Ecological Restoration Institute Fact Sheet
Using a Terrestrial Ecosystem Survey to Estimate the Historical Density of Ponderosa Pine Trees in Northern Arizona
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Introduction
The Terrestrial Ecosystem Survey (TES) delineates ecosystems according to their climate, geology, soils, and potential natural vegetation (U.S. Forest Service 1986). Land managers and planners can use this information to help interpret site suitability for natural regeneration, reforestation, and revegetation potential as well as site suitability for road building, range and timber, range structures (watering sources), and other land uses. However, the TES can be used for other purposes as Ganey and Benoit (2002) demonstrated in their report about identifying potential habitat for Mexican spotted owl on national forest lands. Similarly, Bell and colleagues (2009) used the TES and its specific survey units (TESU) to analyze the characteristics of the Woolsey plots in northern Arizona—plots the Forest Service established in the early 1900s to examine tree regeneration. In our study, we identified historic ponderosa pine densities on various TES mapping units and then correlated our findings with what the TESU predicted we should find.

Study Area
We conducted our study within a 250,000-acre area in northern Arizona on the northern half of the Coconino National Forest and on the Northern Arizona University Centennial Forest. Study sites ranged in elevation from 6,300 to 8,410 ft and were located in ponderosa pine forests. Slope gradients are typically less than 10%, but cinder cones, ravines, and undulating hills of greater slope gradient are present. These forests historically experienced frequent surface fires, with fire intervals of two to five years based on five fire-history studies (Van Horne and Fulé 2006). Understories were dominated by grasses and sedges (Pearson 1942).

The study area is covered by the Coconino National Forest TES (http://alic.arid.arizona.edu/tes/tes.html) and maps ecological units at a 1:24,000 scale with a minimum mapping unit of 40 acres (Miller and others 1995). Ecosystem types are classified and delineated according to soil parent material, landform, climate, and secondarily by dominant overstory trees and understory species (Robbie 1992). The TES uses a three-digit numerical code to identify each ecological unit.

Site Selection and Sampling
We randomly chose a sample location within each of five to seven mapping units in nine ecosystem types. This resulted in 53 independent sites replicated across the landscape (Figure 1). A slight variation in the number of sites among ecosystem types resulted because we rejected mapping units for sampling if evidence of pre-settlement trees was missing. At each site, we established a 2.5-acre plot and, using the methods of Fulé and others (1997), counted the number of evidences of pre-settlement trees (both dead and living). To ensure the accuracy of our live tree observations, we cored trees of uncertain status (typically 10 percent of the total live trees) and counted rings in the field to classify these trees as pre- or post-settlement.

Results—Overall
We found that 1) the density of historical trees differed significantly among ecosystem types, and 2) the densities generally matched the natural tree regeneration potential predicted by the TES. Median densities ranged from 1 tree/acre in a clay basalt ecosystem to 46 trees/acre in a moist basalt ecosystem. Patterns also emerged when partitioning tree density into classes, with the clay basalt, red cinder, and dry limestone ecosystems containing the most sites in the low- and low-medium density classes (Table 1). The black cinder ecosystem had the most medium-density sites. Mixed igneous, basalt, benmorite, and moist limestone ecosystems possessed the most medium-high and high-density sites. Variation in density among ecosystems became even more pronounced when we divided the ecosystems into low-density (less than 24 trees/acre) and high-density (greater than 24 trees/acre) categories. This classification accurately portrayed 42 of the 53 (79 percent) sample sites by TES unit.

Table 1. Distribution of density classes of ponderosa pine trees reconstructed for historical, 1880 forests on 53 sites of nine terrestrial ecosystem survey types in northern Arizona.

	Trees/acre					
TES type	<10	10 to 17	18 to 23	24 to 29	≥30	Total
	Number of sites					
523: clay basalt	6					6
513: red volcanic cinder	1	4			1	6
500: dry limestone	1	3	2			6
558: black volcanic cinder		1	3	1		5
570: benmoreite		1	1	1	2	5
551: mixed igneous	1		1	3	1	6
585: rocky basalt			2	4	1	7
536: moist limestone			1	4	1	6
582: basalt		1	1		4	6
Total	9	10	11	13	10	53

Results by TES Unit

Clay Basalt (TES unit 523, low natural regeneration potential)

None of the six sample sites of this ecosystem had more than 8 trees/acre, and four of six sites contained less than 1 tree/acre, making this the least dense of the nine ecosystem types. We suspect that clayey soils limited density in this ecosystem. Large cracks in the soil--some a foot wide and several feet deep--suggest that soil expansion/contraction could have reduced seedling survival (Haasis 1923). Water ponding on the clay surface in spring also may have influenced survival. The few trees we found were often associated with rocky outcrops.

Red Cinder (TES unit 513, low natural regeneration potential)

On five of six sites, the density ranged from 7 to 17 trees/acre, among the lowest of all ecosystems. Low annual precipitation (less than 20 inches) combined with gravelly, sandy-textured soils low in soil moisture probably limited seedling establishment. However, the sixth sample site contained 74 trees/acre--the highest density by more than 27 percent of all 53 sample sites. This site is perplexing because its soil textural class (sandy loam) is the same as the average for this ecosystem, and there were no readily apparent soil or topographic differences with sites that possessed lower densities.

Dry Limestone (TES unit 500, low natural regeneration potential)

Density was 14 to 24 trees/acre at five of six sites, which was in the low half among ecosystems. At these sites, density was likely limited by dry climate and sandy soils low in available water. The site with an unusually low density (6 trees/acre) for this ecosystem had similar soils and topography, and experienced comparable precipitation, but there were more juniper (*Juniperus* spp.) trees, possibly suggesting a marginal site for ponderosa pine or greater interspecific competition.

Black Cinder (TES unit 558, low natural regeneration potential)

Average tree density was medium (18 to 23 trees/acre) in this ecosystem. While there is little understory vegetation, ponderosa pine seedlings with their deep taproots apparently can work their way through the gravelly cinders to silt layers in the subsurface. In this ecosystem, we think that tree density increases when the thickness of the surficial layer of cinders declines or as the silt content increases.

Benmorite (TES unit 570, high natural regeneration potential)

Three of the five sites contained densities of 16 to 27 trees/acre, while the remaining two sites had particularly high densities of 52 and 57 trees/acre. All sites had loam textures for the 0- to 6-inch layer, and 23 to 24 inches of precipitation/year. The two sites with elevated densities did contain 1.7 times more total nitrogen on average than the three low-density sites.

Mixed Igneous (TES unit 551, high natural regeneration potential)

Density was between 24 and 29 trees/acre at four of six sample sites, but comparatively low (6 and 20 trees/acre) at the two other sites. These two sites were northwest and north of the San Francisco Peaks and had the highest precipitation, soil total nitrogen, and cover of understory grasses and sedges within this ecosystem. We think that understory competition may have limited pine establishment on these sites.

Rocky Basalt (TES unit 585, high natural regeneration potential)

Six of seven sites had a tight range of 21 to 29 trees/acre, while the seventh site contained 46 trees/acre. While all sites studied met TES expectations, one site obviously had a much higher density, although we're not sure why.

Moist Limestone (TES unit 536, high natural regeneration potential)

This ecosystem had among the most consistent density among the TES types, ranging from 22 to 34 trees/acre with four of six sites differing by less than 3 trees/acre. Soil texture from 0 to 6 inches is sandier (sandy loam) in this ecosystem than in the basalt-benmorite types (loam-silt loam). This sandier texture may have constrained the ability of this ecosystem to support the particularly high densities found on some sites of the basalt-benmorite ecosystems. On the other hand, this ecosystem did not have the low-density sites we found on the basalt-benmorite ecosystems.

Moist Basalt (TES unit 582, high natural regeneration potential)

This ecosystem had four of the seven densest sites (39 to 58 trees/acre) among the 53 sample sites. The other two sites in this ecosystem, however, contained only 16 and 18 trees/acre, which is not only an anomaly in our study but does not correlate with what the TES predicts in terms of natural regeneration potential. Surface textures on these low-density sites were loams rather than silt loams as in the other sites of this ecosystem. Still, silt + clay content differed little (62 percent on the low-density sites compared to 69 percent on the high-density sites). Precipitation actually averaged 3 inches more on the low-density than on the high-density sites, and all plots had similar topography (slope gradients less than 5 percent). These sites illustrate that chance or factors (e.g., fire regimes) other than those that we measured may be important in explaining exceptions to typical density patterns.

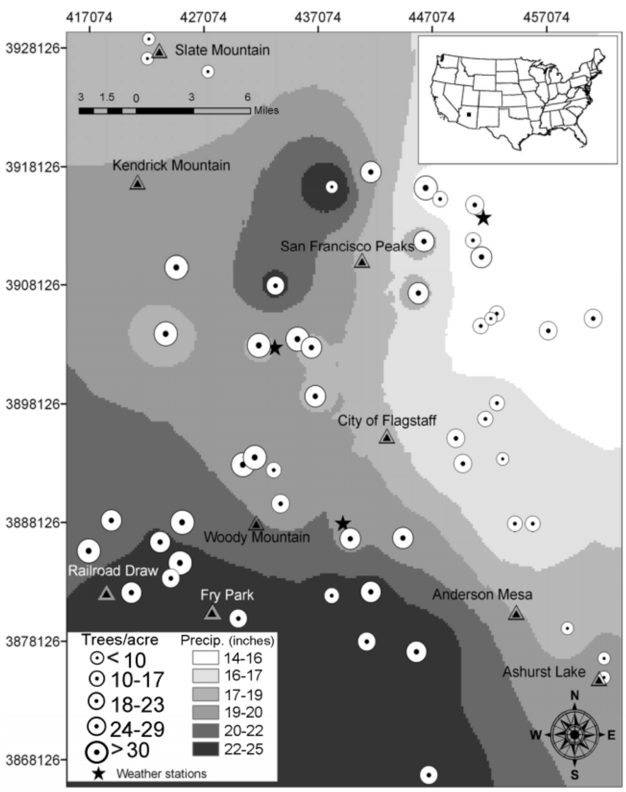

Figure 1. Location of 53 sample sites labeled with their terrestrial ecosystem survey type on a northern Arizona landscape. Sizes of points for sites are scaled to reflect ponderosa pine tree density reconstructed for 1880 forests. Shading depicts gradients in annual precipitation estimated from sample site values using the PRISM model (Daly and others 2008). Coordinates are UTM NAD83.

Limitations

It is important to acknowledge that in any TES many differences in ecosystem properties can occur, even within short distances. In this study, the rather large variations we found in some of the TESUs may be the result of the scale, design, and intended uses of the survey. For instance, most of the units in the Coconino National Forest TES are complexes of two or more dissimilar ecological types that cannot be mapped separately at the scale of 1:24000 (Soil Survey Division Staff 1993). This kind of survey is considered an Order 3 (i.e., it is a mid-level intensity survey) with the minimum size for mapping unit delineations ranging from a low of roughly 5 acres upwards to 40 acres. In addition, all map units have the potential to have inclusions of ecological types (i.e., types that differ from the predominant mapping unit), which in the case of a complex can be as much as 25 percent of the total unit. Thus, if a TESU comprises 50,000 acres within a particular survey area, up to 12,500 acres could be an inclusion with a different set of presettlement evidences and production potentials.

Does this mean the use of TES for broad landscape analysis to determine presettlement tree densities is invalid? Certainly not, the fact that the presettlement densities were generally close in our study indicates that TES can be a valuable tool to determine presettlement tree densities for TES units across the landscape. It should be acknowledged that any outliers encountered in a similar use of a TES are probably the result of 1) an area of a dissimilar soil that was too small to delineate, 2) being located in a soil inclusion within a TESU, or 3) factors associated with tree recruitment that may not be captured by the TES.

Management Implications

- The TES is useful for understanding variation in historical density of ponderosa pine trees across the landscape. The TES correctly categorized 79 percent of 53 sample sites as low-density (less than 24 trees/acre) or high-density (greater than 24 trees/acre).
- The TES is a spatially delineated product (Miller and others 1995) that can help land managers identify ranges of anticipated historical densities within project areas.
- Having these density estimates helps build an understanding of the tree densities that different ecosystems historically supported. These densities may be useful for assessing site capability, evaluating the degree to which forest structure has changed, and preparing tree thinning prescriptions (Figure 1).
- While there will always be anomalies due to the size of the mapping units and other factors, land managers should generally expect drier TES ecosystems to have low to lower tree densities, while more moist ecosystems will contain greater densities.

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