The Hill Plots: A Rare Long-Term Vegetation Study

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Abstract—*One legacy of the Fort Valley Experimental Forest is the number and quality of long-term studies associated with it. One such study is the "Hill plots," which began in 1912 and is still being actively studied. Livestock exclosures were built at five sites to examine vegetation recovery when protected from livestock grazing. Sites span a range of soil types and elevations. Materials associated with the Hill plots include historical data, plant specimens, and photographs. In this paper, we summarize the research that has occurred on the Hill plots, historical personnel who worked on them, threats they have experienced, ecological insights they have provided, and current research directions.*

Introduction

In the decades around 1900, livestock grazing and timber harvesting were largely unregulated and unsustainable in northern Arizona. These land uses clearly needed to be balanced, and the Coconino National Forest (CNF), which was established in 1908, did so by regulating when, where, and how they were conducted. In 1910, Robert R. Hill, a U.S. Forest Service (USFS) Grazing Examiner with District 3 (now Region 3) and the Fort Valley Experimental Forest (FVEF) initiated a study to examine potential livestock damage to ponderosa pine (*Pinus ponderosa* Laws. var. *scopulorum* Engelm.) regeneration (Hill 1917). This study included detailed observations on the amount of browsing damage to pine seedlings and saplings on 150 plots in 1910 and an additional 100 plots in 1912 (250 plots total). All plots were within 40 km (25 miles) of Flagstaff, AZ. The fate of the seedlings and saplings was followed from 1912 to 1914. Hill (1917) concluded that: 1) a third of the seedlings were severely or moderately damaged; 2) damage was concentrated in specific times of the year; and 3) sheep generally do the most severe damage to seedlings, though all classes of livestock are likely to damage small trees on overgrazed range. Hill conducted this study while also leading the first range reconnaissance in the United States, which was conducted on CNF in 1912 (Bodley 1913).

In: Olberding, Susan D., and Moore, Margaret M., tech coords. 2008. Fort Valley Experimental Forest—A Century of Research 1908-2008. Proceedings RMRS-P-53CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 408 p.

Table 1. Summary information about the Hill plots. Information adapted from Bakker (2005).

	Big Fill	Black Springs	Fry Park[a]	Reese Tank[b]	Rogers Lake
Location	SW¼ Sec 21, T21N, R8E,	SW¼ Sec 8, T20N, R7E	NE¼ Sec 31, T20N, R6E	NE¼ Sec 8, T23N, R7E	NW¼ Sec 8, T20N, R6E
Current jurisdiction[c]	CNF	CNF	CNF	CNF	CF/CNF
Exclosure area (ha)	0.618	0.786	0.840	0.669	0.574
Mean elevation (m)	2070	2100	2170	2490	2220
Parent material[d]	Limestone	Limestone/Sandstone	Basalt/Cinders	Mixed Igneous	Basalt/Cinders
Disturbance history[e]					
Localized	PL 1946	PL ca. 1954	None	RD ca. 1978	None
Generalized	SH 1896, 1919, 1947	SH 1902; PCT 1976, 1997	SH 1910	SH 1940,1978,1989; PCT 1964; PB 1999 (west half)	SH 1905
Grazing intensity					
Before 1912[f]	Overgrazed	Overgrazed	Overgrazed	Overgrazed	Overgrazed
1912-1924[f]	Overgrazed	Heavy	Overgrazed	Moderate	Overgrazed
1924-1938[f]	Heavy	Heavy	Overgrazed	Moderate	Overgrazed
1939-1941[g]	0.58; Cattle	1.01; Cattle	1.35; Cattle	0.17; Sheep	-; Sheep
2002-2004[g]	None since 2000	None since ca. 1960	0.03; Cattle	None since ca. 1992	0.18; Sheep

[a] Also known as Frye Park.
[b] Also known as Rees Tank.
[c] CNF = Coconino National Forest; CF = Centennial Forest.
[d] From Miller et al. (1995).
[e] Data obtained from unpublished documents in Fort Valley Archives, Arnold (1950), and Coconino National Forest (J. Rolf, *pers. comm.*). Codes: PB = prescribed burn; PCT = pre-commercial thinning; PL = power/phone line built through site; RD = road built through site; SH = selective overstory harvest.
[f] Descriptions from Merrick (1939).
[g] Units are animal unit months per ha; larger values indicate higher grazing intensity. 1939-41 data are from the Fort Valley Archives, and contemporary data are from annual range inspections on file at the Coconino National Forest. The Big Fill and Black Springs sites were near sheep driveways historically. Grazing intensity data from 1939-1941 are not available for Rogers Lake.

As part of his grazing effects study, Hill established ~ 0.6 ha (1.5 acre) livestock exclosures at five sites to experimentally determine the effects of grazing protection on pine reproduction. Sites were selected to span a range of soil types and elevations (Table 1). An incidental goal of these exclosures was to permit an assessment of the effects of livestock grazing on forage plants (Hill 1917), yet this aspect of the research has been the primary focus since 1914. Collectively, these sites are now known as the "Hill plots" in recognition of Hill's foresight in establishing them. Here, we summarize the research that has been conducted on these sites, historical personnel who worked on them, threats they have experienced, ecological insights they have provided, and current research directions.

Historical Research

Historical work on the Hill plots occurred from 1912 to 1956. Many USFS scientists worked on these plots throughout the years (Table 2), and went on to become leaders in the fields of range ecology and management. Hill served as director of the Santa Rita Experimental Range in 1920, and later became Grazing Examiner in charge of the Regional Office of Grazing Studies. Other notable scientists include W.R. Chapline, M.W. Talbot, C.L. Forsling, E.W. Nelson, C.K. Cooperrider, and J.F. Arnold.

Table 2. Personnel who worked on the Hill plots (1912-1956). Initials are provided for individuals that have not been definitively identified.

Person	Date Range	Activities
Robert R. Hill	1912-1921	Established exclosures; Recorded damage to ponderosa pine regeneration; Chart quadrats
W. R. Chapline	1912	Chart quadrats
M. W. Talbot	1920-1923	Chart quadrats; Photographs
C. L. Forsling	1920	Chart quadrats
Enoch W. Nelson	1924	Chart quadrats
C. K. Cooperrider	1925-1926	Chart quadrats; Photographs
LAW	1925	Chart quadrats
R. F. Copple	1926-1930	Chart quadrats
E. H. Bomberger	1930-1938	Chart quadrats
E. Shirley Bliss	1930	Chart quadrats
Barnard A. Hendricks	1930	Chart quadrats
CFD	1931	Chart quadrats
Oran B. Stanley	1931	Chart quadrats
Hugh O. Cassidy	1930-1933	Chart quadrats
J. D. Jones	1932	Photographs
Gordon D. Merrick	1933-1938	Chart quadrats
TGW	1933	Chart quadrats
William J. Cribbs	1935	Photographs
George E. Glendening	1941	Chart quadrats; Line intercept sampling; Photographs
BHM	1941	Chart quadrats; Line intercept sampling
EES	1941	Chart quadrats; Line intercept sampling
EFP	1941	Line intercept sampling
HAL	1941	Line intercept sampling
James G. Rowbury, Jr.	1941	Line intercept sampling
Joseph F. Arnold	1947-1952	Line transect samples; Photographs
Kenneth W. Parker	1947	Photographs
T. M. Smith	1956	Photographs

Sources: Unpublished records in Fort Valley Experimental Forest Archives; Arnold (1950); Price (1976); Chapline (1980).

In 1912, Hill established fifty chart quadrats, five inside and five outside each exclosure. Quadrats were 1 x 1 m, and were marked in each corner with a wooden stake. Chart quadrats, plots in which the positions of all plants are accurately noted, were a common method of studying vegetation in the early 1900s (e.g., Clements 1905; Weaver and Clements 1929; Figure 1; Table 3). The vegetation on these quadrats was mapped, recording the basal area of grass clumps and prostrate species (e.g., *Antennaria*) as polygons, and individual stems of most forbs and shrubs as points. Quadrats were measured periodically between 1912 and 1941 (Figure 2). Early mapping was done manually until Hill adapted the pantograph for use in vegetation studies (Hill 1920).

Site maps showing the locations of chart quadrats do not appear to have been made originally, and several quadrats could not be relocated after 1914. In 1920, site maps were drawn showing the location of each quadrat relative to fences and other features. In addition, the wooden stakes were replaced around this time with angle iron stakes, and one corner of each quadrat was tagged with a metal numbered tag.

Around 1931, the exclosures at Fry Park and Black Springs were expanded to permit assessments of vegetation recovery in areas that had received two additional decades of livestock grazing. However, these assessments appear to have been done visually or with photographs; we have not found data collected specifically in these areas.

While the pantograph simplified the process of mapping a chart quadrat, the time commitment was still considerable and resulted in a low number of samples for a given area. In the late 1930s, R. H. Canfield adapted the line intercept sampling method to rangeland vegetation (Canfield 1941). This method greatly increased the speed and therefore the number of samples that could be obtained from an area. The Hill plots were sampled in this manner in 1941 and 1948 (Arnold 1950; Bakker and Moore 2007).

Historical Collections

The historical vegetation data (chart quadrat maps and line intercept data sheets) are housed in the Fort Valley Experimental Forest Archives in Flagstaff, AZ. The Archives also contain other pertinent information such as summaries of grazing intensity for the allotments in which the sites are located, and hand-drawn maps of quadrat locations within sites.

Photographs were taken of sites and of individual chart quadrats between 1921 and 1956. Of particular note are a series of photographs taken by M. W. Talbot in 1921 and reshot by K. W. Parker in 1947 (e.g., Figure 3). Many of the photopoints were drawn onto the site maps to permit their relocation. Historical images are housed in the Fort Valley Archives and the National Archives and Records Administration (NARA). Scanned images of many photographs are available in the USFS Rocky Mountain Research Station Image Database (http://www.rmrs.nau.edu/imagedb/bcollection.shtml).

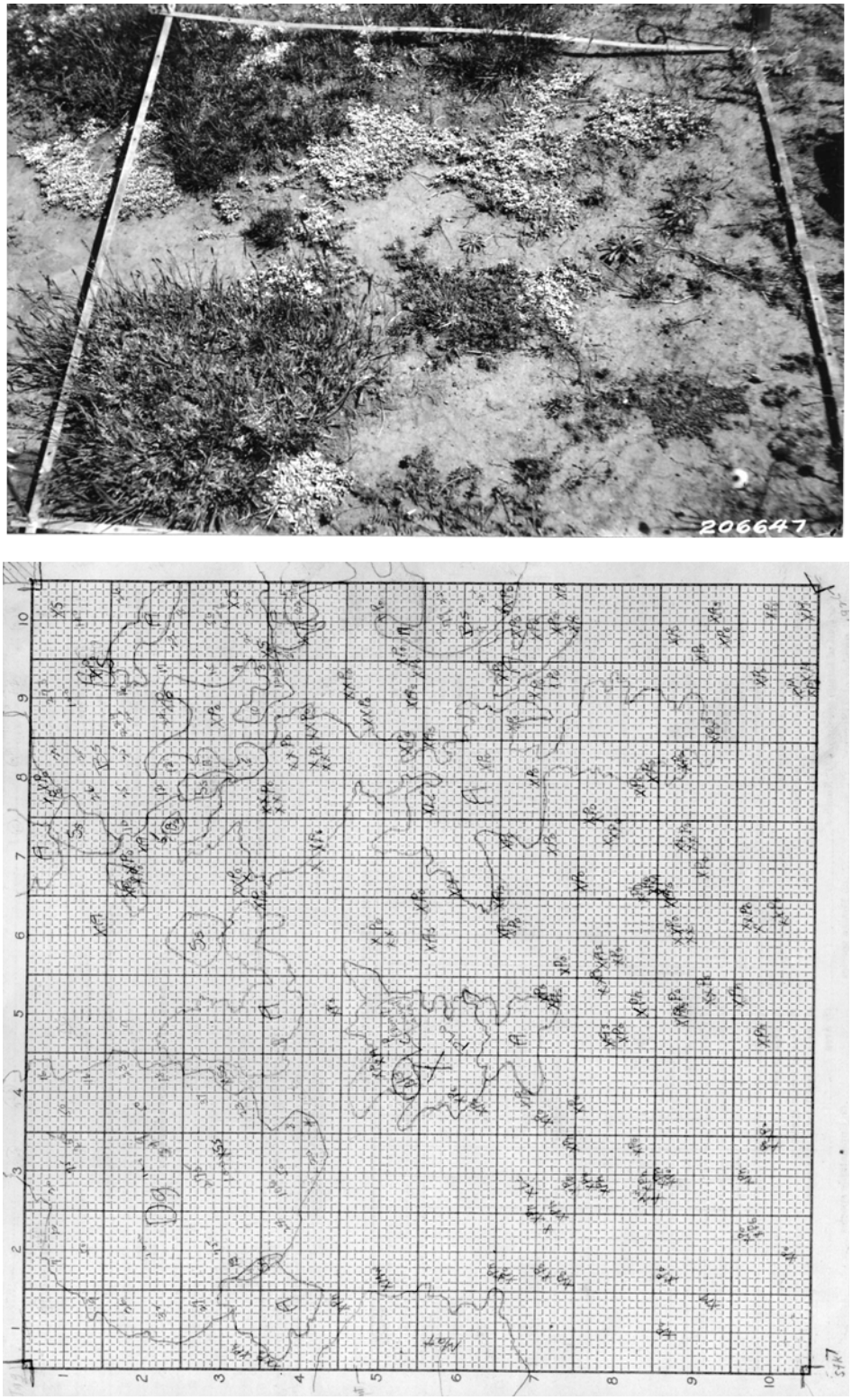

Figure 1. Photo (top) and chart (bottom) of a quadrat (No. 30739) outside the exclosure at the Fry Park site in 1925. The photo was taken by C. K. Cooperrider (USFS photo 206647). The chart has been rotated 90 degrees so plants are in the same relative positions as in the photo. At the time of this mapping, the quadrat contained 13 species, including deergrass (*Muhlenbergia wrightii*; indicated by 'Dg' on chart), *Antennaria* spp. ('A'), and black dropseed (*Sporobolus interruptus*; 'Bs').

Table 3. Examples of chart quadrat studies established in the early 20th century.

Name	Geographic Location	Date Established	Citation
Wallowa Mountains	Northeastern Oregon	1907	Sampson 1914
Woolsey Plots	Northern Arizona	1909	Pearson 1923
Hill Plots	Northern Arizona	1912	Arnold 1950; Bakker and Moore 2007
Great Basin Experiment Station	Wasatch Mountains, central Utah	1913	Sampson 1915; Prevedel et al. 2005
Santa Rita Experimental Range	Southeastern Arizona	ca. 1915[a]	Canfield 1957; McClaran et al. 2003
Jornada Experimental Range	Southern New Mexico	1915	Gibbens and Beck 1988; Yao et al. 2006
Wild Bill	Northern Arizona	1928	Cooperrider and Cassidy 1939
Hays	Hays, Kansas	1932	Albertson and Tomanek 1965
Rodent Study Plots	Northern and Northwestern Arizona	1924	Taylor and Loftfield 1924
Vegetation of NE Arizona	Northeastern Arizona	1924	Hanson 1924
U.S. Sheep Experimental Station	Southern Idaho	1930	West et al. 1979

[a] Established by R.R. Hill (Canfield 1957).

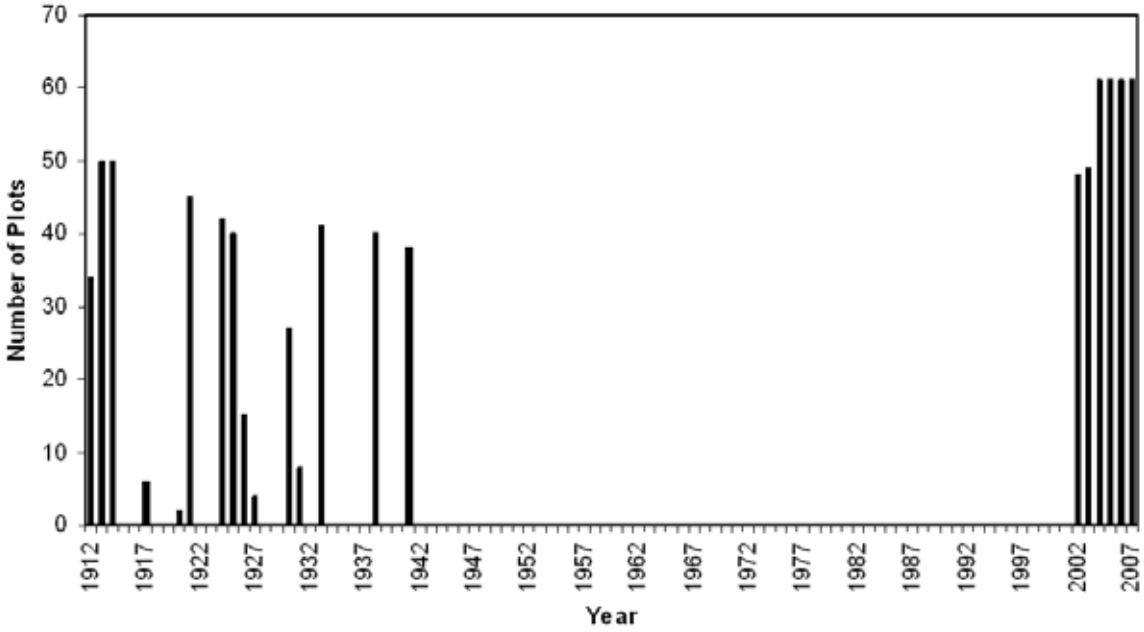

Figure 2. Number of Hill plots sampled in each year between 1912 and 2007.

Early scientists made plant collections a priority; hundreds of specimens were obtained during the CNF range reconnaissance (Bodley 1913; Memo on Plant Identification from W. A. Dayton to J. T. Jardine, 1916, in Fort Valley Archives). Plant samples were taken from the Hill plots between 1921 and 1945. Specimens are housed in numerous herbaria (e.g., CNF, Northern Arizona University, Museum of Northern Arizona, Arizona State University, University of Arizona, Desert Botanical Garden, National Herbarium of the USFS). Plant database projects are increasingly making these records available via the internet.

Figure 3. Repeat photograph series from the Fry Park site in1923 (top), 1947 (middle), and 2005 (bottom). The 1923 photo was taken by M. W. Talbot (USFS photo 184084), the 1947 photo by K. W. Parker (USFS photo K-1144A), and the 2005 photo by J. D. Bakker.

Threats

It has been almost a century since the Hill plots were established, and they have not survived unscathed. Sites have experienced prescribed burns and silvicultural treatments, and have been bisected by power lines, phone lines, and roads (Table 1). Two sites are within the current Flagstaff city limits. In addition, livestock no longer graze at several sites. However, there have also been surprising instances where sites and quadrats have survived major activities such as the building of Interstate 17 (i.e., Black Springs), major forest thinning projects (i.e., Black Springs and Rogers Lake), and large wildfires (i.e., Reese Tank on the edge of the Bear Jaw fire).

Contemporary Research

In 2002, we rediscovered the historical vegetation data in the Fort Valley Archives and the exclosures and chart quadrats in the field. These old exclosures were relatively easy to find since we had specific legal descriptions and some of the fences were maintained over the years. Most of the chart quadrats were relocated with the aid of a metal detector. Since then, we have conducted a number of measurements on these sites.

Vegetation on the chart quadrats has been remapped annually from 2002 to 2007. On sites where quadrats were missing, new quadrats have been established. The chart quadrat maps have been digitized in a geographical information system to permit analyses of spatial dynamics and trends in plant cover and abundance over time. Glendening's 1941 line intercept transects were re-measured in 2004 (Bakker and Moore 2007). Most of the historical photographs were retaken between 2003 and 2005 (e.g., Figure 3).

The overstory vegetation has been measured within all exclosures and in a 20 x 20 m area around each quadrat outside the exclosures. Measurements included tree species, diameter, height, spatial coordinates, and age (for a subset of trees). The contemporary overstory data permits the application of stand reconstruction methods (Bakker et al., these proceedings) to estimate stand dynamics and permit overstory-understory comparisons with historical data.

More recently, we have measured a variety of physical and chemical soil properties for each chart quadrat. We are also quantifying litter decomposition rates and analyzing the relationships between the soil and plant community structure to determine how long-term vegetation changes have influenced ecosystem function.

Ecological Insights

Early work demonstrated that vegetation recovery may take decades following severe livestock grazing (Talbot and Hill 1923; Merrick 1939). Arnold (1950) showed that ponderosa pine in-growth had reduced the abundance of the understory vegetation. More recent work demonstrated that this effect is still evident today, as are the consequences of continued livestock grazing in the early 1900s: current tree densities are twice as high inside than outside exclosures while basal area is 40% higher inside exclosures (Bakker and Moore 2007). Since plot establishment, understory abundance and diversity have declined and plant species have responded differentially to grazing and pine in-growth (Bakker 2005). Effects of vegetation type and livestock grazing on diversity are expressed at different spatial scales (Rudebusch 2006). As noted above, research is ongoing on these sites. Research on these sites has answered questions beyond those originally posed by Hill. Who knows what insights they will provide in the future?

Acknowledgments

We thank D.W. Huffman and R.A. Gill for reviewing an earlier version of this paper. Contemporary measurements of the Hill plots were supported by the Ecological Restoration Institute (ERI) and School of Forestry at Northern Arizona University. We particularly thank the ERI field and lab crews for their assistance with data collection and entry. We thank the U.S. Forest Service and NAU Centennial Forest for permission to sample their lands.

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