Rangeland Ecol Manage 63:599–603 | September 2010 | DOI: 10.2111/REM-D-09-00132.1

Research Note

Weather Variables Affecting Oklahoma Wildfires

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Abstract

Wildfires in the United States can be destructive to human life and property. The ability to predict fire danger helps reduce the risks associated with wildfires by keeping firefighters on high alert and allowing better preparedness. In the state of Oklahoma, fire is a common occurrence. By looking at past wildfire records and researching the weather conditions under which they burned, we were able to determine the most important weather conditions affecting wildfire size. We looked at 10 different weather variables and found that minimum relative humidity ($r = 0.98$, $P = 0.001$), maximum and average wind speed ($r = 0.95$, $P = 0.003$; $r = 0.95$, $P = 0.004$, respectively), and precipitation ($r = 0.88$, $P = 0.02$) were the most important factors relating to wildfire size. Temperature variables did not have significant relationships with wildfire size categories. Additionally, we found that most of the largest wildfires occurred in January and December. This information can be used to adjust and improve current wildfire danger models and predictive abilities. We define conditions under which firefighters should be on high alert with hopes of improving their ability to expediently manage rangeland wildfires.

Resumen

Los incendios sin control en los Estados Unidos pueden ser destructivos para los humanos y para la propiedad. La capacidad de predecir el peligro de incendio reduce los riesgos de los incendios y mantiene a los bomberos en alerta máxima lo que favorece una mejor preparación. En el estado de Oklahoma el fuego ocurre comúnmente. Se investigó la información que se tiene a mano sobre incendios sin control para estudiar las condiciones climáticas de los incidentes, con esto se determinaron las condiciones meteorológicas más importantes que afectan la magnitud de este tipo de incendios. Tomamos en cuenta 10 variables climáticas diferentes y encontramos que la humedad mínima relativa ($r = 0.98$, $P = 0.001$), velocidad máxima y promedio de la velocidad del viento ($r = 0.95$, $P = 0.003$; $r = 0.95$, $P = 0.004$, respectivamente), y la precipitación ($r = 0.88$, $P = 0.02$) fueron los factores más importantes que se relacionan con la magnitud de los incendios no controlados. Las variables de temperatura no tuvieron relación significativa con la magnitud del incendio. Además, se encontró que la mayoría de los incendios más grandes ocurren en enero y diciembre. Esta información puede utilizarse para ajustar y mejorar los modelos actuales de peligro de incendios forestales así como la habilidad para predecirlos. Definimos las condiciones bajo las cuales los bomberos deben estar en alerta máxima con la esperanza de mejorar su capacidad para manejar apropiadamente los incendios forestales.

Key Words: climatic conditions, fire size, precipitation, relative humidity, temporal distribution, wind speed

INTRODUCTION

Wildfire is both a threat to human life and personal property and a natural occurrence in most ecosystems throughout the world. The United States federal government spends billions of dollars each year to suppress wildfires and reduce associated damages. For example, the Forest Service spent $1 835 667 998 and the Department of the Interior spent another $395 040 000 in 2002 toward the suppression of wildfires throughout the United States, and these costs, along with total area burned, follow an increasing trend; larger fires account for the overwhelming majority of these expenditures (Strategic Issues Panel on Fire Suppression Costs 2004). It is likely that climate change will impact the severity, frequency, and distribution of wildfires (Intergovernmental Panel on Climate Change 2007), thus influencing the size and cost of wildfire events.

The North American Great Plains region experiences regular wildfire due to the available fine fuel loads, undeveloped land, and temperate weather patterns (Wright and Bailey 1982). Weather variables such as wind (Cheney et al. 1993; Cheney and Gould 1995), relative humidity (Crimmins 2006; Evett et al. 2008), and air temperature (Westerling et al. 2006; Heyerdahl et al. 2008) affect wildfire behavior and frequency. Oklahoma experiences frequent wildfires with 3 519 wildfires burning 28 290 ha in 2007 and 5 572 wildfires burning 79 546 ha across the state in 2008 (National Interagency Fire Center, undated). Oklahoma has one of the most comprehensive environmental monitoring networks in the United States, the Oklahoma Mesonet, for local weather data collection. This network consists of 120 measuring stations across the state that record environmental data every 5 min (McPherson et al. 2007).

It is becoming ever more important that we understand what conditions present the highest fire danger in order to prevent

Research was funded by Oklahoma State University.

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Manuscript received 5 October 2009; manuscript accepted 22 April 2010.

loss of life and personal property, and equip trained professionals with the most relevant information possible. Our main objective was to use the unique Mesonet system and a large, comprehensive body of wildfire data to describe weather conditions characteristic of different-sized wildfire events occurring in Oklahoma. A second objective was to describe the timing of wildfires. This information is important for establishing basic guidelines for use by fire management professionals to determine wildfire danger, guiding state officials in the implementation of burn bans, and assisting with fire planning to promote efficient risk management for natural resources.

STUDY AREA

Oklahoma has a continental climate with maximum precipitation occurring during the late spring for the entire state, except the panhandle, which experiences its highest precipitation during June and July. Average annual precipitation varies across the state and is lowest in the western panhandle at 432 mm, increasing to the east at a maximum of 1 422 mm in the southeastern corner. As with all states in the Great Plains region, drought is a common part of Oklahoma's climate. Drought events can last several months to several years, depending upon severity. Annual average relative humidity ranges from about 60% to 70%, increasing from west to east. March and April tend to be the windiest months, whereas July, August, and September are the calmest. The Oklahoma Climatological Survey provides extensive information for the study area (Arndt 2005).

METHODS

Fire data including county, date, and area burned were provided by the Oklahoma State Fire Marshall's Office for the years 2000–2007, which yielded a total of 17 499 wildfires. All 17 499 wildfires were analyzed to determine the temporal distribution, but only a sample of these were used to examine weather conditions. Preliminary analyses were conducted on the data set containing weather conditions, including list-wise regression for all 10 weather variables considered ($r^2 = 0.13$), and with the three variables considered most important (minimum relative humidity, precipitation, and maximum wind speed; $r^2 = 0.08$), and step-wise regression including all 10 weather variables ($r^2 = 0.08$). These weak models were largely due to the fact that small fires can occur under any condition; they are regulated by weather but also by fragmentation, land use, etc. Large fires only occur under specific conditions, and so wildfire data were separated into six categories (Table 1), based on size of burned area, to better evaluate which weather variables are characteristic of large wildfires. Not all wildfires were included for weather analysis due to the time-consuming nature of finding and recording weather variable data for all 17 499 wildfires. Considerably more wildfires occurred in categories 1 through 4 than the other categories; thus, to facilitate data analysis, all fires in categories 5 and 6 and 5% of fires from categories 1 through 4 were included in the final data set. The 5% of wildfires sampled from the smaller size categories were determined using random number generation. The final data set analyzed for weather contained a total of 945 wildfires.

Table 1. Size and number (*n*) of Oklahoma wildfires from 2000 to 2007 sampled for analysis of weather variables. All fires were included for the two largest categories (5 and 6) and 5% of categories 1–4 were randomly included.

Category	Size (ha)	*n*
1	≤ 0.41	335
2	0.42–4.05	334
3	4.06–40.47	166
4	40.48–404.69	33
5	404.70–4 040.46	67
6	≥ 4 040.47	10

Weather data for each wildfire were obtained using archived Mesonet data for each day there was a wildfire event. The data for each wildfire were taken from the Mesonet site nearest to the wildfire. Weather variables recorded for each wildfire date and location include maximum temperature, minimum temperature, average temperature, dew point temperature, maximum relative humidity, minimum relative humidity, average relative humidity, precipitation, average wind speed, and maximum wind speed. Mean and 95% confidence limits were calculated for each weather variable for all size categories. SPSS 17.0 for Windows (SPSS 2008) was used to conduct simple linear correlations between fire size categories and all weather variables.

RESULTS

Most of the wildfires occurred throughout the winter and in early spring (November–April) before vegetation greenup (Fig. 1). Wildfire numbers declined during late spring (May–June). An additional peak in wildfire occurrence happened in July and August before again declining in the fall. Average number of wildfires per month was 1 458 but ranged from 3 099 in March to 556 in May. More fires occurred in March than any other month for all wildfire size categories except category 6, which had the highest number of fires occur in January and December, two of the driest months in Oklahoma and when fine fuels are dormant (data not shown).

The distribution of area burned resembles that of the number of wildfires. March had the most total area burned, 68 124 ha, and May had the least, 1 939 ha. Average area burned per month was 23 049 ha with a total area of 276 585 ha burned by wildfire during the 8 yr. The most notable difference between the number of wildfires and area burned distributions was that throughout the summer, though there were numerous wildfires (34% of total), the actual area burned by these fires was small (15% of total). The above information was not statistically analyzed and is provided to give a general description of the temporal distribution of all wildfires recorded in the state over this 8-yr period.

Weather characteristics examined had varying relationships with wildfire size categories (Fig. 2). Six of the 10 measured weather variables had significant relationships to wildfire size

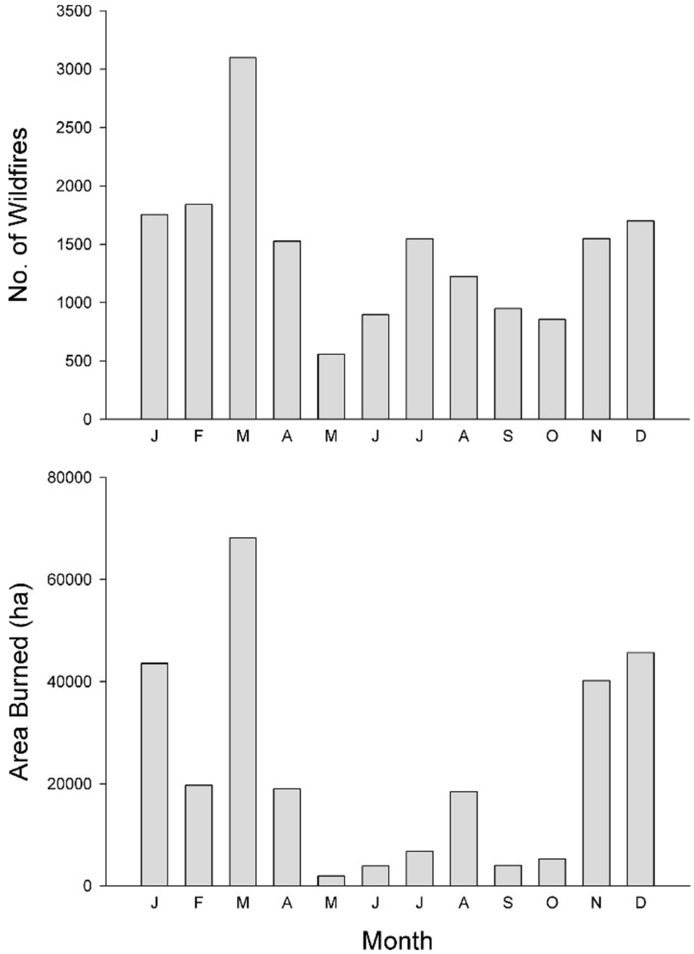

Figure 1. Number of wildfires and area burned (ha) by month for 17 499 wildfires across Oklahoma between 2000 and 2007.

categories ($P < 0.05$). Maximum, minimum, and average relative humidity, precipitation, and average and maximum wind speed all had strong relationships with wildfire size (see Fig. 2 for summary statistics). None of the four temperature variables was significantly related to wildfire size categories.

Relative humidity relates negatively to wildfire size. Minimum relative humidity had the strongest relationship with wildfire size of the three relative humidity measurements, as determined by r. Minimum relative humidity was negatively correlated with wildfire size. Category 1 fires occurred under conditions with a minimum relative humidity of 10–90% with an average of 35%, whereas category 6 fires ranged between 8–39% with average conditions of 15% (range data not shown). Though variation within and across categories was high, precipitation had a significant negative relationship with fire size (Fig. 2). Category 6 is the only category without any precipitation recorded.

Average and maximum wind speed both had strong positive relationships with wildfire size (Fig. 2). The smallest fires occurred during periods of low wind speeds; category 1 had an average of 3.5 $m \cdot s^{-1}$ wind speeds, whereas category 6 had an average double that, 7.0 $m \cdot s^{-1}$. Maximum wind speeds varied from 10.6 $m \cdot sec^{-1}$ to 17.4 $m \cdot s^{-1}$ on average for the smallest and largest fire categories, respectively.

DISCUSSION

Weather conditions are some of the best predictors to determine present and future wildfire danger. By looking at the past wildfire weather data for Oklahoma, we are able to identify the strongest relationships between weather variables and wildfire size, specifically looking at those characteristic of large wildfire events. Small wildfires can occur under a wide range of weather conditions. We are also able to determine when the largest wildfire events occur throughout the year. Relative humidity, wind speed, and precipitation all are important factors relating to wildfire size and also play a part in seasonal distribution of wildfires.

Relative humidity is a strong predictive factor leading to wildfire occurrence (Crimmins 2006; Evett et al. 2008). Although all of the relative humidity variables (maximum, minimum, and average) were related to fire size, minimum relative humidity had the strongest relationship. Low relative humidity causes fine fuels to dry out and become more combustible (Lindenmuth and Davis 1973) and enhances fire spread (Cheney and Sullivan 1997).

Rate of fire spread is increased by higher wind speeds (Cheney and Sullivan 1997), creating more dangerous fire conditions. Both average and maximum wind speed had equally strong relationships with wildfire size. High wind speeds, like low relative humidity levels, can act to dry out fuel (Whelen 1995). March and April are Oklahoma's windiest months (Arndt 2005) and March had the highest number of wildfires and more area burned than any other month. The time of year with the least amount of wind, July to September, had some of the lowest total wildfire numbers and total area burned.

Precipitation also plays a part in the seasonal distribution and size of wildfires. The month of May, with the fewest wildfires and least area burned, has the highest average precipitation across 90% of the state (Arndt 2005). May also is a time that plants are actively growing, so fine fuel would include substantial green biomass. However, in parts of Oklahoma there can be a secondary peak in precipitation during or after September. There also are some areas where the dual maximums converge into a single peak precipitation period during June (Arndt 2005). This precipitation trend concurs with our findings that the least amount of wildfires and lowest total area burned occurred between May and October. One interesting exception occurred in the month of July, which had a relatively high number of wildfires but low area burned. This was due to the Fourth of July holiday. Ninety-nine wildfires ignited on that day during the 8 yr of our study, three times more than the daily average for May to October of 33 wildfires. Five hundred and nine more wildfires are recorded for that day without area burned data and were not included in the analysis (data not shown).

Temperature can impact various aspects of wildfire; however, our findings indicate that temperature alone did not significantly relate to wildfire size. The US Department of Agriculture Natural Resource Conservation Service (NRCS) provides recommendations that limit temperature, relative humidity, and wind speed for prescribed fires, at least partially because of wildfire danger. In Oklahoma, burning with air temperatures greater than 38°C, wind velocities exceeding 8.9 $m \cdot s^{-1}$, or relative humidity less than 20% is considered extremely high risk (NRCS, OK 2007). Some other states' temperature recommendations are much more

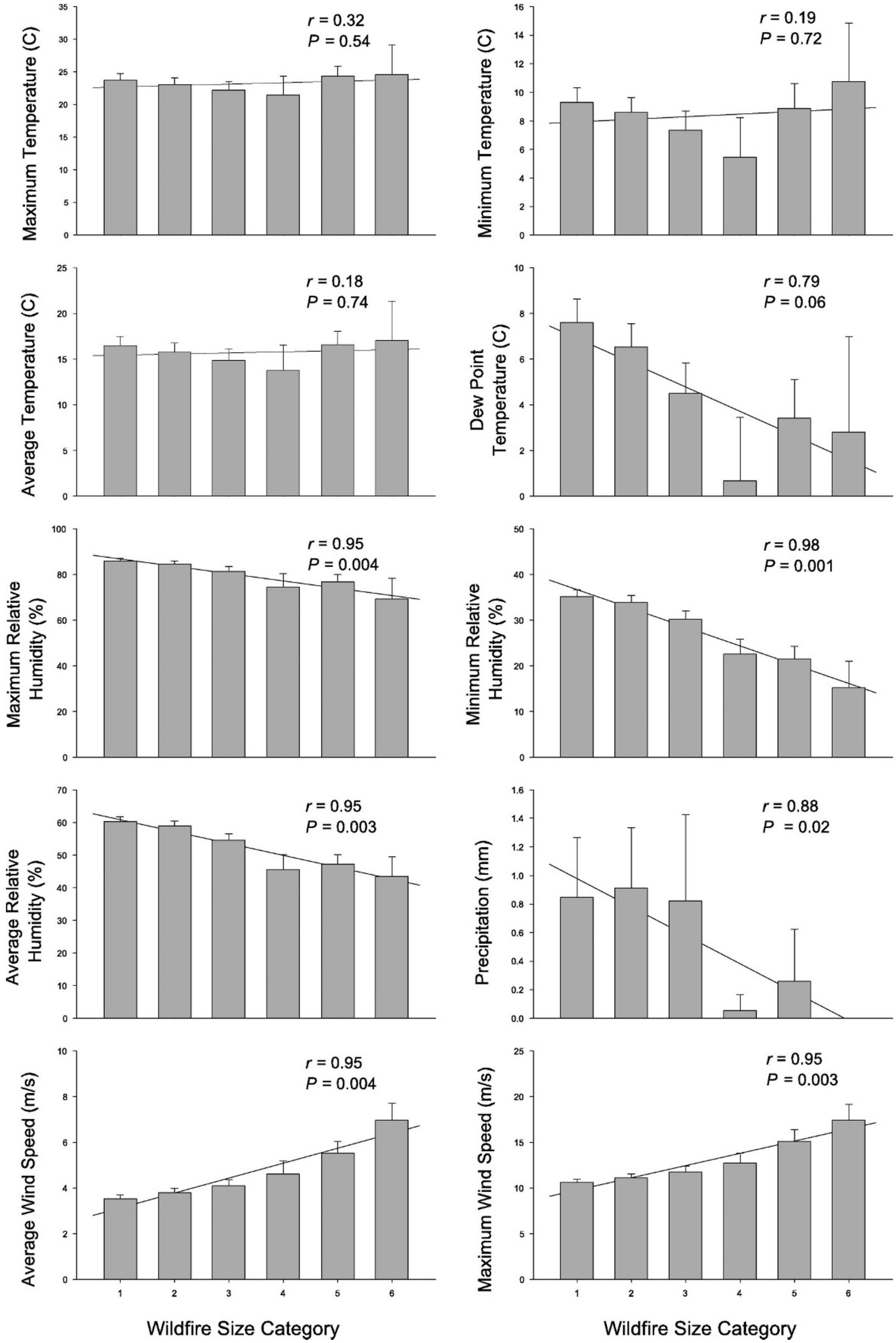

Figure 2. Oklahoma wildfires from 2000 to 2007 related to temperature, relative humidity, precipitation, and wind speed by wildfire size category (Table 1). Mean and 95% confidence intervals are reported for each wildfire size category.

conservative. Although we agree that relative humidity and wind speed limitations are needed, we suggest that from a fire danger standpoint, temperature might not be as relevant as other weather variables for this region of the United States, likely because high temperatures are associated with actively growing vegetation.

A relationship is apparent between weather factors creating low fuel moisture and high rates of spread and dangerous fire conditions. Minimum relative humidity, wind speed, and precipitation are the most important weather variables in detecting dangerous fire conditions leading to large wildfires in Oklahoma. Modeling systems, such as OK-FIRE, already exist to provide fire danger predictions (University of Oklahoma 2009); by finding what weather conditions are characteristic of large, dangerous wildfires, models can be improved and firefighters better prepared.

IMPLICATIONS

Large wildfires characteristically occur when minimum relative humidity is below 20% or maximum wind speeds are above $15\ m \cdot s^{-1}$. Additionally, most of these large fires occurred in January and December when precipitation levels are at their lowest and vegetation is dormant. It is necessary that, under these dangerous fire conditions, fire safety personnel are prepared and able to respond to the fires immediately. This study was conducted in a single state; however, data were collected from every ecosystem present and from every county in Oklahoma. These results have regional importance for ecosystems with similar climatic regimes and vegetation in describing the characteristic conditions of large and dangerous wildfires. This type of data is available in every state and is largely ignored by researchers, yet it provides an extensive wildfire record of what actually occurs, as opposed to model predictions, that should be analyzed and described for each region.

ACKNOWLEDGMENTS

We would like to thank the Oklahoma State Fire Marshall's Office for providing wildfire information used in this research. We also thank the research technicians responsible for compiling the weather conditions for each fire, Kevin Spears and John Worthington.

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