Long-Term Vegetation Studies in the Southwest

Jonathan D. Bakker[1], Margaret M. Moore[2], and W. Wallace Covington[1,2]

[1]Ecological Restoration Institute and [2]School of Forestry,
Northern Arizona University, Flagstaff, AZ 86011

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Introduction

Vegetation studies have been conducted in the American Southwest for well over a century. Studies such as C. Hart Merriam's classic survey of life zones on the San Francisco Peaks (Merriam & Stejneger 1890) were conducted over short time periods, while others have continued for decades and rival the length of studies in other regions of North America. For example, Sonoran desert plots established by V. M. Spalding in 1906 have been the subject of ongoing research (Shreve 1929; Shreve & Hinckley 1937; Goldberg & Turner 1986).

Long-term studies vary in familiarity. Some are well documented because they are part of the Long Term Ecological Research network (e.g., Jornada Experimental Range; http://usda-ars.nmsu.edu/), associated with a University (e.g., Santa Rita Experimental Range; http://ag.arizona.edu/SRER), or part of the Biosphere Reserve Program (e.g., Beaver Creek Experimental Watershed; http://ag.arizona.edu/OALS/watershed/beaver/). However, other studies are equally rich in data depth, but have been long forgotten or ignored by many researchers and managers. In this paper, we describe several long-term studies in the ponderosa pine (*Pinus ponderosa*) forests of the American Southwest, focusing on the unique insights and contributions of these studies.

Many of the studies that we discuss were established by staff from the Fort Valley Experiment Station (FVES; http://www.rmrs.nau.edu/fortvalley/). Located in Flagstaff, Arizona, FVES was the first US Forest Service (USFS) research facility in the nation. FVES was established in August 1908 after the Riordan brothers, owners of the Arizona Lumber and Timber Company, asked Gifford Pinchot to study why ponderosa pine forests were not regenerating after logging (Olberding 2000). Abundant regeneration occurred within a few decades because a wet year and good seed crop coincided with several years of fire suppression and livestock grazing (Meagher 1950); today, the forests are greatly overstocked and at risk from severe crown fires, insect attacks, and other disturbances.

FVES and its research forest, the Fort Valley Experimental Forest (FVEF), were primary sites for forest management studies in District 3 (now USFS Region 3) through the 1940s. Many young foresters worked and trained at FVES, including Yale alumni such as C. F. Korstian, W. R. Mattoon, T. S. Woolsey, Jr., R. H. Westveld, F. Hassis, and E. Fritz (Fritz 1964). While FVES is no longer active, it is listed on the National Register of Historical

Places and efforts are underway to restore the buildings (Olberding 2000). Research begun by the FVES continues to be conducted by the US Forest Service Rocky Mountain Research Station (RMRS), Northern Arizona University, and other agencies. Data collected by the FVES is housed in the Fort Valley Archives, RMRS.

Growth and Yield Studies

Trees have been a primary focus of vegetation studies in the ponderosa pine forests of the Southwest. Many of the early studies were established by foresters, often with an eye on tree growth and timber yield.

The Woolsey Plots

As early as 1906, there was a recognized need for studies of western yellow pine (now ponderosa pine) and its management (Pearson 1910; Woolsey 1911, 1912). In 1909, a set of instructions were drafted by T. S. Woolsey, Jr. (Assistant District Forester and Chief of the Office of Silviculture, District 3, USFS) and G. A. Pearson (Director, FVES) that led to the establishment of a network of permanent plots in the ponderosa pine forests of the Southwest. Between 1909 and 1915, approximately 50 permanent sample plots ranging up to 6 ha in size were established (Woolsey 1911; Pearson 1923, 1933, 1950). Trees were measured on a five-year cycle to evaluate stand growth and commercial potential. Pearson died in 1949, and remeasurements ceased soon afterwards as he had no clear successor and research priorities had shifted.

In 1997, the RMRS funded personnel at the School of Forestry and Ecological Restoration Institute at Northern Arizona University (NAU) to begin relocating and remeasuring the plots (Malakoff 2002). While many plots were relocated, others had been destroyed by road construction, crown fires, and urban development. Remeasurements were conducted using the original methods but with different objectives. Rather than focusing on timber production, the historical and contemporary data have been used to quantify historical stand conditions (Moore et al. 2004a), assess our ability to reconstruct those conditions (Huffman et al. 1999, 2001; Sánchez Meador et al. 2003, 2004; Bakker, *in press*), and analyze changes in spatial pattern and ecosystem structure and function (Moore et al. 2004b). In addition, recent work (Bell 2005) suggests that ongoing management activities can change the trajectory of stand structural development.

A set of smaller (4.5 m^2) subplots were established on some plots in 1914 to assess ponderosa pine regeneration. The herbaceous vegetation on each subplot was mapped along with the locations of pine seedlings relative to grass clumps, rocks, and other features. By remapping the subplots, we have examined long-term (85-year) changes in plant diversity and cover (Bakker et al. 2002).

Taylor Woods

Taylor Woods was a sheep pasture in the early 1900s until stocked by the abundant pine regeneration of the early 1900s. As part of FVEF, Taylor Woods received silvicultural treatments in 1925 and 1942. In 1962, the even-aged regeneration in Taylor Woods was thinned at different stocking levels to examine tree and stand growth patterns; similar studies were established on the Pringle Falls Experimental Forest, Black Hills Experimental Forest, and other sites in the western United States (Schubert 1971; Ronco et al. 1985).

The experiment was originally planned to run for 20 years, with measurements every 5 years and subsequent thinning treatments every 10 years. Tentative conclusions were drawn after 5 years (Schubert 1971), some of which were confirmed after 20 years while others were contradicted (Ronco et al. 1985). Taylor Woods was one of the first experiments to demonstrate that ponderosa pine trees within dense dog-hair thickets would release following thinning.

The Taylor Woods experiment has continued to be supported by the RMRS (notably by C. B. Edminster) and has run for more than 40 years, with the most recent measurements and treatments in 2002 (J. D. Bailey, *pers. comm.*). While scientists no longer focus primarily on timber production as they did when Taylor Woods was established, they have increasingly recognized the unique long-term nature of Taylor Woods and the potential to use this experiment to address a variety of other research questions. Examples of these studies include assessments of overstory thinning effects on tree regeneration (Bailey & Covington 2002), foliage and soil nutrients (Wollum & Schubert 1975) tree physiology (T. E. Kolb, *pers. comm.*), tree resistance to attack by insects (Kolb et al. 1998), and microbial communities (Overby et al. 2005).

Range Studies - the Hill Plots

While foresters focused on the overstory, range scientists focused on the herbaceous understory vegetation (Olberding et al. 2005). R. R. Hill, a USFS Grazing Examiner, began to study the effects of intense livestock grazing on tree regeneration in 1910 (Hill 1917). In 1912, he established a secondary study of how the understory vegetation recovers when protected from livestock grazing. At each of five sites on the Coconino National Forest, an exclosure (~0.7 ha) was built to exclude livestock (Figure 1). Quadrats were established inside and outside the exclosures, and the vegetation mapped periodically between 1912 and 1941. New vegetation sampling methods such as the line intercept method (Canfield 1941) were developed on these and other sites, including the Santa Rita Experimental Range, in part because of recognized inadequacies of existing methods for sampling these long-term sites. Early reports (e.g., Talbot & Hill 1923; Merrick 1939; Arnold 1950) concluded that the herbaceous understory vegetation requires several decades to recover from severe livestock grazing.

The last historical data that we are aware of from these plots was collected in 1947. Data collection resumed in 2002, but in the interim, part of one site was subject to a prescribed burn, several sites received silvicultural treatments, power and phone lines bisected two sites and a Forest Service road another, and one site was nearly destroyed by the construction of an interstate highway. The Coconino National Forest was not alerted to the fact that the proposed highway ran through the plot until the final road surveys were almost complete. In a memo dated June 7, 1957, E. M. Gaines noted that the Supervisor of the forest would insist that the state of Arizona relocate the highway "if we feel that the plot has sufficient historic and current value". Thankfully, they did recognize its value, and the relocated highway runs near instead of through the plot.

Thanks to the advent of increasingly powerful computers, historical data have been reanalyzed using techniques undreamt of when the data were collected. For example, statistical significance has been assessed by permuting the data thousands of times, and mapped quadrats have been digitized and entered into a geographic information system (GIS) database. The GIS database permits the easy quantification of areas and spatial patterns. Previously, the area occupied by each plant was measured by overlaying a fine grid on the map and painstakingly counting the number of cells occupied by it; these measurements were then confirmed by having another person make the same measurements.

Recent analyses (Bakker 2005) have shown that continued livestock grazing reduced the establishment of pine trees and found some differences between grazing treatments. After accounting for shading and other overstory effects, however, observed differences in species richness and cover between grazing treatments were no longer evident. Computer-intensive techniques were used to analyze historical and contemporary species data and identify species that were more abundant and frequent in particular grazing treatments and years, and in the open or under the tree canopy. In addition, cryptogamic crusts have been sampled within the exclosures, as few other sites in the region have been undisturbed for as long as these (M. A. Bowker, *unpub. data*).

Ecological Restoration Experiments

Frequent surface fires were a natural disturbance in southwestern ponderosa pine forests prior to settlement of the area by Euro-Americans (Dieterich 1980). The subsequent suppression of these fires caused tree densities to increase dramatically and greatly increased the risk of crown fires (Cooper 1960; Covington & Moore 1994).

Interval Burning Studies - Chimney Springs and Limestone Flats

In 1976, studies were implemented to identify a burning interval that would reduce the risk of crown fire. Replicate studies were established on basalt soils at Chimney Springs (located in the FVEF) and sandstone soils at Limestone Flats (located in the Long Valley Experimental Forest; http://www.fs.fed.us/rm/main/expfor/longvalley.html). Seven treatments were established at each site, including unburned plots and plots burned at intervals ranging from 1 to 10 years (Sackett 1980). The expectation was that fires would consume surface fuels and thin the dense stands of small trees, enabling the older and larger trees to survive and grow.

Given that one of the treatments involved burning every 10 years, a long-term approach was obviously required. Repeated burning did not kill as many postsettlement trees as was hoped but, unexpectedly, a number of the large trees began to die several years later. Further research demonstrated that surface fuel accumulations were so great under these trees that fires were more intense and damaged the roots and cambium (Sackett et al. 1996).

Since their establishment, the interval burning studies have been the subject of numerous other studies, including analyses of tree regeneration rates (Bailey & Covington 2002), soil chemistry (Neary et al. 2003; S. C. Hart, *pers. comm.*), root and mycorrhizae dynamics (Hart et al. 2005), and whether fire interval affects the frequency with which a dominant grass is infected by endophytic fungi (Faeth et al. 2002). A long time frame is necessary for these studies as the effects of repeated fires may accumulate and gradually become more important.

Gus Pearson Natural Area Restoration Experiment

The Forest Service manages a network of Research Natural Areas that are permanently protected and maintained in natural conditions (a list of RNAs in the western U.S. is available at http://rna.nris.state.mt.us/rna_about.html). One of these, the Gus Pearson Natural Area (GPNA), is an old-growth ponderosa pine forest within the FVEF. GPNA has been measured since 1925 and is the subject of numerous publications (e.g., Avery et al. 1976; Dieterich & Swetnam 1984; White 1985; Biondi 1994, 1996, 1999; Biondi et al. 1994; Fulé et al. 2001). A portion of GPNA was decommissioned (withdrawn from RNA status) in 1992 to serve as a fuelbreak for the FVES (Edminster & Olsen 1996). The preparation of the fuelbreak was incorporated into an ecological restoration experiment involving untreated controls and thinning and composite (thinning, forest floor fuel reduction, and prescribed burning) treatments (Covington et al. 1997).

The restoration experiment was developed in part because of the results from the interval burning studies. Prescribed fire alone was insufficient to restore presettlement forest structure in these forests, suggesting that an initial thinning and the raking of the extensive litter layer away from the bases of large trees were required. The development of this experiment provides an excellent example of adaptive management.

Research at this experimental site has generated valuable insights about stand age structure (Savage et al. 1996; Mast et al. 1999) and the effects of restoration treatments. Seven years after thinning, old ponderosa pine trees in the stand continued to respond positively in terms of leaf physiology and insect resistance (Wallin et al. 2004). Herbaceous understory vegetation responds to restoration treatments (Moore et al., *in revision*), but responses differ between patches in the open and under the canopy and among functional groups and species (Laughlin et al., *in revision*). Other studies have examined the effects of treatments and patch types on soil chemistry (Wright & Hart 1997; Kaye & Hart 1998a, b), nutrient fluxes (Kaye et al., *in press*), and soil microbes (Boyle et al. 2005).

Ponderosa Pine Provenance Trials

In 1911, ponderosa pine seed was gathered at 26 locations throughout the western US, and seedlings were grown near Flagstaff, AZ. The objective of this study was to identify seed sources (provenances) whose seedlings would survive and grow well in this environment. Seven provenances from the west coast and northern Rockies grew well in the nursery but were killed by the frosts and droughts common to this area before they could be outplanted. Eight provenances were eliminated within 5 years of planting, and another one after 50 years. The remaining 10 provenances were from the southern and eastern portions of ponderosa pine's range in the United States (Larson 1966; Silen et al. 2003). Taller provenances had higher yields (volume of live trees per acre) in the early years but survival became more important than tree height in determining yield in later years. After 80 years, it was apparent that the locally collected provenance (Coconino) was also the best-yielding one. In comparison, another Southwestern provenance, the Gila, had equal seedling heights as the Coconino but was 25% shorter and had one-twentieth as much volume after 80 years as the Coconino provenance (Silen et al. 2003).

These findings are important when deciding how far away from its collection point seed can safely be used. However, these trees can also be used in other studies by capitalizing on features such as the expression of genetic traits at different points in an organism's life cycle. Since provenances differ genetically but have been grown in the same environment, this and other long-term trials have been used to examine genetic differences in physiology (T. E. Kolb, *pers. comm.*) and in resistance to insect attack (M. R. Wagner, *pers. comm.*). Trees do not become susceptible to attack by insects such as sawflies and tip moths until they are about 15 years old and to attack by bark beetles until they are even older, demonstrating the value of long-term studies for addressing such questions.

Summary

There are many long-term studies in the Southwest beyond those described here. One of the main challenges surrounding the use of long-term studies is simply learning about their existence. Sites may be destroyed or abandoned as research priorities change. Location maps and data may be lost or poorly documented, and raw data may be discarded or stored in formats that are inaccessible (e.g., on magnetic tapes or 8.5" floppy disks). Support of long-term ecological research should include funds and personnel to maintain research sites and to preserve data in accessible formats and locations. The studies described here demonstrate that long-term experiments can yield valuable insights, and can be used to address questions that were not anticipated when the experiments were established.

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Figure 1. Repeat photograph of the grazing exclosure at Rogers Lake, one of the Hill plots, in 1935 (top) and 2005 (bottom). The right half of each photo is within the area fenced to exclude livestock since 1912. The 1935 photo (USFS image 318895) was taken by W. J. Cribbs and the 2005 photo by J. D. Bakker.