PIONEER FOREST: IN THE HEART OF ROUGHNESS

Richard P. Guyette and Michael C. Stambaugh[1]

Abstract—Landscapes in the Ozarks vary greatly with respect to surface topography. Some are very rough and steep, while others are rolling and smooth. Landscape roughness or *topographic roughness* mitigates and slows the movement and propagation of humans, fire, and commerce across the land. The degree of landscape roughness can be quantified as indices of topographic roughness, calculated here as the ratio of the surface of the earth measured with large and small surfaces. Maps of indices of topographic roughness indicate that Pioneer Forest is one of the roughest landscapes in the Ozark Highlands region of Missouri. Topographic roughness insulates forests from many types of human and natural terrestrial disturbances such as wildland fire. Here, we define and calculate topographic roughness and discuss the relevance of topographic roughness to the natural heritage and silvicultural practices of Pioneer Forest.

PROLOGUE

On the road to Mauser Mill one gets a feel for landscape roughness. The road is bumpy and rocky in every sense of the word. Sharp curves and steep short hills slow the rate of travel, accelerate vehicle wear and tear, and turn back the faint and ill-provisioned. Forests on each side of the road drop down out of sight and define a landscape almost intimidating to the social psyche. Here lies Pioneer Forest 'in the heart of roughness'; a landscape that has resisted the pressures of human population and disturbance for millennia.

INTRODUCTION

Some two decades ago at the Missouri Botanical Garden's Ridgeway Center, an exhibit described the art and sciences that use old trees and tree-rings, in particular eastern red cedar (*Juniperus virginiana*). This exhibition was inspired by the many old eastern red cedars of the Leatherwood Creek area located on Pioneer Forest. We thank Leo Drey for the preservation of such wildlands and forests and for the opportunity to work in this great natural library. Research on landscape ecology that is published and stored in the human libraries of the world and partially derived from the tree rings and forests of Pioneer Forest and the Missouri Ozark Forest Ecosystem Project (Guyette and others 2002) is presented in this paper.

Dendrochronology is the technique of using the annual woody growth increments (e.g., tree rings) of trees to date wood, interpret the information contained in the rings, and answer environmental and cultural questions. Crossdating is the crux of dendrochronology and allows for annual precision in the dating of tree rings and injuries from both live trees and long dead wood. The research presented here began with a tree-ring data base of fire scar occurrence from Pioneer Forest, State forestlands, and the Ozark National Scenic Riverways. A landscape analysis of tree rings, wildfire, and topography is used to address the effects of topographic roughness on Pioneer Forest. We show in a quantitative manner why Pioneer Forest is the 'heart of roughness', and how this has affected its forests. This rough landscape has likely slowed the propagation of people, disturbance, and particularly wildland fire for thousands of years. Topographic roughness inhibits many of the most important causes of disturbance to forest canopies.

If forest management objectives include understanding or mimicking processes of past ecosystems, then an analysis of the topographic roughness of this landscape can yield insightful conservation and silvicultural guidelines. The objectives of this research are to define and calculate topographic roughness in and around Pioneer Forest and to discuss the relevance of topographic roughness to the natural heritage and forestry of Pioneer Forest.

METHODS

Topographic roughness is a relative measure of variability in a landscape surface. Irregularities in the landscape influence the propagation and behavior of fire, particularly in the highly dissected landscape of the Current River region (Guyette and others 2002). In highly dissected landscapes, the propagation of low intensity surface fires across hills and valleys is lessened as the spread rate is slowed and as fire moves downslope because preheating of fuels is less than preheating as fires move upslope. In addition, ravines, creeks, and rivers break fuel continuity, and fuel moisture content increases on northern aspects. We used indices of topographic roughness to reflect topographic inhibition of the propagation of fire across the landscape.

Indices of topographic roughness were developed using Geographic Information Systems (GIS) by comparing surface area measurements made with two different sized scales. A circle, 5000 meters in diameter, is identified on a digital elevation model (DEM). The surface area of the earth circumscribed by this circle is calculated using a 30-m cell (i.e., small scale). Cell slope and a trigonometric conversion are used to estimate the area of the uneven land surface. The cell surface areas are summed and used as an estimate of the uneven surface area of the landscape enclosed by the circle. This estimate is divided by the planimetric surface area (i.e., large scale) of a circle that is 5000 meters in diameter. This ratio of the small-scale surface area to the large-scale surface area is the Index of Topographic Roughness. In short, the topographic roughness value of an individual place represents the amount of variability in the landscape surface around that place. We describe the relationship between historic mean fire intervals and their respective topographic roughness indices using correlation analysis.

[1] Richard P. Guyette, Associate Professor, and Michael C. Stambaugh, Research Specialist, University of Missouri, School of Natural Resources, Columbia, MO 65211.

RESULTS AND DISCUSSION

Topographic roughness index values are classed and mapped for the region in and around the Current River Hills (Nigh and Schroeder 2003) and Pioneer Forest (fig. 1). Topographic roughness increases from horizontal and rolling landscapes (fig. 1, lighter shaded areas) to rough and steep landscapes (fig. 1, darker shaded areas). Index values range from approximately 1.000 (i.e., perfectly smooth and level) to 1.044 (i.e., rough) in this region.

The topographic roughness map (fig. 1) illustrates that Pioneer Forest is one of the roughest regions in the Current River Hills and located within a topographically rough region, the Ozark Highlands. The topographic roughness of the region is due to the erosion of bedrocks and soils by precipitation and the down cutting of streams and rivers. Complex subsurface geology, such as the near surface Precambrian geology that underlies the Current River Region, can create variable uplifting and fracturing of surface sedimentary rocks. Surface and ground water hydrology may cause variable patterns of erosion and topographic roughness. For example, just southeast of Van Buren (fig. 1) is an area of topographic roughness we termed the "Big Springs butterfly", a pattern in topographic roughness that is underlain by a peak in subsurface Precambrian igneous rock (Kisvarsanyi 1981). Pioneer Forest just south of Mauser's Mill is anomalously topographically rough. This area is underlain by a ring intrusion of granite that may contribute to increased

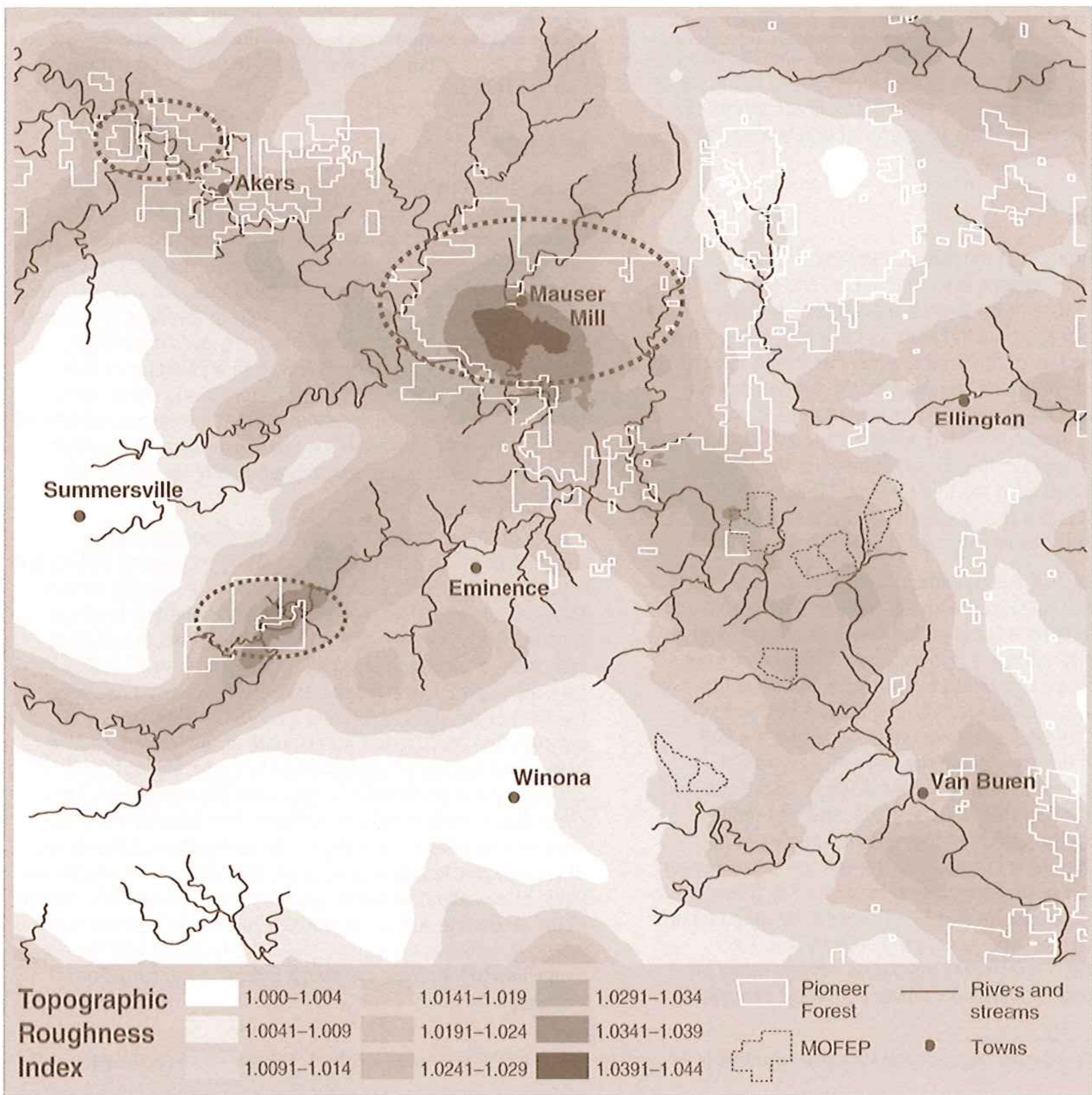

Figure 1—Variation in topographic roughness in the Current River region. The lighter shades represent topographically smooth landscapes, whereas the darker shades represent rough landscapes. The regions of large Pioneer Forest holdings are circled with dashed ellipses and have some of the highest calculated topographic roughness indices values.

topographic roughness. These examples are evidence that riparian erosional processes, surface bedrock, and subsurface geology influence topographic roughness.

Topographic roughness mitigates the rate and movement of fire, vehicles, commerce, and human travel. This mitigation is evident in fire history data (Guyette and Dey 2000) and the speed limits, curvature, surface type, and distribution of roads. Thus, many of the anthropogenic disturbances to the forest canopies are minimized by the reduced fire frequency and access in areas surrounded by landscapes with high topographic roughness. Topographic roughness is likely associated with many biological processes. The association with different variables is both causal and incidental. For instance, topographic roughness may be associated with the slope of a site but has little to do with slope effects on soil hydrology that influence the abundance of certain plants. On the other hand, there are causal relationships, such as the direct effect of topographic roughness on the rate of propagation of surface fires, which are the primary objective of quantifying and mapping topographic roughness. There are also the secondary effects of topographically mitigated disturbance, such as the size of a canopy disturbance, canopy density, and forest structure.

Topographic roughness has been associated with mean fire intervals (Guyette and Dey 2000, Guyette and others 2002). The relationship between topographic roughness and the time between fires was positive, particularly when human population densities were low (Guyette and Dey 2000). Fire scar chronologies within Pioneer Forest have some of the longest mean fire intervals in the Current River region during the period just before Euro-American settlement circa 1820 (Batek 1999). For example, the mean fire interval between 1620 and 1700 for Big Creek (16 years) in the heart of Pioneer Forest is 3 times longer than that of Hartshorn State Forest (5.3 years), a more topographically smooth region to the east. During more recent and more densely populated periods, this difference disappears, and fire intervals at both sites shorten to 2.8 years by the late 1800s.

A portion of Pioneer Forest (fig. 2) was mapped for mean fire intervals (average time between fires in a 1.5-km area) during the period 1700 to 1820. This map was calculated from regression equations that used several thousand fire scars, indices of topographic roughness, fuel quantity, fuel moisture, and human population density (Guyette and others 2003). Modeled mean fire intervals on this part of Pioneer Forest ranged from about 10 to 50 years. These intervals are up to 10

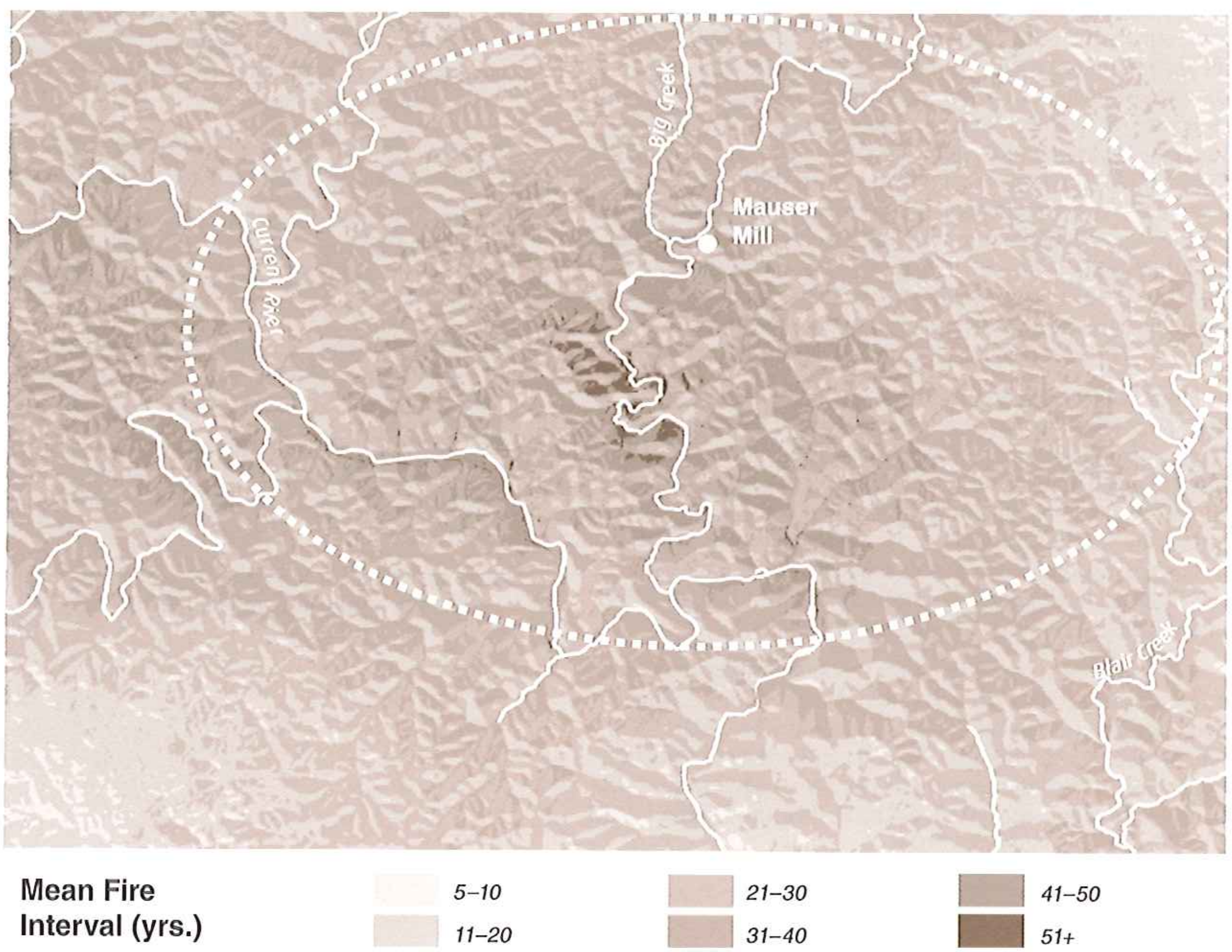

Figure 2—Reconstructed mean fire intervals for part of Pioneer Forest between 1700 and 1780 that are partially modeled with topographic roughness. *(Guyette and others 2003)*

times longer than those calculated for less topographically rough areas of the Ozarks.

The topographic roughness map (fig. 1) shows that Pioneer Forest is in one of the most topographically rough landscapes in the Ozarks. This has several implications for conservation plans and forest management practices given that management goals are designed to mimic the historic disturbance regimes, such as the frequency of fire. Three important points may be considered when comparing forest management to forest disturbance with the disturbances estimated from pre-Euro-American fire frequency and topographic roughness.

1. Fire disturbance was less frequent at Pioneer Forest in comparison to much of the greater Current River Hills region because of the relatively high degree of topographic roughness. This was particularly the case prior to 1820 when the propagation of fire contributed greatly to the fire frequency in a given location. The role of fire in influencing vegetation was reduced, particularly in the Big Creek vicinity of Pioneer Forest, because of the low frequency of fire. A reconstruction of the vegetation in this area from General Land Office Survey notes (1815-1850) showed a dominance of white oak (*Quercus alba*) in a closed canopy forest structure (Batek and others 1999, Hughes and Nigh 2000) relative to many adjacent forests. White oak, which is shade tolerant and fire sensitive, was competitive in this low frequency disturbance regime. Forest management that mimics the historic frequency and size of canopy disturbance would likely maintain a more closed canopy structure. For example, tree harvesting would be limited to small areas where there were single-tree or small group canopy disturbances. The removal of one to several trees from any given area is a management approach already employed by Pioneer Forest's single tree selection practices. The silvicultural practice used on Pioneer Forest mimics the scale of the pre-Euro-American canopy disturbance regime as predicted by corollaries of topographic roughness and as supported by studies at the MOFEP sites (Guyette and Kabrick 2002).

2. Topographic roughness and legacies of its effects likely have long-term influence on forest communities, particularly resident populations of forest interior wildlife. At Pioneer Forest, conservation and temporal continuity of certain indigenous species would be maintained or promoted with small-scale disturbances as they would represent the long-term disturbance frequency related to topographic roughness. Topographic roughness may be positively correlated to forest bird territories in the Ozark region (Guyette and Kabrick 2002).

3. If Pioneer Forest lies in the most topographically rough region of the Ozarks and has the least often disturbed forest canopy and litter layer in the Current River Hills, we would expect to find an abundance of species that are sensitive to disturbance, particularly to fire. This hypothesis has been tested and seems plausible for many ecosystem variables measured at the MOFEP sites (Guyette and Kabrick 2002).

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