The site (Figure 2) was established in 1913 as part of the FVEF by Hermann Krauch (Forest Examiner) and C.F. Korstian (Silviculturist), who initially divided the site into four harvesting systems: Scattered Seed-tree (61 ha or ~151 ac), Group selection (56 ha or ~138 ac), Light selection (45 ha or ~111 ac; originally called "Shelterwood" but later changed as the prescription was altered; essentially the same as the group selection except more mature trees were left), and the Wagner border method (not examined in this study). Their goals were to examine the effects of harvesting, grazing, and slash disposal methods on advanced regeneration, new seedling establishment, and residual tree growth (Krauch 1916, 1933, 1937; Lexen 1939; Pearson 1923, 1944, 1950).

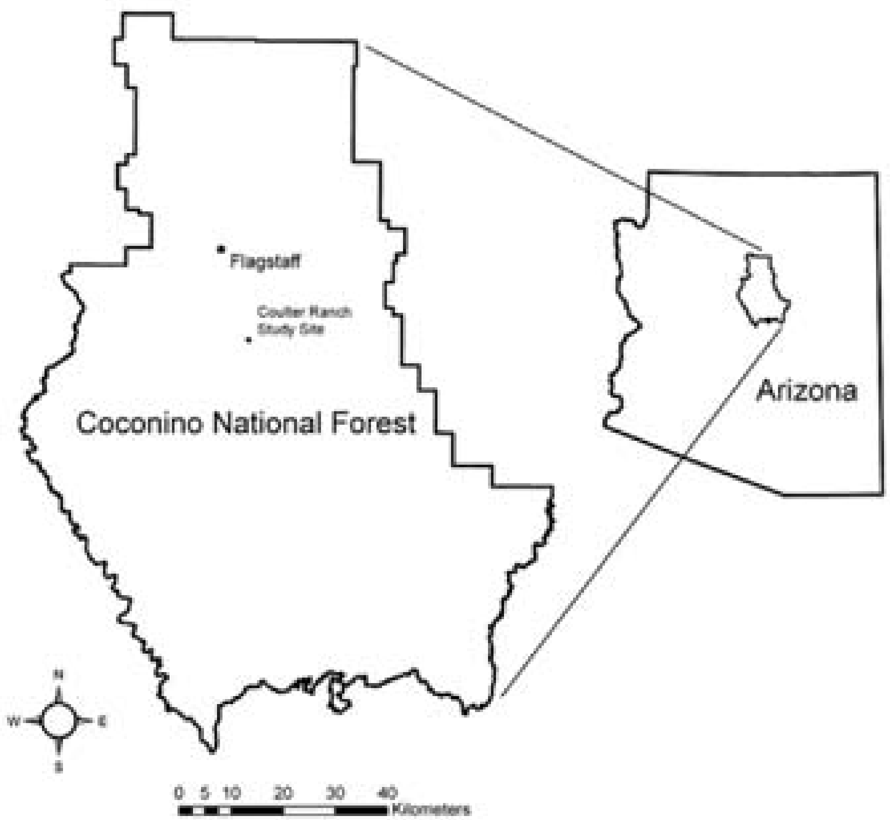

Figure 1. Location of the Coulter Ranch Study Site on the Coconino National Forest in northern Arizona.

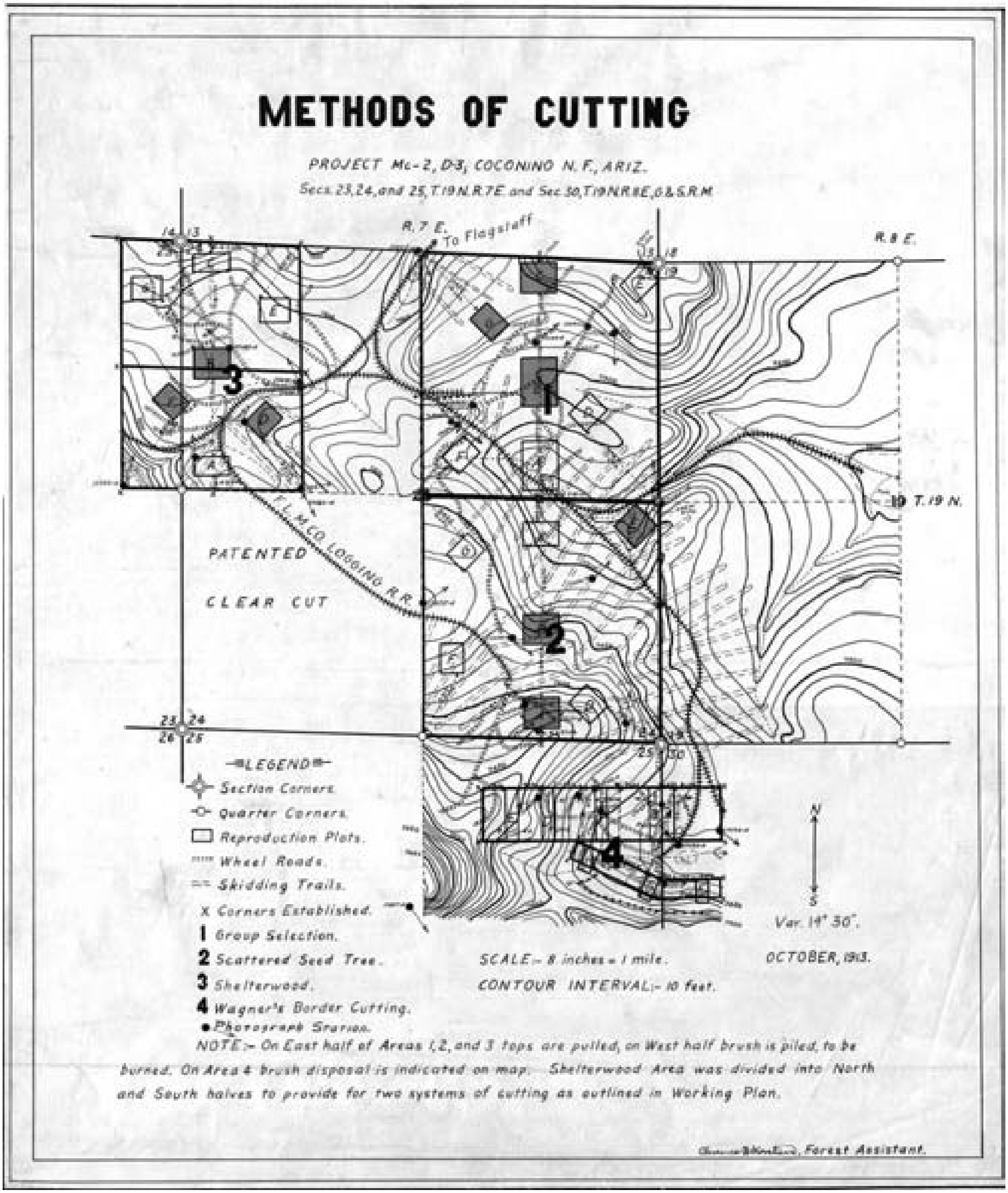

Figure 2. Original site map created by C.F. Korstian in 1913. This map shows several features including the harvesting treatment, repeat photography stations, topography, skid trails, and permanent sample plots (called "reproduction plots"). The nine plots remeasured for this study are shaded (dark grey).

Table 1. Plot descriptions and management histories for nine historical permanent plots established in 1913 at Coulter Ranch, Coconino National Forest (Arizona).

Plot	Size (ha)	Elevation (m)	TEU[a]	Livestock Excluded?[b]	Harvesting System
S5A2	1.2	2300	585	N	Seed-tree
S5B2	1.2	2272	585	Y	Seed-tree
S5E2	1.0	2239	582/585	Y	Seed-tree
S5B1	1.9	2260	585/586	Y	Group selection
S5C1	1.2	2272	585	N	Group selection
S5G1	0.8	2267	585	N	Group selection
S5B3	1.2	2255	582/585	Y	Light selection
S5D3	0.8	2262	585	N	Light selection
S5F3	0.8	2255	585	N	Light selection

[a] Terrestrial Ecosystem Unit (Miller and others 1994). The corresponding soil orders are: 582 = Typic Argiborolls and Mollic Eutroboralfs; 585 = Lithic Eutroboralfs; 586 = Mollic Eutroboralfs and Lithic Eutroboralfs.
[b] Sites excluded from livestock grazing by fencing in 1919.

Twenty-one permanent, stem-mapped plots were established; seven per harvesting system. In this study, we examined nine plots (Table 1), ranging in size from 0.8 to 1.9 ha. We selected the largest plots, and also made sure that one plot per harvesting system had been excluded from grazing. Plots are identified using the original FVEF naming system (Figure 2), which used a combination of letters and numbers representing the silvicultural unit (S5, Coulter Ranch), the harvesting system or method (Group selection = 1, Seed-tree = 2, or Light selection = 3) and individual permanent plot designations (A, B, ..., G).

Field Measurements

Historical (1913) and contemporary (2003-2006) field methods for measuring these plots are detailed by Moore and others (2004). Contemporary species identity and diameter at breast height (DBH; 1.37 m aboveground) data for all live and dead (stumps, snags, logs) trees were obtained in the 2003-2006 field seasons. Historical (1913) individual tree data were obtained from the plot ledgers located at the USFS RMRS Fort Valley Archives (Flagstaff, AZ). All analyses focus on trees ≥ 9.14 cm (3.6 inch) DBH.

Analyses

To quantify how stand density changed in the short-term (immediately following harvesting in 1913) and over the long-term (2003-2006; 93 years later), we examined changes in the mean number of trees per hectare and basal area (m^2 ha^{-1}) by tree species by harvest method. In addition, we were interested in how the stand density may have looked in the absence of timber harvesting in 1913, so we obtained an estimate of tree density and basal area in the absence of harvesting by adding the number and size of older cut stumps to the living tree data of 1913. Reconstruction model assumptions and details regarding the methods used to determine how the stand density may have looked in the absence of timber harvesting and the number of oak present at the time of harvest are found in Sánchez Meador (2006) and Sánchez Meador and others (2008).

To summarize, we examined the following three stand structural scenarios on each plot: (1) '1913 unharvested' (stand density as if harvesting had not occurred in 1913); (2) '1913 harvested' (actual 1913 stand density); and (3) 'contemporary' (actual 2003-2006 stand density) for each harvest method.

Results

While the 1913 harvest reduced average pine density (for tree ≥ 9.14 cm DBH) by one- to two-thirds (Figure 3), tree densities at the end of the 93-year period were three (Light selection) to nine (Seed-tree) times higher than those observed prior to harvest. Reconstructed (1913) tree density was highest on S5C1 (164 trees ha^{-1})

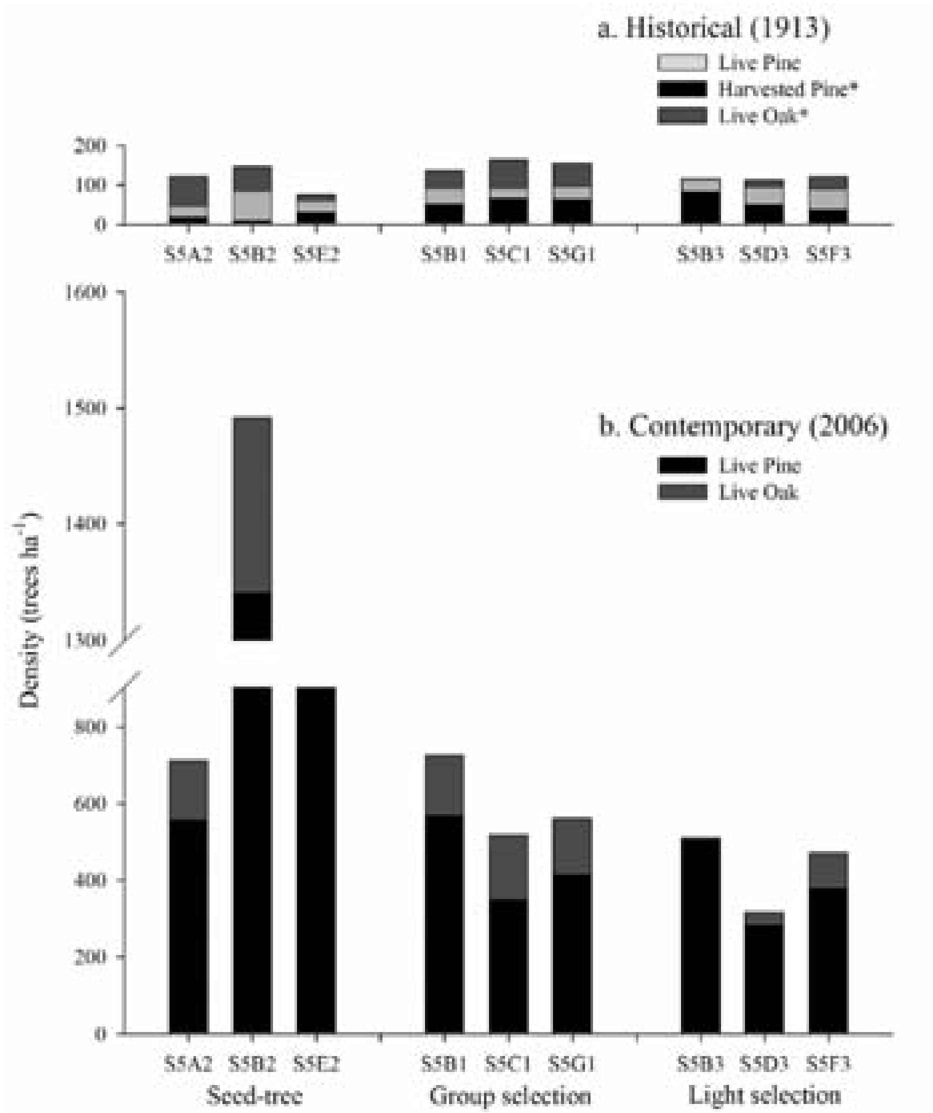

Figure 3. Historical (a) and Contemporary (b) tree density (tree ha^{-1}) for ponderosa pine and reconstructed Gambel oak trees (≥ 9.14 cm DBH) on plots at the Coulter Ranch Study Site. Historical densities include trees that were reconstructed because they were either harvested prior to (Harvested Pine* - light grey) or not measured at the time of plot establishment (Live Oak* - dark grey).

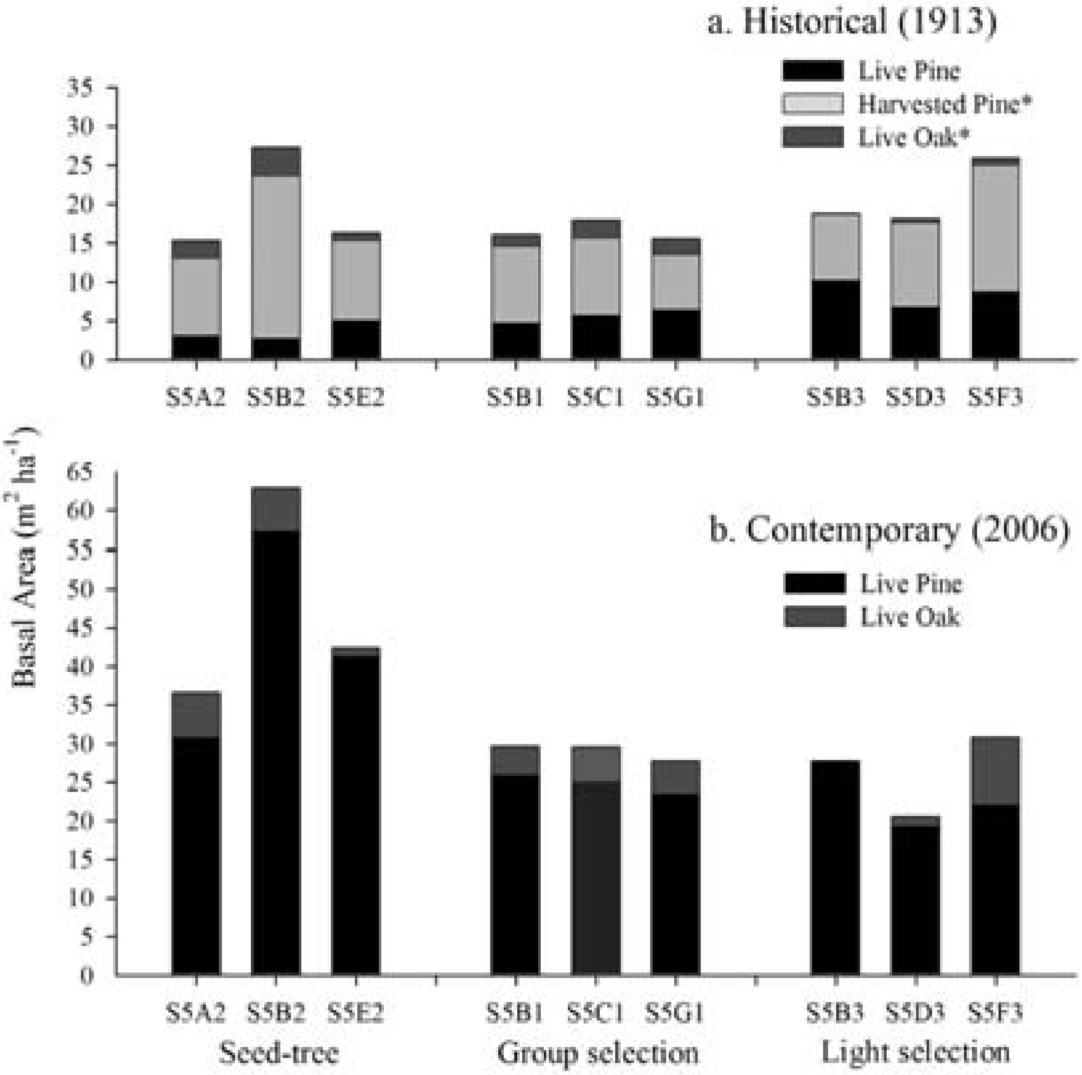

Figure 4. Historical (a) and Contemporary (b) stand basal area (m^2 ha^{-1}) for ponderosa pine and reconstructed Gambel oak trees (≥ 9.14 cm DBH) on plots at the Coulter Ranch Study Site. Historical stand basal area includes trees that were reconstructed because they were either harvested prior to (Harvested Pine* - light grey) or not measured at the time of plot establishment (Live Oak* - dark grey).

and was lowest on S5E2 (75 trees ha^{-1}). Similar trends were observed for mean basal area (e.g., Figures 3 & 4) and DBH (not shown), which prior to harvest were 19.0 m^2 ha^{-1} (s = 4.5) and 38.3 cm (s = 7.5), respectively. Contemporary mean basal area and DBH for all plots (regardless of grazing history) had increased to 34.2 m^2 ha^{-1} (s = 12.4) and decreased to 21.0 cm (s = 5.1), respectively. Contemporary (2003-2006) tree density was highest on S5B2 (1492 trees ha^{-1}), lowest on S5D3 (317 trees ha^{-1}), and found to be higher on plots where livestock grazing was excluded (e.g., Figure 5), regardless of harvesting method.

Figure 5. 1913 (left) and 2006 (right) photographs taken on S5B3 (Light selection System). The circles indicate the plot corner in each photo. Note the even-aged recruitment in foreground near plot corner, general increases in tree density, the complete decomposition of logging slash, and increased numbers of small trees throughout. The 1913 photo was taken by H. Krauch (USFS photo 17011A), and the 2006 photo by A.J. Sánchez Meador.

Discussion and Conclusions

Overall, both pine and oak densities increased with each harvesting system, but the seed-tree had the largest increase and the light selection had the least. Previous research on these sites showed that pine recruitment, over the past 93 years, occurred commonly in interspaces or canopy gap (e.g., Figure 6) and away from older, live trees or residual tree patches (Sánchez Meador and others 2008).

The tree density differences observed in the harvest methods are not surprising, though there are few long-term studies that quantify these differences. The Seed-tree method essentially removed the overstory, leaving only a few widely spaced trees to provide for uniformly distributed seed. Drastically opening the tree canopy, and increased disturbance to the forest floor by the harvest itself, likely increased the sites for ponderosa pine seedlings to establish. The Light group selection method, on the other hand, harvested mature and older pines, either isolated or in groups.

Figure 6. 1913 (left) and 2006 (right) photographs taken on S5B2 (Seed-tree system). The circles indicate the plot corner in each photo. Note the increased numbers of small trees in 2006, the presence of ladder fuels, the complete decomposition of logging slash, and loss of herbaceous plants in the understory. The 1913 photo was taken by H. Krauch (USFS photo 16976A), and the 2006 photo by A.J. Sánchez Meador.

These overall increases in tree density are consistent with the structural changes in ponderosa pine ecosystems reported throughout Arizona (Fulé and others 1997, Mast and others 1999, Moore and others 2004). Contemporary stand conditions (increased density and smaller trees) most likely resulted from numerous pulses of pine establishment in the early 1900s (Savage and others 1996, Sánchez Meador and others 2008) following heavy livestock grazing and intensive harvesting (e.g., seed-tree or clearcut systems). Intense grazing provided favorable seedbeds for seedling establishment, similar to those created historically by fire or more recently by harvesting, and when combined with fire exclusion would allow an unusually high density of trees to become established and persist (Bakker and Moore 2007, Cooper 1960, Mast and others 1999, White 1985).

Although we found differences in tree densities among the harvest treatments in 1913 and 2003-2006, and also differences due to livestock grazing, we must interpret these results with caution. Our ability to draw causal inferences is limited by the lack of treatment replication, which is a common problem in assessing change using retrospective studies (Carpenter 1990) and with case studies in general.

In addition, we also note that the 1913 reconstructed data (unharvested scenario) do not represent presettlement reference conditions (Kaufmann and others 1994, Fulé and others 1997, Moore and others 1999). The 1913 unharvested scenarios embodies some 30+ years of fire exclusion and intense livestock grazing.

Despite the cautions and limitations, historical permanent plot data can provide unique opportunities to quantify temporal and spatial changes in forest structure, and to determine the impacts of past land-use (harvesting, livestock grazing, fire exclusion), natural disturbances, and climate.

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References

Bakker, J.D.; Moore, M.M. 2007. Controls on vegetation structure in southwestern ponderosa pine forests, 1941 and 2004. Ecology. 88: 2305-2319.

Carpenter, S.R. 1990. Large-scale perturbations: opportunities for innovation. Ecology. 71: 2038-2043.

Cooper, C.F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecological Monographs. 30: 129-164.

Fulé, P.Z.; Covington, W.W.; Moore, M.M. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications. 7: 895-908.

Kaufmann, M.R.; Graham, R.T.; Boyce, D.A., Jr.; Moir, W.H.; Perry, L.; Reynolds, R.T.; Bassett, R.L.; Mehlhop, P.; Edminster, C.B.; Block, W.M.; Corn, P.S. 1994. An ecological basis for ecosystem management. Gen. Tech. Rep. RM-246. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p.

Krauch, H. 1916 .Report on Project Mc-2-D-3 “Different methods of cutting,” Coconino National Forest. Unpub. Pap. on file at Flagstaff, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Valley Experimental Forest archives.

Krauch, H. 1933. Increment and mortality in cutover stands of ponderosa pine as based on records of permanent sample plots. Report. Washington, D.C.: United States Government Printing Office. 13 p.

Krauch, H. 1937. Growth and yield of cut-over stands of ponderosa pine in Arizona under different methods of cutting. Journal of Forestry. 35: 1134-1147.

Lexen, B.R. 1939. Growth following partial cutting in ponderosa pine. Journal of Forestry. 37: 943-946.

Mast, J.N.; Fulé, P.Z.; Moore, M.M.; Covington, W.W.; Waltz, A.E.M. 1999. Restoration of presettlement age structure of an Arizona ponderosa pine forest. Ecological Applications. 9: 228-239.

Miller, G.; Ambos, N.; Boness, P.; Reyher, D.; Robertson, G.; Scalzone, K.; Steinke, R.; Subirge, T. 1994. Terrestrial ecosystems survey of the Coconino National Forest. Albuquerque, NM, U.S.A.: U.S. Department of Agriculture, Forest Service, Southwestern Region.

Moore, M.M.; Covington, W.W.; Fulé, P.Z. 1999. Reference conditions and ecological restoration: A southwestern ponderosa pine perspective. Ecological Applications. 9: 1266-1277.

Moore, M.M.; Huffman, D.W.; Fulé, P.Z.; Covington, W.W.; Crouse, J.E. 2004. Comparison of historical and contemporary forest structure and composition on permanent plots in southwestern ponderosa pine forests. Forest Science. 50: 162-176.

Pearson, G.A. 1923. Natural reproduction of western yellow pine in the southwest. Bull. 1105. Washington, D.C.: U.S. Department of Agriculture. 143 p.

Pearson, G.A. 1944. Cutting cycles in ponderosa pine. Journal of Forestry. 42: 575-585.

Pearson, G.A. 1950. Management of ponderosa pine in the Southwest. USDA Agri. Mono. 6. Washington, D.C.: United States Government Printing Office. 218 p.

Sánchez Meador, A.J. 2006. Modeling spatial and temporal changes of ponderosa pine forests in northern Arizona since Euro-American settlement. Flagstaff, AZ: Northern Arizona University. 154 p. Ph.D. Dissertation

Sánchez Meador, A.J.; Moore, M.M.; Bakker, J.D.; Parysow, P.F. 2008. 108 years of change in spatial pattern following selective harvest of a ponderosa pine stand in northern Arizona, USA. Journal of Vegetation Science. *In press.*

Savage, M.; Brown, P.M.; Feddema, J. 1996. The role of climate in a pine forest regeneration pulse in the southwestern United States. EcoScience. 3: 310-318.

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