THE EFFECTS OF HUMANS AND TOPOGRAPHY ON WILDLAND FIRE, FORESTS, AND SPECIES ABUNDANCE

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Abstract—Ignitions, fuels, topography, and climate interact through time to create temporal and spatial differences in the frequency of fire, which, in turn, affects ecosystem structure and function. In many ecosystems non-human ignitions are overwhelmed by anthropogenic ignitions. Human population density, culture, and topographic factors are quantitatively related to fire regimes and the long-term pattern in fire frequency and species composition. These factors can be quantitatively related and used to reconstruct and predict the frequency of fire in ecosystems and to identify changing factors involved in anthropogenic fire regimes. Quantitative fire histories from oak-pine sites in Arkansas, Indiana, Missouri, and Ontario are used to examine patterns of interaction in fuels, ignitions, and topography over a period of 300 years. Fire regimes and fire frequencies are associated with the abundance of many species of reptiles, birds, fungi, and plants. Human population density and topographic roughness are master variables in understanding temporal and spatial differences in fire regimes and their effects on ecosystems.

INTRODUCTION

Temporal and spatial differences in the frequency of fire effect ecosystem structure and function. In many fire regimes non-human ignitions are overwhelmed by anthropogenic ignitions. Consequently, human population density, culture, and topography control ignition in these fire regimes affect the long-term disturbance frequency and species composition. These factors can be quantitatively used to predict the frequency of fire in ecosystems. The interactions of fuels, ignitions, and topography as they affect the fire regime over a period of 300 years can be derived from analyses of fire history data.

The scale, frequency, and legacy of disturbance regimes and their effects on the distribution of forest species also have important management, policy, and political implications. Debates about even-aged versus uneven-aged management, or no timber harvesting often hinge on what is natural, or what was the pre-European disturbance regime. Managers and policy makers are often interested in mimicking natural disturbance regimes with silvicultural prescriptions to foster native plant and animal species diversity (Loucks 1970). The species composition of Ozark forest ecosystems is a legacy of their long-term disturbance regimes. Thus, fire regimes and fire frequencies are associated with the abundance of many species of reptiles, birds, fungi, and plants in the Ozarks. Knowledge of these regimes and their effects is valuable for understanding present-day forest species composition and structure. We show the long-term affects of anthropogenic disturbance and topographic roughness on forests, flora, and fauna using data from the Missouri Ozark Forest Ecosystem Project (MOFEP), a long-term study initiated to quantify forest management effects on flora and fauna (Brookshire and others 1997; Brookshire and Hauser, 1993). The goal of this paper is to illustrate how anthropogenic disturbance and topography have been major factors affecting disturbance frequency at the MOFEP sites and that historic disturbance regimes have a legacy that continues to affect contemporary plant and animal distributions today.

FIRE HISTORY SUMMARY

The three important factors that determine fire regimes in oak-dominated ecosystems are topographic roughness, human population density, and culture. Specifically, the roughness of the topography around a site mitigates the propagation of disturbance related factors, such as fire, logging, and human travel into a site. Topographic roughness is positively correlated with the length of mean fire intervals. Consequently, fires are less frequent in rough than in flat terrain, especially during periods of limited anthropogenic ignitions (fig. 1). The strength and direction of the topographic effect diminishes as the spatial and temporal frequency of anthropogenic ignitions increases to a point of pyro-saturation (ignitions occur throughout the landscape and fuels are burned as soon as they are able to support the spread of a fire). Since topography generally changes through time very slowly, its influence on fire regimes is not only long-term but dates to long before the first effects of human ignitions.

Fire has been an integral tool in the lives of humans for many thousands of years. Thus, humans are a potential and dynamic source of ignition, when and wherever they are present and irrespective of whether landscape burning is promoted (Pyne 1982, 1995) or suppressed (Westin 1992). The early records of fire history support the idea that fire frequency is a function of potential human ignitions. Fire frequency has been correlated with human population in a number of studies (Dey and Guyette 2000, Guyette and Dey 1997, Guyette and others 2002). The positive relationship between population density and fire frequency diminishes as ignitions become more frequent and fuels fail to accumulate. As population density increases further, fire frequency lessens due to change in land use and fire suppression.

Cultural values have influenced wildland fire use and suppression in different ways through time. Historically fire was used to improve travel, for hunting wild game, to

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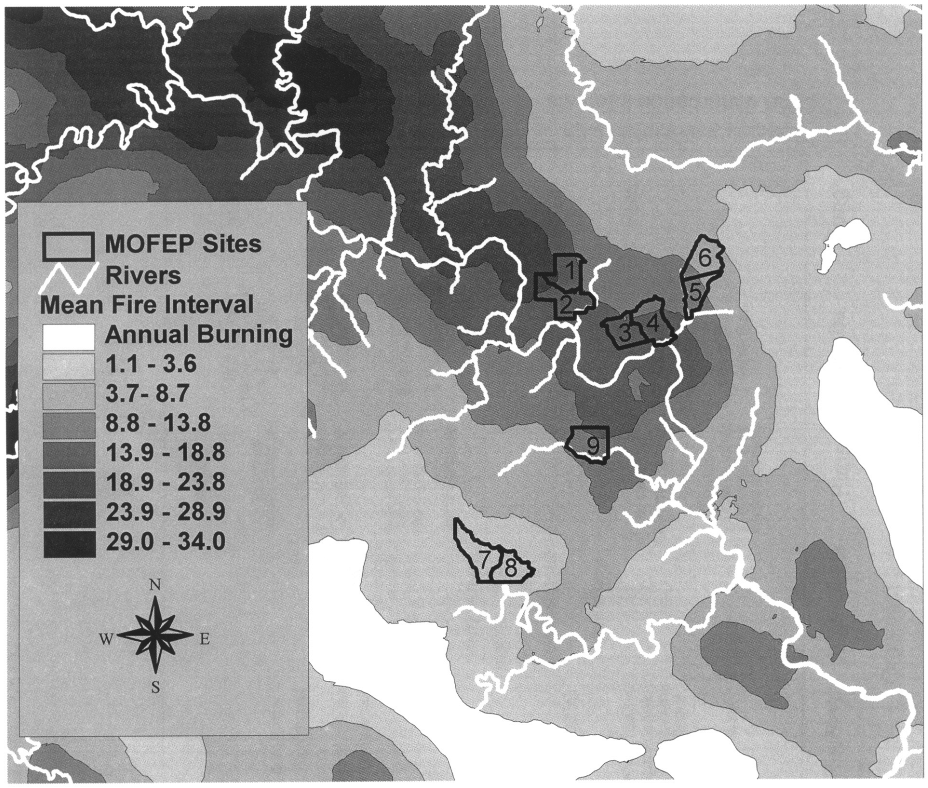

Figure 1—Landscape roughness and human population are major factors in disturbance regimes. Here, mean fire intervals are mapped for the period 1700-1780 in the MOFEP study region. Fire intervals are based on the model: MFI = -442.1 + (449.9 x topo) -(0.001 x pop), where MFI is the mean fire interval, topo is an Index of topographic roughness, pop is the natural log of human population density times the square of river mile (Guyette and Dey 2000). Numbers are site designations and locations for the nine MOFEP sites.

promote nut and berry production, to prepare sites for agriculture, to improve browsing and grazing conditions, etc. But as a timber economy developed, and people built homes in the hinterlands, suppressing fire became a necessity. In the modern era, cultural values have become the most important factors controlling fire frequency as increasing population density increases the risk of wild fire to human safety and economics. Good pasture may require burning while defect free timber may require fire suppression. Unlike incidental anthropogenic ignitions (proxy: human population density), which stem directly from basic human requirements for cooking, transport, warmth and safety, value oriented cultural constraints on wildland fire originate from our societies economic system. This includes fire suppression for perceived and real safety as well as prescribed fire for ecosystem diversity, safety, and silvicultural purposes. The artifact of fire suppression (the human separation of ignition and fuels) creates its own dangers especially since fuel and economic conditions can be highly variable through time.

LONG-TERM LEGACY OF FIRE, DISTURBANCE, AND SPECIES GROUPS

Landscape level fire histories and species population data allow for the study of species abundance, distribution, and *beta* diversity within a region. Species groups are sensitive to the long-term effects of fire and forest disturbance as shown by the data collected on a wide array of species as part of the Missouri Ozarks Forest Ecosystem Project (Brookshire and Shifley 1997). Data on plant and animal abundances (Kabrick and others 1997, Bruhn and others 1997, Clawson and others 1997, Grabner and others 1997, Renkin 1997, Fantz and Renken 1997) at nine sites in the Ozarks are associated with regional differences in the historic fire and disturbance regimes as quantified by an index of disturbance (Guyette and Kabrick, 2002). Disturbance interval indices are correlated with the abundance of tree species, small mammals, reptiles, amphibians, birds, herbaceous plants, fungi, oak species in the overstory, and ground flora (fig. 2). Trees, reptiles, birds, herbaceous plants, and *Armillaria* species, as groups, all show sensitivity to long-term disturbance regimes. This may be a positive or negative association with fire and disturbance. Amphibians show a lower sensitivity to disturbance. The low sensitivity of amphibians to disturbance may be explained by their subterranean habitat (e.g., salamanders), which may buffer them from aboveground disturbances and by the limiting effects on populations of scarce breeding habitat (water bodies) in the MOFEP study area.

Fire and disturbance result in changes in the distribution of light and spatial structure of forests that, in turn, regulates microclimate (i.e., light, temperature, humidity and moisture). Species have adapted to niches created by varying frequencies of disturbance. In the southeastern Ozarks,

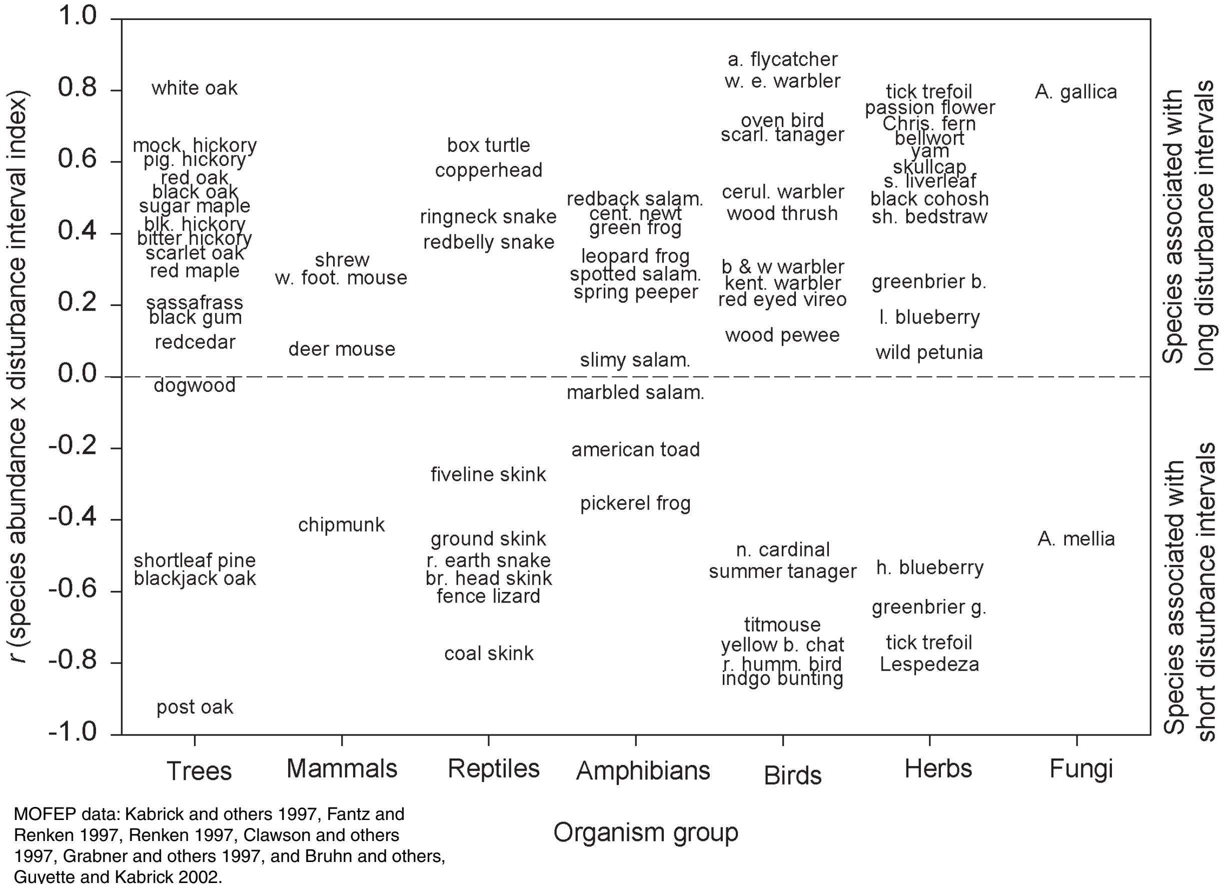

Figure 2—The association between fire and disturbance and the abundance of 75 species by group. Species near a correlation of 1 on the y-axis are strongly and negatively associated with frequent disturbances. Species near a correlation of -1 on the y-axis are strongly and positively associated with the frequent disturbances. Species near a correlation of 0 on the y-axis are not strongly associated with the frequency of disturbance. Significant ($p < 0.05$) correlations for a single species-disturbance test are greater than 0.60 or less than -0.60. While the power of an individual species test is low (only 9 sites), differences in the sensitivity of species groups to disturbance are evident.

several closely related species (fig. 2) are associated with very different frequencies of disturbance in the same region. The abundances of some closely related (in the same genus) trees, birds, and fungi (*Armillaria* spp.) have contrasting correlations with the frequency of disturbance (table 1).

Post oak (*Quercus stellata*), summer tanagers (*Piranga rubra)*, and *Armillaria mellea* are found at sites with frequent disturbance while white oak (*Quercus alba*), scarlet tanagers (*Piranga olivacea)*, and *Armillaria gallica* are found in forests with less frequent canopy disturbance.

Table 1—Correlation coefficients among genus pairs and disturbance illustrate how closely related species at the Missouri Ozark Forest Ecosystem Project sites are often very different in their association with long-term disturbance frequency[a]

Genus	LS species, r	ES species, r	Difference[b], r
Quercus	*alba,* ***+0.92***	*stellata,* ***-0.96***	*alba-stellata,* ***+0.97***
Armillaria	*gallica,* ***+0.88***	*mellea, -0.49*	*gallica-mellea,* ***+0.84***
Piranga	*olivacea,* ***+0.68***	*rubra, -0.55*	*olivacea-rubra,* ***+0.79***

[a] Correlation coefficients are for the disturbance interval index (Guyette and Kabrick 2002) and species abundances at the nine sites. Note the opposite signs of correlation coefficients by different species within the same genus.
[b] Difference is the abundances of early successional (ES) species subtracted from late successional (LS) species. Significant ($P < 0.05$) correlations are shown in bold.
Source: Bruhn and others (1997); Clawson and others (1997); Guyette and others, in press; Kabrick and others (1997).

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