RESEARCH ARTICLE

Assessing the Representativeness of the Oldest Permanent Inventory Plots in Northern Arizona Ponderosa Pine Forests

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Abstract

A network of permanent plots established between 1909 and 1913 (the Woolsey plots) contains the oldest measured data in northern Arizona ponderosa pine forests. These forest inventory data offer a unique opportunity to reconstruct pre-settlement reference conditions, as well as detect and quantify changes in southwestern forest structure and composition. However, the selection of plot locations in the early 1900s followed a subjective nonrandom approach. To assess the applicability, or inference space, of results obtained from these historical plots, we compared their environmental characteristics (terrestrial ecosystem unit [TEU, based on a U.S. Forest Service (USFS) ecological classification system], site index, elevation, insolation index, and soil parent material) as well as contemporary forest structure (trees per hectare, basal area, and quadratic mean diameter) with two large inventory

Introduction

Reference conditions, the characteristics of an ecosystem prior to Euro-American and Hispanic settlement (presettlement), play an important role in guiding ecological restoration activities in the southwestern United States (Kaufmann et al. 1994; Moore et al. 1999; Swetnam et al. 1999; Egan & Howell 2001; Friederici 2003). Many studies have been conducted to reconstruct pre-settlement fire regimes prior to the beginning of settlement in this region (1870s-1890s) based on fire scar and forest structural and dendrochronological evidence (e.g., Swetnam 1990; Covington & Moore 1994; Fulé et al. 1997, 2002; Mast et al. 1999; Moore et al. 1999; Swetnam et al. 1999; Groven et al. 2002). Still, the Southwest is characterized by a great diversity of landscapes and ecosystems (Morgan et al. 1994; White & Walker 1997; Landres et al. 1999), whereas the number and type of sites amenable to pre-settlement reconstruction are limited.

One such set of sites in Arizona and New Mexico dates back to the early days of the U.S. Forest Service (USFS). samples: USFS Forest Inventory and Analysis (FSFIA) and Arizona State Land Department Continuous Forest Inventory (AZCFI). Analytical methods included multivariate permutation tests, ratios of variance, and Kolmogorov–Smirnov two-sample tests. Results indicated that the Woolsey plots (1) were neither historically nor contemporarily representative of the entire study area because of environmental and current forest structural differences with respect to the FSFIA and AZCFI and (2) may be considered historically representative of their corresponding TEUs. Our study supports the use of TEUs for defining the applicability of information obtained from the Woolsey plots.

Key words: ecological classification, historical plots, *Pinus ponderosa*, pre-settlement reference conditions, subjective nonrandom sampling.

The oldest permanent forest inventory system in the Southwest was established by the USFS Southwestern Forest and Range Experiment Station beginning in 1909. These plots, known locally as the Woolsey plots, were part of a silvicultural experiment concerning regeneration and volume accretion of southwestern ponderosa pine (*Pinus ponderosa* var. *scopulorum* P. & C. Lawson) after initial timber harvests (Woolsey 1912; Pearson 1923, 1933; Krauch 1926; Moore et al. 2004).

The wealth of contemporary and historical data associated with the Woolsey plots provides unique opportunities for assessing reference conditions as well as changes that have occurred in southwestern ponderosa pine forest ecosystems since plot establishment (Moore et al. 2004). Specifically, these plots offer a complementary approach to traditional methods for establishing pre-settlement ecosystem structure and/or process. Traditional methods have relied on currently available evidence of live and dead trees, which is particularly problematic when reconstructing populations of small trees or applying techniques over long periods of time (often >100 years; Johnson et al. 1994). Historical plots can reduce such uncertainty by providing actual historical inventory data as well as shortening the reconstruction time span (White & Walker 1997). Other early forest inventories, such as those originally established by T. T. Munger in 1910, have proven vital in

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understanding old-growth forest structure and patterns of mortality in the Pacific Northwest (Duncan 2004).

However, the concept of randomization was not proposed by Sir Ronald Fisher (1925) until after the Woolsey plots were established, and therefore, selection of Woolsey plot locations was conducted in a nonrandom fashion. Subjective plot selection, together with the small sample size of this rare dataset, raises questions about the inference space with regard to the larger, heterogeneous landscape of ponderosa pine forests in northern Arizona.

Assessing representativeness in ecological studies may be strengthened by jointly analyzing relevant variables from independent datasets through multivariate techniques (Sætersdal & Birks 1993). Large, representative inventories conducted independently of the sample of interest may be assumed to supply environmental and contemporary forest structure information for the population from which that sample was taken (Couteron et al. 2003). Two large inventories in Arizona provide important information about environment and forest condition: the USFS Forest Inventory and Analysis (FSFIA) and the Arizona State Land Department Continuous Forest Inventory (AZCFI). The FSFIA program in northern Arizona is conducted by the USFS Interior West Forest Inventory and Analysis Program on both public and private lands, whereas the AZCFI is conducted by the Arizona State Lands Department (ASLD) on State lands.

Assessing representativeness may prove challenging after years of intense and diverse land use (Covington & Moore 1994; Fulé et al. 1997; Allen et al. 1998, 2002). Nevertheless, ecological classification systems (Bailey 1996; Pregitzer et al. 2001) may help us recreate the distribution of ecosystems in pre-settlement landscapes (Bell et al. 1997), thus adding an important piece of information to the assessment of this region's historical range of variability (Morgan et al. 1994; Allen et al. 1998, 2002; Landres et al. 1999). An ecological classification system is a method of assigning areas of land to map units characterized by common factors such as soils, climate, topography, and potential vegetation (Cleland et al. 1997; Kerns et al. 2003). For practical purposes, these units may be assumed to remain constant at spatial scales comprising an ecoregion over roughly one century. It is important to emphasize that these classifications are based on the concept of potential or climax vegetation, even though at certain points in time units may be occupied by other vegetation successional stages caused by disturbances (Demarchi 1996). For example, the Terrestrial Ecosystem Survey (the ecosystem classification system used by the USFS Southwestern Region [region 3]) classifies the landscape into ecological units based on climate, topography, soils, and vegetation at a mapping scale of 1:24,000 (USDA 1986; Miller et al. 1994; Ganey & Benoit 2002). Therefore, these classification systems provide an appealing means of identifying inherent environmental and potential vegetation similarities among areas regardless of their current

vegetation structure and composition (Archambault et al. 1990; Palik et al. 2000; Goebel et al. 2001; Abella 2005).

Defining the forestlands to which information from the Woolsey plots can be applied is a priority because of the unique opportunities these data offer. For instance, we are interested in assessing the ecological pre-settlement similarities between target areas and sites used to derive reference conditions for guiding restoration management. However, historical forest structural data available on the Woolsey plots are missing on other areas. Nevertheless, as mentioned above, environmental conditions may be assumed to have either remained constant or changed equally across this ecoregion over the period that has elapsed since plot establishment. Thus, assessing environmental as well as contemporary forest structural similarities between the Woolsey plots and other populations is essential to understanding the environmental and management influences under which forest structure has developed on these historical plots as well as on nearby populations (Mackey et al. 1988; Neyland et al. 2000). This information would, in turn, allow us to assess applicability of results obtained from the Woolsey plots to those populations. Therefore, the objectives of this study were to (1)develop a framework for assessing representativeness of historical forest inventory plots and (2) implement this framework on a series of forest inventory plots in northern Arizona. Specifically, we hypothesize that the forest structure on the Woolsey plots would be similar to, and thus representative of, other ponderosa pine forests with similar environmental conditions and management regimes.

Methods

Study Area

The spatial extent of the three forest inventories used in this study is shown in Figure 1, which overlap within the Coconino Plateau Coniferous Forest and the San Francisco Peaks Coniferous Forest ecological subsections of the National Hierarchical Framework of Ecological Units (Cleland et al. 1997; W. Robbie 2005, USFS, personal communication). These ecological subsections have similar (but not identical) subregional climatic regimes, geomorphic processes, surficial geology, and lithology. The Woolsey plots were composed of either pure ponderosa pine or ponderosa pine/Gambel oak (Quercus gambelii Nutt.). The majority of FSFIA and AZCFI plots were pure ponderosa pine (69.2 and 78.6%, respectively), whereas the Woolsey plots were evenly divided between pure ponderosa pine and ponderosa pine/Gambel oak. All plots were used regardless of the presence of Gambel oak. To match the overstory composition of the Woolsey plots, FSFIA and AZCFI plots from the upper- and lowerelevation ecotones (adjacent to piñon/juniper and mixedconifer forests) were not included. Under these geographical and compositional limitations, 14 Woolsey, 58 FSFIA, and 98 AZCFI plots were selected and compared.



Figure 1. Geographic range of FSFIA plots and locations of AZCFI and Woolsey plots in relation to the Coconino National Forest. Flag-staff, Arizona, is located at lat 35°7'N, long 111°40'W.

Analytical Framework

When both environmental characteristics and contemporary forest structure of the Woolsey sample were typical of the population of interest, that sample would be considered representative both historically and contemporarily. In cases where both were atypical, the sample would be considered unrepresentative at both points in time. If typical environment and atypical forest structure were found, samples would be considered historically representative, and the contemporary differences in forest structure attributed to the influence of different management regimes. Finally, in cases where atypical environment and typical forest structure characterized the sample, we would speculate that contemporary representativeness resulted from management practices that have counteracted environmental influences.

Data Collection

Remeasurement of subplots (\geq 1.01 ha) within the original Woolsey permanent plots took place between 1997 and 2003 and included all trees at least 1.37 m in height (Moore et al. 2004). The FSFIA plots were made up of four clustered subplots equivalent to one plot of 0.1667 ha in size (O'Brien 2002; Van Deusen 2004) and included measurements on trees at least 2.54 cm diameter. The last periodic inventory of FSFIA plots in Arizona occurred from 1995 to 1999 (O'Brien 2002), and data were available online through the National FIA Data Base System (http://www.fia.fs.fed.us/tools-data/data). The AZCFI plots (0.0404-ha circular plots) were last measured between 1990 and 1994 (K. Pajkos 2005, ASLD, personal communication). The following variables from those inventories were used in this study: elevation, site index (SI), terrestrial ecosystem unit (TEU), and live tree diameter at breast height (dbh; 1.37 m). Trees per hectare (TPH), basal area per hectare (BA), quadratic mean diameter (QMD), and frequency of dbh classes per hectare (dbh distributions) were calculated from each of the three forest inventories and used to characterize overstory forest structure. Because of lack of information about small-diameter trees (<13.97 cm) on AZCFI plots, per hectare estimates were computed for trees less than 15 cm (TPH₀₋₁₅, BA₀₋₁₅, and QMD₀₋₁₅) and greater than or equal to 15 cm (TPH₁₅₊, BA_{15+} , and QMD_{15+}) so that AZCFI plots could be compared directly with FSFIA and Woolsey plots. All measures of forest structure reported in this study represent estimates for ponderosa pine greater than or equal to 2.54 cm dbh. Gambel oak were not included in the estimation of forest structure because measurement and reporting of tree diameters for this species were not consistent across inventories. Thus, comparisons in this study involve only ponderosa pine, the dominant tree species at all sites being examined.

Analyses

To compare environmental and forest structural data from the three inventories across the entire study area, we applied a distance-based multivariate nonparametric permutation method (Anderson 2001; McArdle & Anderson 2001). This method may be classified as a permutation test and does not rely on the traditional assumptions for linear models. We used the program DISTLM, version 5, to carry out calculations. Euclidean distances standardized by the range of each variable were used as a measure of dissimilarity between plots (Legendre & Legendre 1998). We conducted permutation tests with inventory (FSFIA, AZCFI, or Woolsey) as the factor. We performed separate tests for small-dbh trees (TPH₀₋₁₅, BA₀₋₁₅, and QMD₀₋₁₅), largedbh trees (TPH₁₅₊, BA₁₅₊, and QMD₁₅₊), and environmental variables (elevation, SI₁₀₀, and TEU).

We evaluated equality of variances using the ratio of sample variances (s_1^2/s_2^2) ; Ott & Longnecker 2001) for TPH₀₋₁₅, TPH₁₅₊, BA₀₋₁₅, BA₁₅₊, QMD₀₋₁₅, QMD₁₅₊, elevation, and SI₁₀₀. We used the Kolmogorov–Smirnov two-sample test to compare distributions of elevation, SI₁₀₀, TPH₀₋₁₅, TPH₁₅₊, BA₀₋₁₅, BA₁₅₊, QMD₀₋₁₅, QMD₁₅₊, and dbh distributions for the three forest inventories. The dbh distributions for each inventory were plotted for visual inspection.

Additionally, we constructed a discriminant plot to examine the effect of environment and forest structure on the three inventories (Brown & Wicker 2000). For this analysis, we used the CANPLOT version 1.3 macro (Friendly 2003) developed for the statistical software package SAS 8.2 (SAS Institute, Inc., 2000). Forest inventory (FSFIA, AZCFI, or Woolsey) was used as the grouping variable, whereas three discriminator variables were chosen to account for either environment (SI₁₀₀ and TEU) or forest structure (BA₁₅₊).

We carried out additional comparisons between inventories within TEUs where Woolsey plots were located. For this purpose, we used multivariate permutation tests to examine small-dbh trees (TPH_{0-15} , BA_{0-15} , and QMD_{0-15}) and large-dbh trees (TPH_{15+} , BA_{15+} , and QMD_{15+}). We examined s_1^2/s_2^2 within each TEU with regard to the forest structural variables listed above. We also plotted dbh distributions and applied Kolmogorov–Smirnov two-sample tests within each TEU.

The Woolsey plots are represented in three TEUs: 551, 582, and 585. All three TEUs are dominated by ponderosa pine. TEU 551 is characterized by both ponderosa pine and Arizona fescue (Festuca arizonica), whereas 582 and 585 typically contain Gambel oak. TEU 551 has relatively deep soils derived from mixed igneous and alluvium, and soils in 582 and 585 developed from residuum, basalts, and cinders. The primary difference between 582 and 585 is that the latter has generally shallower soils. These three TEUs account for 112,902 ha, which represents approximately 17% of the study area. Some AZCFI plots also fall into TEUs 582 and 585, but none are found in 551 due to lack of ASLD ownership in that TEU. To compare forest structural conditions within similar environments, we used FSFIA and AZCFI plots located in TEUs 551, 582, and 585. The number of plots within each TEU is as follows: (1) TEU 551: 3 Woolsey, 2 FSFIA, and no AZCFI; (2) TEU 582: 5 Woolsey, 9 FSFIA, and 28 AZCFI; and (3) TEU 585: 6 Woolsey, 9 FSFIA, and 5 AZCFI.

We set the probability of type I error (α) at 0.05 for all tests in this study, except where multiple contrasts between each inventory were carried out. In the latter situation, we used a Bonferroni correction ($\alpha = 0.0167$; Ott & Longnecker 2001).

Results

Analysis across the Entire Study Area

Table 1 displays the results from the multivariate permutation tests that compared environment and contemporary forest structure among inventories. Forest density means for Woolsey tended to be greater than FSFIA and AZCFI (Fig. 2). No clear differences in mean tree size were found. The environment between FSFIA and AZCFI was significantly different (p = 0.0074).

Sample variances for Woolsey were generally not different from the other two inventories, although exceptions

 Table 1. p Values for multivariate permutation tests across the entire study area.

	~	Woolsey vs.	Woolsey vs.
Variable Set	General Test	FSFIA	AZCH
Environmental	0.0060*	0.4273	0.0143*
Forest structural (<15-cm trees)		0.5947	
Forest structural (≥15-cm trees)	0.0057*	0.0003*	0.0050*

* Statistically significant differences.

occurred. FSFIA and Woolsey sample variances were significantly different for TPH₀₋₁₅ and QMD₀₋₁₅, resulting in s_1^2/s_2^2 of 0.21 and 0.03, respectively. AZCFI and Woolsey sample variances were significantly different for QMD₁₅₊, resulting in s_1^2/s_2^2 of 0.21. FSFIA and AZCFI sample variances were significantly different for TPH₁₅₊, QMD₁₅₊, and elevation with s_1^2/s_2^2 of 0.51, 0.51, and 3.03, respectively.

Mean elevation of Woolsey (2,242 m) was greater than that of FSFIA (2,180 m) and AZCFI (2,182 m). Woolsey also had lower mean SI₁₀₀ (19.5 m) than FSFIA (21.3 m) and AZCFI (23.6 m). Examination of environmental and forest structural distributions (Kolmogorov–Smirnov tests) revealed environmental and structural differences between the Woolsey and the other two inventories for elevation, BA, and dbh distribution (Table 2). Statistically significant differences were also noted between AZCFI and Woolsey for SI₁₀₀.

The average 5-cm dbh distributions for all inventories exhibited a reverse exponential trend (Fig. 3). The average Woolsey dbh distribution showed more TPH for most dbh classes than the other inventories. The Kolmogorov– Smirnov two-sample tests indicated differences between Woolsey and FSFIA for distributions including all dbh as well as dbh less than 15 cm and also marginal differences between Woolsey and AZCFI for distributions including dbh 15 cm and greater (Table 2).

Discriminant analysis indicated that differences between the three inventories were driven by both environment and forest structure (Fig. 4). FSFIA and AZCFI shared similar space in the canonical discriminant structure plot, but Woolsey was located to the right of the centers of the other two inventories and also appeared more variable. All analyses indicated dissimilarity between FSFIA and AZCFI with respect to Woolsey.

Analysis of Environmentally Similar Plots (within the Same TEU)

No statistically significant differences in forest structure were noted between the Woolsey and the other two inventories; however, practical differences were present for TPH_{0-15} , TPH_{15+} , BA_{0-15} , and BA_{15+} in all three TEUs (Fig. 5). Differences in TPH_{15+} and BA_{15+} were relatively small, but Woolsey was still consistently denser. QMD_{0-15} and QMD_{15+} showed little differences between Woolsey



Figure 2. Mean TPH, basal area, and QMD for trees less than 15 cm dbh and trees greater than or equal to 15 cm dbh for FSFIA, AZCFI, and Woolsey plots across the study area.

means and either FSFIA or AZCFI means except in TEU 551 where the Woolsey mean for QMD_{0-15} was 8.1 cm greater than the mean for FSFIA. Although not statistically tested in this study, there appeared to be clear differences in forest structure by TEU. When comparing means for a single inventory across the three TEUs, TPH_{0-15} , BA_{0-15} , TPH_{15+} , and BA_{15+} tended to be highest in 585, moderate in 582, and lowest in 551 (Fig. 5). In TEU 551, mean QMD_{15+} was the highest, whereas QMD_{0-15} was the lowest of these three TEUs.

Based on the comparison of sample variances within each TEU, the three inventories are relatively similar, with the exception of QMD. For TEU 551, ratios were generally close to 1.0, with the exception of TPH₀₋₁₅, BA₀₋₁₅, and QMD₀₋₁₅ s_1^2/s_2^2 , which could not be calculated due to the lack of trees smaller than 15 cm dbh in the three FSFIA plots. For TEU 582, FSFIA sample variance was significantly larger than Woolsey in terms of QMD₀₋₁₅ $(s_1^2/s_2^2 = 0.04)$. For TEU 585, FSFIA sample variances were significantly larger than those found for Woolsey plots in terms of QMD₀₋₁₅ and QMD₁₅₊ with s_1^2/s_2^2 of 0.02 and 0.13, respectively. No statistically significant differences were found between AZCFI and Woolsey, except for TPH₁₅₊ in TEU 582 with s_1^2/s_2^2 equal to 0.21. Average 5-cm dbh distributions in the same TEU (Fig. 3) showed that most differences between the Woolsey and the other two inventories occurred in the smallerdiameter classes (<15 cm dbh). The Kolmogorov–Smirnov two-sample tests also showed significant statistical differences in these small–tree diameter distributions (Table 2).

Discussion

In our specific case, environmental and forest structural data showed lack of representativeness of the Woolsey plots with respect to both FSFIA and AZCFI inventories across the entire study area. Our results indicate that the Woolsey plots have atypical environmental conditions and current forest structure and, therefore, cannot be considered representative of either historical or contemporary conditions of the population encompassing the entire area analyzed in this study.

However, given that TEUs intrinsically represent areas of similar environmental conditions, we can presume that the Woolsey plots may be deemed historically representative of forested lands within the three TEUs to which these plots belong. In addition, comparison of the three contemporary inventories for trees greater than or equal

 Table 2. p Values for Kolmogorov–Smirnov two-sample tests across the entire study area.

Variable	FSFIA vs. Woolsey				
	All	<15-cm Trees	≥15-cm Trees	AZCFI vs. Woolsey	FSFIA vs. AZCFI
Elevation (m)	0.0024*			<0.0001*	0.2906
SI ₁₀₀ (m)	0.1879			0.0082*	0.0003*
TPH		0.0383	0.1317	0.1467	0.7954
BA (m^2/ha)		0.0122*	0.0006*	0.0012*	0.7987
QMD (cm)		0.0303	1.0000	1.0000	0.9982
Dbh distribution					
All TEU	0.0044*	0.0008*	0.3800	0.0147*	0.4538
551	< 0.0001*	< 0.0001*	0.0206		
582	< 0.0001*	0.1298	0.5824	0.0005*	0.0002*
585	<0.0001*	< 0.0001*	0.2500	<0.0001*	<0.0001*

Also included are results from Kolmogorov–Smirnov two-sample tests of dbh distributions within each of the three TEUs represented by the Woolsey plots. Missing *p* values indicate inappropriateness of test in the case of environment or lack of data in case of forest structure.

* Statistically significant differences.



Figure 3. Average 5-cm dbh distribution for FSFIA, AZCFI, and Woolsey plots in each of the three TEUs: 551, 582, and 585. For trees greater than or equal to 15 cm dbh, differences are smaller in comparison to the differences.

to 15 cm dbh within the same TEU shows that the Woolsey plots have moderately higher tree frequency and basal area, especially for trees greater than or equal to 40 cm dbh. Although these differences indicate lack of contemporary representativeness, land use history may help



Figure 4. Canonical discriminant structure plot showing the separation of FSFIA, AZCFI, and Woolsey plots due to SI, TEU, and basal area per hectare (BA) for trees greater than or equal to 15 cm dbh.

explain this phenomenon. The Woolsey plots experienced initial selection harvests between 1894 and 1913 similar to the surrounding ponderosa pine forests (Pearson 1923). However, these historical plots were subsequently either unharvested or thinned more lightly than other forested lands outside those plots. This difference in management is a plausible explanation for the higher large-tree densities currently observed on the Woolsey plots (Sánchez Meador 2006).

Differences in within-TEU forest structure between the Woolsey plots and the other two inventories were also found in small-diameter trees (<15 cm), further indicating lack of contemporary representativeness of the Woolsey plots. However, it is feasible that these differences resulted from an artifact caused by livestock grazing in the early 1900s (Foster et al. 2003) on and off the Woolsey plots. The Woolsey plots were fenced at establishment, causing reduced browsing and trampling damage from livestock. This reduced grazing pressure likely increased seedling height growth and survival rates (Hill 1917) and may have been enough to promote the contemporary denser small-tree conditions on the Woolsey plots (Bakker 2005; Bakker & Moore 2007). Thus, information gathered or reconstructed from the Woolsey plots may be considered representative of its corresponding TEU until plot establishment (1909-1913), when distinct harvesting and grazing schemes began on and off these plots.



Figure 5. Sample means of TPH, basal area, and quadratic mean dbh (for trees <15 cm on the top row and trees \geq 15 cm on the bottom row) for FSFIA, AZCFI, and Woolsey plots within TEUs 551, 582, and 585.

Differences in sample design further challenge interpreting the results from this study. Plots of different sizes are expected to capture a dissimilar portion of the inherent forest variability. A single AZCFI plot covering 0.0404 ha or even the combined FSFIA subplots of 0.1667 ha are unlikely to consistently include openings, small-diameter thickets, and old-growth clumps. However, a 1.01-ha Woolsey plot may encompass all these components several times over. As expected, the effect of plot size was reflected in greater sample variances observed for both FSFIA and AZCFI plots. Nevertheless, the relatively large, representative samples for FSFIA and AZCFI inventories still likely allow for an accurate and precise estimation of the population characteristics.

Assessment of pre-settlement forest conditions as well as ecosystem change since Euro-American settlement are important in guiding restoration management in southwestern ponderosa pine forests. However, because the Woolsey plots are only represented on a limited number of TEUs, it would be important to assess how results from these plots might be applied to other TEUs that were not represented. For instance, mapping units could be grouped based on common characteristics correlated with forest structure (i.e., soil depth, parent material, and SI). Developing coefficients to modify estimates of historical structure based on ecological classifications could prove useful as well. Although the degree to which results from the Woolsey plots apply to other similar TEUs is yet to be assessed, information obtained from similar ecological units should be preferred for assessing changes over time and applying restoration treatments. Finally, in relation to temporal trends, information gathered or reconstructed from these plots may be considered representative of its corresponding TEU until plot establishment, when fencing and distinct harvesting schemes began. From that point forward, the effect of those different management approaches would have to be successfully modeled to claim representativeness even within the same TEU. Thus, the use of ecological classification systems should be tempered by knowledge of human activity at the site of interest and in the surrounding ecosystems.

Successful ecosystem restoration will depend on adapting pre-settlement reference-condition information into management prescriptions that also pursue other objectives such as wildlife, range, recreation, and timber. However, translating results from historical forest plots into forest management prescriptions may face additional challenges because forestry operations are often applied to stands whose boundaries may not match ecological classification delineations.

Implications for Practice

- Historical permanent plot data can provide unique opportunities to reconstruct pre-settlement reference conditions, as well as detect and quantify changes in vegetation structure and composition on a site.
- However, plot data collected from the early 1900s were often located subjectively, and therefore, the practitioner should determine the representativeness of historical data before using it to guide management or restoration activities.
- Regional forest inventories offer an excellent tool for determining the applicability of reference conditions developed at one site to another.
- The application of information derived from historical forest inventory plots can be guided by ecological classification systems, such as the TEUs in the Southwest.
- To use information pertaining to historical conditions at one site to inform restoration objectives or prescriptions at another, careful consideration of management history is needed because contemporary structural differences between sites may be due to land use history rather than ecological characteristics.

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