FOREST FUELS AND LANDSCAPE-LEVEL FIRE RISK ASSESSMENT OF THE OZARK HIGHLANDS, MISSOURI

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Abstract—In this paper we describe a fire risk assessment of the Ozark Highlands. Fire risk is rated using information on ignition potential and fuel hazard. Fuel loading, a component of the fire hazard module, is weakly predicted ($r^2 = 0.19$) by site- and landscape-level attributes. Fuel loading does not significantly differ between Ozark ecological landtypes. Drought and exposure are related to fuel moisture content. Drought is particularly important to the Ozark fire regime and fire risk as it is related to both ignitions and fuels.

INTRODUCTION

In recent decades much attention has centered on the occurrence of wildfires and the concomitant changes in vegetation, climate, and human population. Despite over 15,000 fires occurring annually in the Central Hardwoods Region (National Fire Occurrence Database 2001), little work has been done to assess fire risk. The high number of fire events and relatively low level of concern supports the widely recognized fact that the region's fire risk is much lower than that of western states. Although unrealized, extreme drought conditions enhance the potential for high fire risk in the Central Hardwoods.

The importance of fire risk information lies in understanding its spatial and temporal variability, knowledge that can be used for a variety of purposes. Managers can prioritize areas for fuel reduction treatment and integrate fire risk into regional fire plans. Community and rural fire district managers can use fire risk information to improve protection and response to fires (Winter and Fried 2001). Forest harvesting schedules can be planned and optimized to reduce fuel hazard (Englin and others 2000).

OZARK FIRE REGIME

For over 400 years the fire regime of the Ozark Highlands has been influenced by humans (Guyette and Dey 2000, Guyette and Spetich 2003). The historic frequency of burning was largely a result of changing human population and culture (Guyette and others 2002). Today, human ignitions represent over 98 percent of the total ignitions (1980-2003; Missouri Department of Conservation fire data) and their number is highly correlated to drought. Arson is the largest cause of human ignitions. Year to year changes in number of acres burned are correlated (r = .61) between state lands and the Mark Twain National Forest suggesting a larger scale influence on fire occurrence (data: Westin 1992, National Fire Occurrence Database 2001, USFS Missouri fire records unpublished data). Previous studies have characterized the dynamics of surface fires and vegetation in the Ozarks (Jenkins 1997, Batek and others 1999, Kolaks 2004, Nigh 2004). Mean fire size in the Ozark Highlands is about 31 acres and 54,502 acres burn annually on average (1939-2003: Missouri Department of Conservation data, Westin 1992). Before European settlement, 250,000 acre fires were estimated to have occurred at least once per century in the Current River watershed (Guyette and Kabrick 2002)-an area that represents about 8 percent of the Missouri Ozark Highlands. Even larger fires occurred during extreme drought years [e.g., 1780 (Guyette and others 2002)]. Due primarily to fire suppression, average annual fire size in Missouri has decreased exponentially from about 100 acres to 15 acres during the period 1939 to 2001.

FIRE RISK MODEL

A fire risk model is being developed from current and historic fire records to provide information for fire preparedness and prevention (USDA and others 2002). Fire risk is defined as the probability of a fire

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of a specified severity happening during a given period, in a given area (Preisler and others 2004). Fire risk assessments provide a means for quantifying fire risk and prioritizing fire management activities on multiple spatial scales (Haight and others 2004). Multiple approaches have been taken to assess fire risk including theory-based functions (Prestemon and others 2002), analysis of satellite imagery (Maselli and others 2003), and landscape simulation models (Shang and others 2004). For the Ozarks, a large set of landscape-level data makes possible an index modeling approach for fire risk assessment. Fire risk indices are used to classify a landscape into incremental levels (e.g., low to high). The model is based on two modules: ignition potential and fuel hazard (fig. 1). Ignition potential is rated using data on human population, topographic roughness, roads, and suppression potential. Similarly, fuel hazard is estimated from data on fuel loading, fuel moisture, vegetation, precipitation, land-use, and multiple topographic

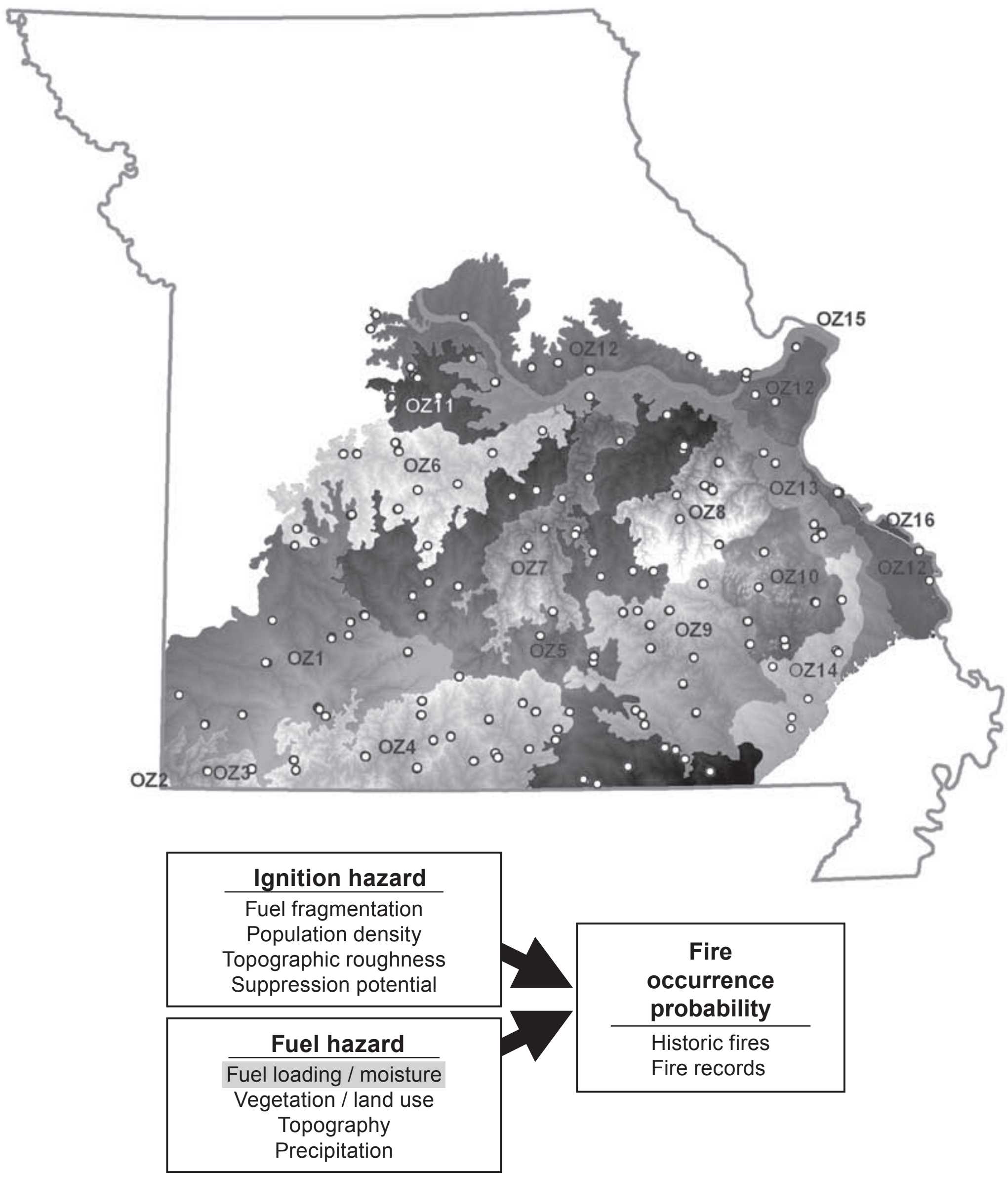

Figure 1—(Top) The Ozark Highlands section of Missouri with 16 ecological subsections. Subsection names are given in table 1. Small circles are locations of fuel loading plots (n = 1030). (Bottom) Conceptual model showing integration of fuel loading and moisture data into the fuel hazard module of the fire risk assessment model.

features. In our model, fuel loading is based on a region-wide collection of fuels data, which is unlike many models that do not include empirical fuel loading data.

In this paper, we describe results of the Ozark Highland region-wide fuel measurements. Fuel data and relationships will be used in the development of the fuel hazard module for the assessment of fire risk. The objective of this paper is to describe the regional fuel variability and discuss its relevance and use in fire risk assessment.

METHODS

Fuel Loading

Utilizing ESRI® ArcGIS™ v 9.1 (Environmental Systems Research Institute 2005), ecological subsections (Nigh and Schroeder 2002) were identified within the Ozark Highlands section of Missouri (fig. 1). One hundred fifty-nine fuel transect locations were randomly placed within 17 subsections. The number of transects per subsection was weighted by subsection area. Transect locations were moved to the nearest forested public property ownership within the same subsection. Ownerships included state conservation areas, national forest lands, and state and county parks. Transects consisted of multiple fuel loading plots using methods described by Brown (1974) with modification. Transects were randomly located within forested areas. Transect bearings were randomly chosen from a predetermined bearing range that ensured crossing landforms and that varied in location, topography, and vegetation. Three to ten fuel plots were sampled per transect depending on forested area and landform. A total of 1,030 fuel loading plots were sampled across the region, and their locations were recorded by a GPS and entered into a GIS. Data were collected from July 2004 through June 2005, a period of highly variable drought conditions.

Fuels were tallied and measured in four size classes (0.0-0.25 inch (1-hour), 0.26-1.0 inch (10-hour), 1.01-3.0 inch (100-hour), and > 3 inch (1000-hour)). No differentiation was made between solid and rotten 1000-hour fuels. Fuel loading constants, specific gravities, and squared average-quadratic-mean diameters are unavailable for most tree species in the Central Hardwoods Region. Thus, constants for fuel calculations were derived from several sources (Brown 1974, Adams and Owens 2001) including field measurements of fuels. At each plot we collected data on species composition, elevation, slope, aspect, slope shape and position, basal area, percent ground cover (leaves, needles, herbaceous plants, bare soil), estimate of down dead wood, number of snags > 3 inches dbh, small diameter stem density, moisture content of 1000-hour fuel, and evidence of past fire. Moisture content of 1000-hour fuels was measured with a Protimeter® hand-held moisture meter on stems at least 3 inches in diameter and 1 foot above the forest floor. Additional GIS data were spatially joined to the plot data. These data included elevation, precipitation, topographic roughness (Guyette and Dey 2000), land-use, vegetation, and geographic coordinates (decimal degrees, UTM, Zone 15N). Spatial trends in litter loading were examined using ArcGIS™.

Fuel loading data were summarized by ecological subsection and tested for normality using the Shapiro-Wilk test (SAS/STAT 2002). Fuel loading data were modeled for the purpose of predicting region-wide fuel variation. Combinations of fuel variables were developed from the original litter and time-lag class fuel data, and a model was constructed describing fuel variation using multiple regression. We chose the simplest model whose relevance could be verified both statistically and biologically.

Litter and Moisture

In mixed hardwood forests of the Ozark Highlands, much of the energy released during fires results from combustion of litter (i.e. leaves, needles, twigs,) and 1-hour fuels (Kolaks 2004). For this reason, emphasis is placed on the litter layer for the purpose of evaluating risk and understanding landscape variation in litter loading. We measured litter depth (cm) at 3 points at each fuel loading plot (n = 3,090). In a separate experiment we measured litter loading using randomly placed 0.5 m^2 clip plots located in the Current River Hills (Guyette and others 2003, 112 plots) and Outer Ozark Border subsections (51 plots). Litter collection was completed within a two day period so that sampling time and date had minimal effect on moisture content. Litter was placed in sealed plastic bags, weighed at field moisture content, and then dried at 60° C until weight became constant. Percent moisture content was calculated by dividing the weight of water in the litter by the oven-dried weight of the litter and then multiplying by 100. Repeated collections (September 2004, March 2005, June 2005) were made at clip plots located in the Outer Ozark Border for the purpose of understanding within year temporal changes in loading and moisture. Regression analysis was used to develop equations that relate litter loading and moisture content to landscape variables. Both litter and 1000-hour fuel moisture contents were correlated against monthly divisional Palmer Drought Severity Index data (Palmer 1965, National Climate Data Center 1994). As drought conditions increase, it is hypothesized that the differentiation in litter moisture by solar exposure is lessened.

RESULTS AND DISCUSSION

Fuel Loading

Total fuel loading averaged 4.5 tons per acre and ranged from 0.1 to 70.3 for all Ozark plots (table 1). Mean 1-hour and mean 10-hour fuel loading were similar among all Ozark subsections. Trend analysis indicated a small decrease in 1-hour and 10-hour fuel loading along a north to south Ozark gradient, and geographic location was a significant variable in predicting total fuel loading (see below). None of the fuel time-lag classes were normally distributed ($p < 0.0001$) (figs. 2 and 3). High variability existed in 1000-hour fuel loading with the majority of plots having no 1000-hour fuels and 51 plots having over 15 tons per acre. The majority of plots with high 1000-hour fuel loading (>15 tons per acre) had usual levels of tree mortality; however, many of the highest loadings (e.g., > 50 tons per acre) resulted from forest management activities and windthrow disturbance. Fuel loadings between time-lag classes are correlated because larger fuels are typically connected to and provide smaller fuels.

Multiple regression analysis of landscape variables on plot fuel loading resulted in a four variable model ($r^2 = 0.19$, $p < 0.0001$, all variables and intercept significant, $p < 0.0001$):

$$FUEL = -417.33 + (1.76^{*}10^{-5})^{*}tri + 0.08^{*}elev + 0.07^{*}ba - (5.48^{*}10^{-12})geo$$

where

FUEL = litter depth (cm)*[log(tons of 1-hour fuel]+log(tons of 10-hour fuel)+log(tons of 100-hour fuel)
tri = an index of topographic roughness (Guyette and Dey 2000)
elev = elevation in m
ba = basal area
geo = (-1* y UTM coordinate)*(x UTM coordinate)

Although significant, the fuel model explains a low percentage of fuel variation, suggesting that little regional variability in fuel loading exists. In a separate study within the Current River Hills subsection no significant differences were found in fuel loading between forest types (Personal communication. 2005. Keith Grabner, Community Ecologist, USGS Columbia Environmental Research Station, 4200 New Haven Rd., Columbia, MO 65201). Model variables, spatial fuel loading trends, and fuel statistics support that both large- and small-scale factors influence fuel variation within the Ozark Highlands.

Litter and Moisture

Decomposition causes total forest litter depth to decrease between litter fall events. However, our measurements of litter loading showed erratic changes in litter depths between the three collection dates likely due to the high spatial variability in litter within small extents (e.g., 3 m) and the movement of litter by wind (e.g., leaves). Fifty-nine percent of the plots decreased in litter loading from September 2004 (pre-leaf fall) to March 2005 (post-leaf fall) and 61 percent increased from March 2005 to June 2005. Maximum litter loading occurred when basal area was approximately 150 square feet per acre and decreased as basal areas deviated both above and below this stand density.

Table 1—Summary of fuel loading for Missouri Ozark Highlands ecological subsections

Ozark ecological subsections	Subsection code	Fuel transects, (plots)	Fuel loading (tons per acre)														
			1 hour			10 hours			100 hours			1,000 hours			Total		
			mean	*s.d.*	*range*	*mean*	*s.d.*	*range*	*mean*	*s.d.*	*range*	*mean*	*s.d.*	*range*	*mean*	*s.d.*	*range*
Springfield Plain	OZ1	19 (115)	0.1	0.1	0 – 0.6	0.3	0.1	0 – 0.7	1.1	1.2	0 – 8.8	2.9	6.2	0 – 36.9	4.4	6.4	0.1 – 36.8
Elk River Hills	OZ3	2 (14)	0.1	0.1	0 – 0.4	0.3	0.1	0.1 – 0.5	1.5	0.7	0.4 – 2.8	4.5	5.1	0 – 15.6	6.4	5.7	1.1 – 18.8
White River Hills	OZ4	17 (112)	0.1	0.1	0 – 0.4	0.3	0.2	0 – 1.0	1.2	1.0	0 – 4.9	2.3	4.7	0 – 25.4	4.0	5.1	0.2 – 31.0
Central Plateau	OZ5	26 (158)	0.1	0.1	0 – 0.3	0.2	0.2	0 – 1.3	1.1	0.8	0 – 6.2	3.5	7.2	0 – 51.2	5.0	7.4	0.1 – 53.4
Osage River Hills	OZ6	14 (94)	0.1	0.1	0 – 0.4	0.2	0.2	0 – 1.5	1.1	1.2	0 – 8.8	7.6	8.0	0 – 68.9	3.7	8.3	0.1 – 70.3
Gasconade River Hills	OZ7	11 (68)	0.1	0.1	0 – 0.4	0.2	0.1	0 – 0.6	0.8	0.8	0 – 4.2	3.1	5.8	0 – 26.0	4.2	5.6	0.1 – 27.1
Meramec River Hills	OZ8	8 (53)	0.1	0.1	0 – 0.3	0.3	0.1	0 – 0.5	1.1	1.0	0 – 6.2	4.0	6.5	0 – 30.8	5.4	6.5	0.3 – 32.6
Current River Hills	OZ9	15 (112)	0.1	0.1	0 – 0.4	0.2	0.1	0 – 1.5	1.3	0.9	0 – 6.2	4.1	6.1	0 – 29.3	5.8	6.6	0.3 – 31.8
St. Francious Knobs and Basins	OZ10	6 (37)	0.1	0.1	0 – 0.2	0.3	0.2	0 – 0.4	0.9	0.6	0 – 2.9	1.7	2.9	0 – 12.7	2.8	3.2	0.1 – 15.9
Prairie Ozark Border	OZ11	5 (31)	0.1	0.1	0 – 0.4	0.3	0.2	0 – 1.1	0.8	0.6	0 – 2.2	2.5	6.7	0 – 36.5	3.8	6.8	0.2 – 38.0
Outer Ozark Border	OZ12	16 (106)	0.1	0.1	0 – 0.4	0.2	0.2	0 – 0.9	1.1	0.7	0 – 3.3	4.3	8.2	0 – 44.9	5.8	8.4	0.1 – 47.1
Inner Ozark Border	OZ13	11 (73)	0.1	0.1	0 – 0.3	0.3	0.1	0 – 0.9	0.7	0.7	0 – 4.0	1.8	3.6	0 – 24.4	2.9	4.0	0.1 – 28.7
Black River Ozark Border	OZ14	7 (46)	0.1	0.1	0 – 0.3	0.2	0.1	0 – 0.5	0.8	0.6	0 – 3.0	2.1	4.1	0 – 23.6	3.2	4.3	0.1 – 24.9
Missouri River Alluvial Plain	OZ15	1 (5)	0.2	0.1	0.1 – 0.3	0.3	0.1	0 – 0.4	1.6	0.7	0.7 – 2.6	15.1	13.4	0 – 36.4	17.1	13.5	1.1 – 37.6
Mississippi River Alluvial Plain	OZ16	1 (6)	0.1	0.04	0.1 – 0.2	0.2	0.1	0 – 0.3	0.5	0.4	0 – 1.1	1.0	2.2	0 – 5.9	1.8	2.1	0.3 – 6.5
All (Ozark Highlands Section)			0.1	0.1	0 – 0.6	0.3	0.2	0 – 1.5	1.0	0.9	0 – 8.8	3.1	6.5	0 – 68.9	4.5	6.7	0 – 70.3

Source: Nigh and Schroeder (2002).
s.d. = standard deviation.

1-hour	0.11 tons/acre	1-hour	0.14 tons/acre	1-hour	0.16 tons/acre
10-hour	0.19 tons/acre	10-hour	0.31 tons/acre	10-hour	0.06 tons/acre
100-hour	1.80 tons/acre	100-hour	6.20 tons/acre	100-hour	1.48 tons/acre
1,000-hour	0.0 tons/acre	1,000-hour	4.40 tons/acre	1,000-hour	28.50 tons/acre

Figure 2—Three examples of fuel loading illustrating the physical variability of the four time-lag fuel classes.

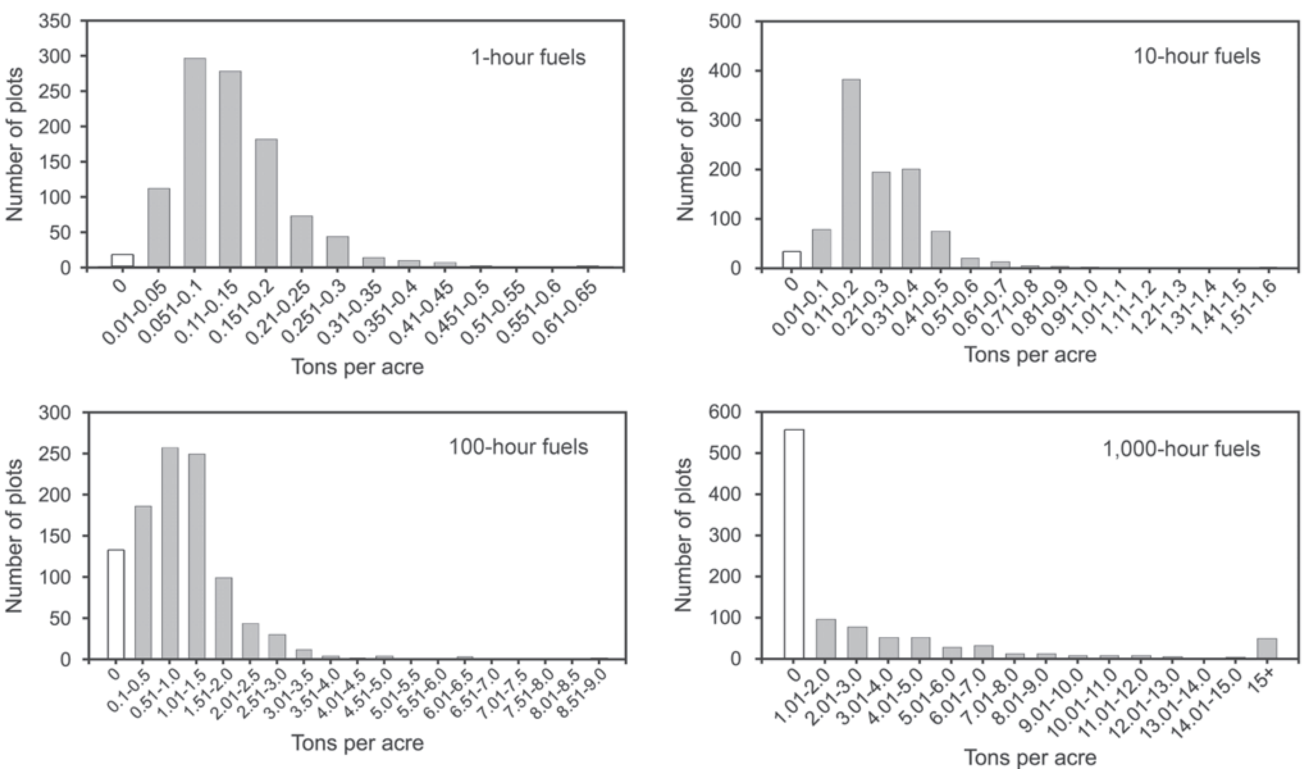

Figure 3—Histograms of the four fuel time-lag classes. Scales of x- and y-axes differ between graphs.

Percent moisture content (PMC) of litter was a function of solar exposure. Differences in PMC were greatest when conditions were slightly wet (PDSI = 1.0 - 1.99). The equation describing PMC of litter during incipient wet (0.5 - 0.99) conditions is:

$$PMC = 63.2 - 18.4^{*}\left(exposure\right)\left(r^2 = 0.43, p < 0.01\right)$$

where
exposure = COS(3.1415/180*(180-aspect))+1.

During wetter conditions no relationship existed between PMC and solar exposure, and during drier conditions the differentiation in PMC is lessened (fig. 4). During mild droughts (PDSI = -1.95) PMCs, regardless of exposure (i.e., aspect), became nearly equal or "undifferentiated dry". This is similarly true during extreme wet conditions when PMCs are "undifferentiated wet" by exposure. Assessment of the equation's predictive ability in modeling the spatial patterns in PMC during various PDSI conditions would be valuable, however requires additional collections during wet and dry extremes.

Drought has been an important component of the Ozark fire regime for centuries, even during the recent period (1940 to present) of fire suppression. Drought influences multiple components of the Ozark fire regime including the number of acres burned, average fire size, fire severity (percent trees scarred), and number of arson fires (Guyette and others, in press). Understanding the effects of drought on ignition potential and fuel hazard would be valuable, particularly for the assessment of fire risk.

Both fire hazard and ignition potential can be better understood from the conditions of litter. For hazard, litter is the key fuel type facilitating surface fire propagation. Even during rare crown fire events, fires are initiated from surface fires that burn litter. Likewise, litter is likely the primary material for initial ignitions regardless of fire cause. As drought increases, the area for potential ignitions is increased because more area of the landscape contains dry fuels. During droughts (PDSI < 0) moisture contents of 1000-hour fuels were at levels below the common fuel moisture prescription range (e.g., 17-20 percent) (fig. 5) which indicates conditions of increased fire danger.

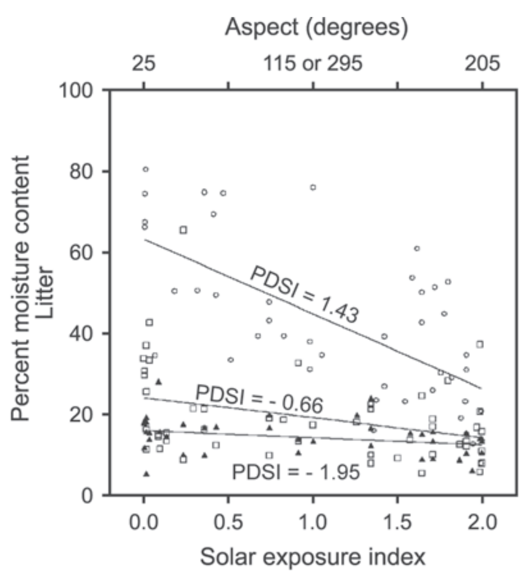

Figure 4—The relationship between percent moisture content of litter and solar exposure index for three Palmer Drought Severity Index (PDSI) values. Solar exposure variable is significant in all models (p ≤ 0.05).

CONCLUSIONS

Information about fire regimes in deciduous forests is needed in order to adequately assess fire risk. Although wildfires rarely threaten lives and homes in the Ozarks and Central Hardwoods region, the potential exists and is increased during droughts. During drought and dry weather, "undifferentiated dry" litter and low moisture content of 1000-hour fuels increase fuel hazard and ignition potential. Forests of greatest fuel loading are those of high elevation, greatest basal area, and highest topographic roughness that occur in the southeast portion of the Ozark Highlands region.

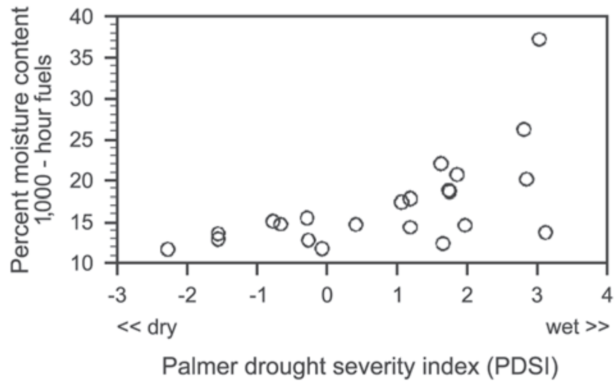

Figure 5—The relationship between 1,000-hour fuel moisture and Palmer Drought Severity Indices. Data were collected throughout the Missouri Ozark Highlands during the period July 2004 to July 2005.

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