TOP TEN SMOKE MANAGEMENT QUESTIONS FOR FIRE IN EASTERN OAK FORESTS

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INTRODUCTION

In a time when fire planners and forest supervisors in many parts of the United States are implementing plans to increase the number and frequency of prescribed burns, the issue of smoke impacts on air quality is becoming increasingly important. Smoke from prescribed fires can have a dramatic impact on air quality and visibility on local, regional, and national scales, with corresponding temporal scales ranging from hours to days to months. As new national air quality regulations are implemented, smoke management will become an increasingly important concern when planning prescribed burns in the Eastern Oak Forests.

In the Eastern Oak Forests, prescribed fire is becoming a more common practice in ecosystem management (Ward and Brose 2004). Although there are many resource benefits associated with prescribed fire, the potential for the resultant smoke to impact human health and public safety also needs to be addressed. Wildland fires release various pollutants, including, but not limited to, fine particulate matter, nitrogen oxides (which are precursors to ozone formation and, thus, a surrogate for ozone), volatile organic compounds (also precursors to ozone formation), and carbon monoxide. However, in terms of prescribed fire, the pollutants of major concern are the fine particulates, referred to as $PM_{2.5}$. About 70 percent of particulates released by wildland fires are within the fine particle size class (particles less than 2.5 microns in diameter) (Hardy et al. 2002). Elevated levels of fine particulates are dangerous because they can penetrate deep into human lungs and increase the risk of serious health problems, especially for those with respiratory illnesses. Furthermore, when smoke plumes with high particulate concentrations intersect roads and highways, visibility is reduced and the likelihood of traffic accidents increases. Ozone, which is formed through atmospheric reactions of nitrogen oxides and volatile organic compounds, is also a respiratory irritant.

As population centers surrounding eastern oak forests expand and encroach on these ecosystems, increasing the wildland/urban interface, smoke management issues will become increasingly important and increasingly complex. In some situations, smoke management could become the determining factor in "go/no go" decisions for prescribed burning.

The purpose of this paper is to outline pertinent smoke management questions that fire and smoke managers in the Central Hardwoods will face in the near future. The next section identifies and describes the "Top Ten" management questions that burn planners should address when implementing burning programs in the region. Section 3 will then describe the smoke management tools that are currently available, or that will be available in the near future, to help fire and smoke managers address these questions when preparing for prescribed burns. Section 4 includes a discussion and some concluding points.

TOP TEN SMOKE MANAGEMENT QUESTIONS

This section presents what we feel are the Top Ten smoke management questions that will impact prescribed burn decisions in eastern oak forests in the near future.

10. *Where are eastern oak forests—Where will burning occur?*

The Central Hardwoods (Fig. 1) cover an area from northern Georgia, west to Arkansas, northeast to the Great Lakes and New England, and then south along the eastern slopes of the Appalachians (Stringer and Loftis 1999). This area is predominantly oak-dominated deciduous forests in hilly-to-mountainous areas. The

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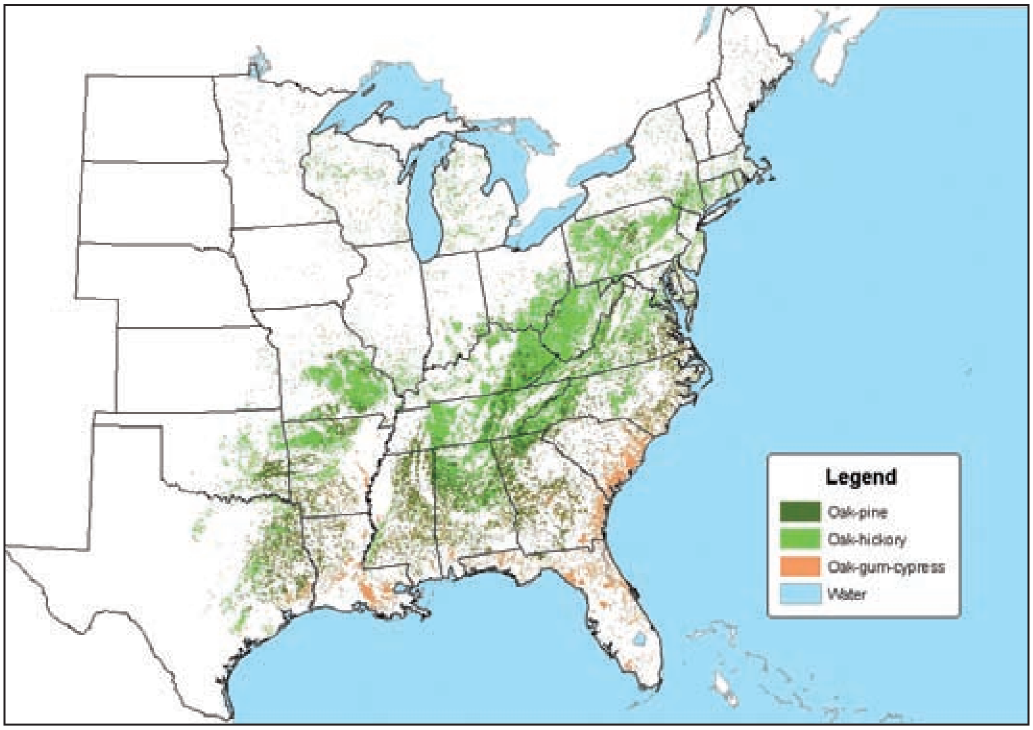

Figure 1.—Distribution of forests in the eastern United States.

Central Hardwoods cover approximately 125 million acres in eleven states, making it the most extensive temperate deciduous forest in the world.

9. *Where are the people—what percentage of people in the US live within the vicinity of eastern oak forests?*

Approximately 65 million people live in the states east of the Mississippi (U.S. Bureau of the Census 2000), with the highest population density along the Eastern Seaboard, the Great Lakes coast, and the southern tip of the Appalachians (Fig. 2). Approximately 25 percent of the population of the United States lives in the Central Hardwoods states, and over 90 percent of the Central Hardwood Forest is owned by private interests, primarily non-industrial forest owners (Hicks 1997).

8. Where are the roads?

One of the major concerns with smoke management is whether the smoke from a prescribed burn will impact a roadway. The highest density of interstate highways and primary and secondary roads in the Unites States occurs east of the Mississippi (Fig. 3). A major source of complexity in eastern smoke management and prescribed burning is the fact that a road of some sort almost invariably occurs within the immediate locale of a burn site.

7. Where are existing air pollution problem areas?

Outside of California, the eastern United States has the greatest number of areas not meeting the National Ambient Air Quality Standards (NAAQS) for a variety of criteria pollutants (U.S. EPA 2006): sulfur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter less than or equal to 10 microns or 2.5 microns in diameter (PM_{10} and $PM_{2.5}$), ozone (O_3), carbon monoxide (CO), and lead (Pb) (Fig. 4). The NAAQS were developed by the Environmental Protection Agency for a specific set of "criteria" pollutants to protect public health and welfare. NAAQS are defined as the amount of a criteria pollutant above which detrimental effects to human health or welfare may result. The NAAQS are set at conservative levels, with the intent of protecting even the most sensitive members of the public including children and people with asthma and cardiovascular disease (http://www.epa.gov/air/criteria.html). Nevertheless, states can

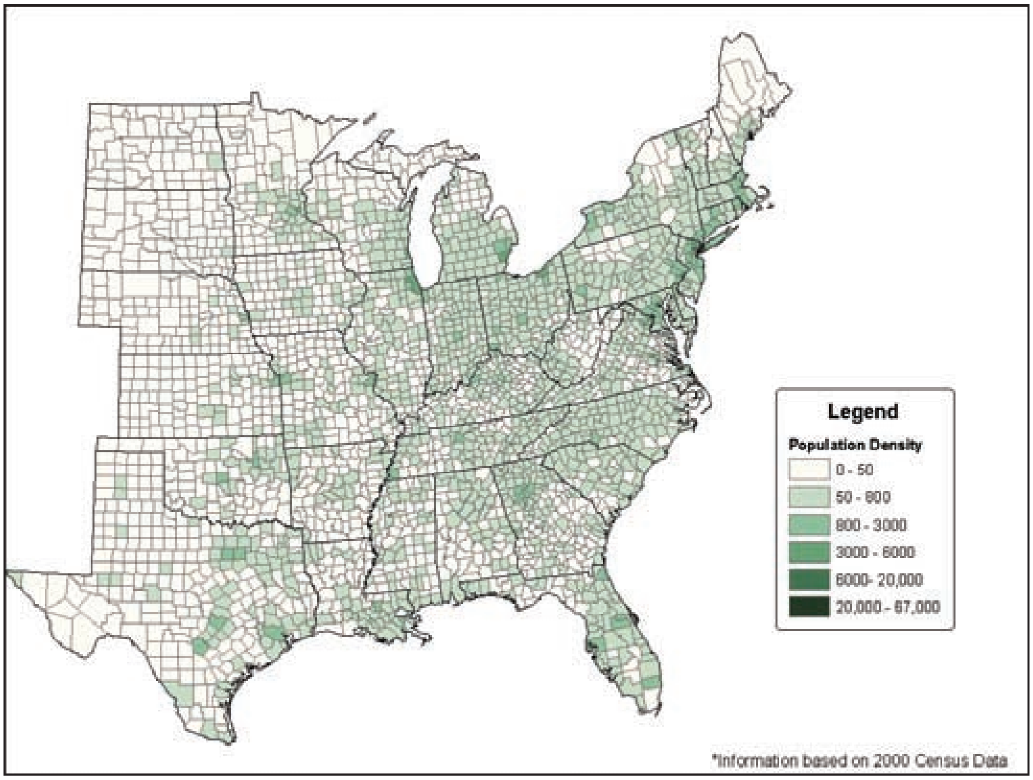

Figure 2.—Population density in the eastern United States.

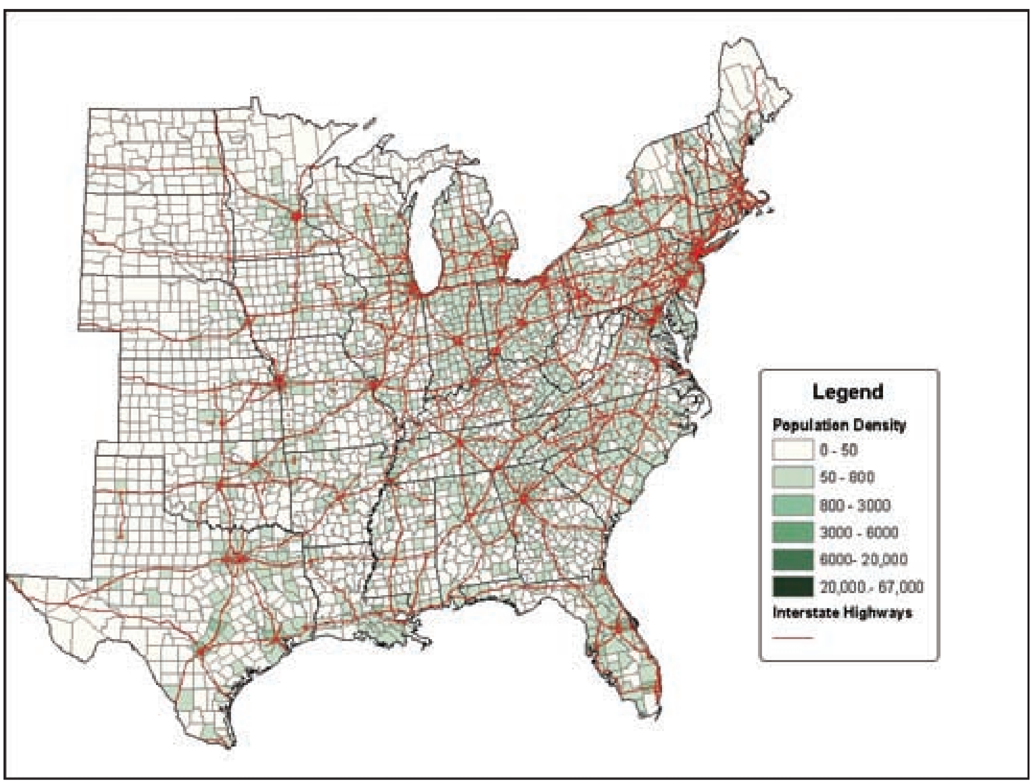

Figure 3.—Locations of Interstate Highways overlaying population density in the eastern United States.

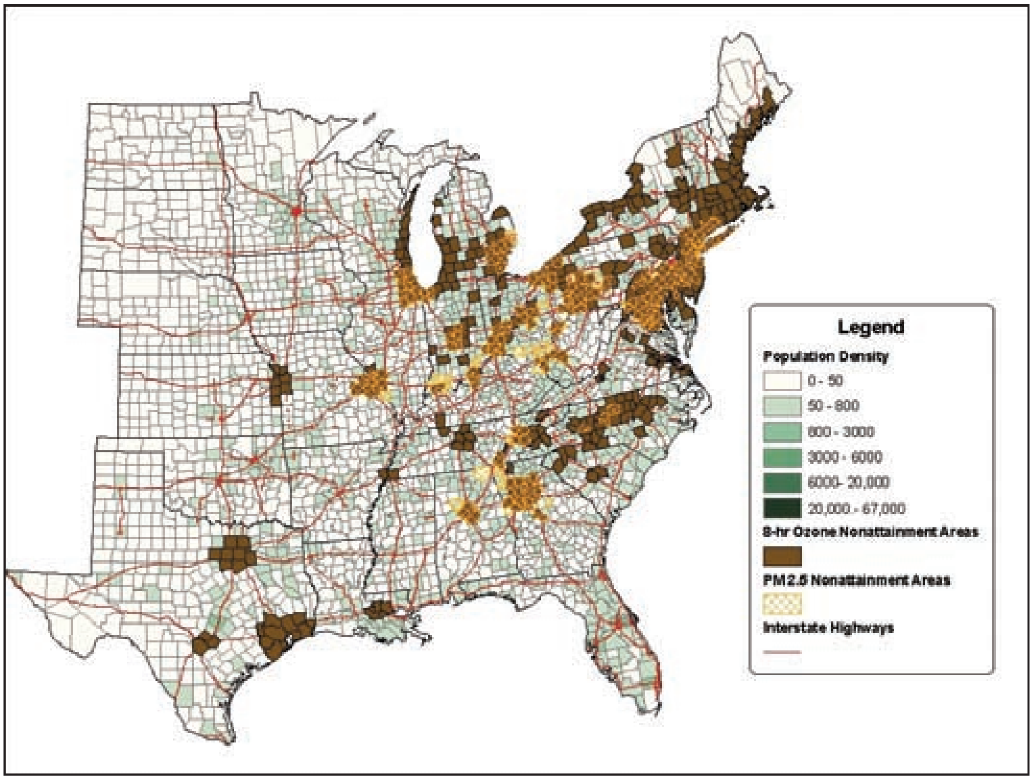

Figure 4.—Locations of federally designated Ozone and PM2.5 non-attainment areas overlaying interstate highway locations and population density in the eastern United States.

adopt standards even more stringent than the federal standards. If an area consistently violates one of the NAAQS, that area will be federally designated as a "non-attainment" area for the specific criteria pollutant(s). States are required to demonstrate to the public and the EPA how emissions will be controlled in order for the non-attainment area to again comply with the NAAQS. These demonstrations are included in a State Implementation Plan (SIP), which may include methods to control emissions from prescribed fire.

6. *Where/What are the Class I areas?*

Mandatory federal Class I Areas were designated by the Clean Air Act amendments (CAAA) of August 7, 1977, and include national parks greater than 6,000 acres and national wilderness areas and national memorial parks greater than 5,000 acres which existed at that time (42 U.S.C. 7401 et seq). Resources such as soils, streams and visibility in these Class I Areas (called Air Quality Related Values) were given an additional measure of protection under the CAAA. Although the majority of Class I areas are in the west, several are scattered across eastern oak forests (Fig. 5). The eastern Class I areas are often located in, or near, densely populated areas, and receive extensive visitor use.

Regional Haze Rules address regional emissions that affect visibility in Class I areas. Recognizing that regional haze results from many sources of pollution over a large geographic area, these regulations require states (and tribes who choose to participate) to review how emissions generated within the State affect visibility at "Class I" areas. The EPA has encouraged states and tribes across the U.S. to address visibility impairment from a regional perspective and as a result the Regional Planning Organizations (RPO's) (Fig. 6) were formed. These organizations are evaluating available technical information to better understand how the sources within their states and Tribal lands impact Class I areas across the country. This technical information can then be used by the states and tribes to develop regional strategies to reduce emissions of pollutants leading to regional haze (from: http://www.epa.gov/air/visibility/regional.html).

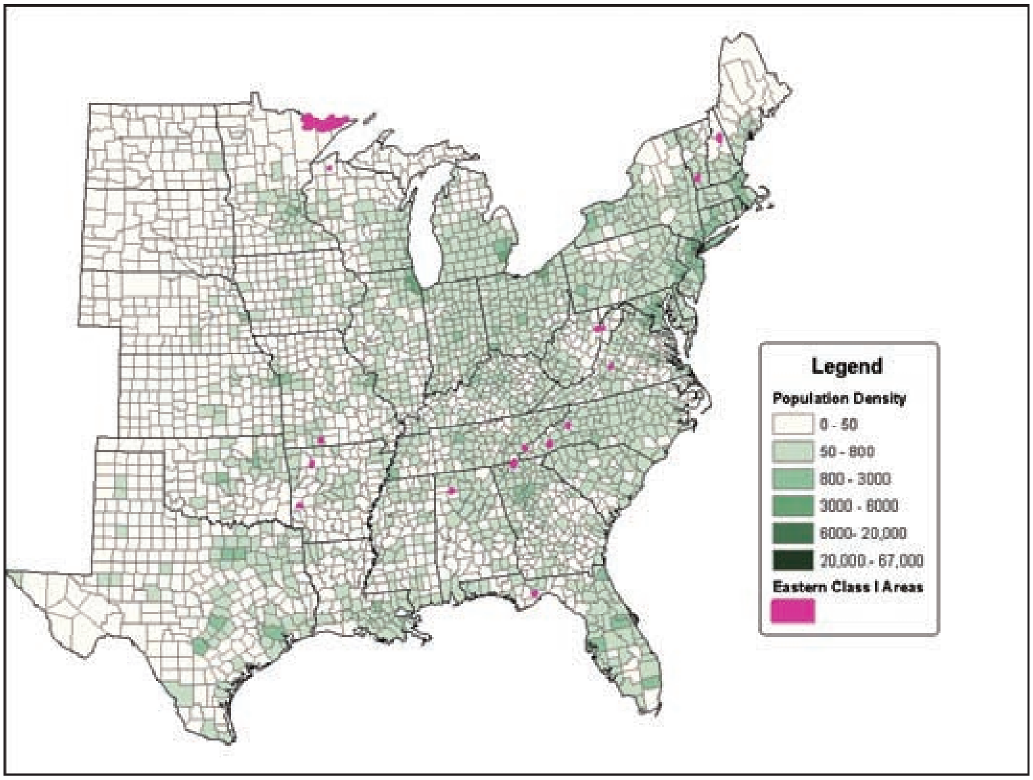

Figure 5.—Locations of Class I areas overlaying population density in the eastern United States.

Figure 6.—Names and member states of the five Regional Planning Organizations

States are required by the rule to analyze a pathway that takes the Class I areas from currently impaired conditions to "natural conditions" in 60 years. The term, "natural visibility conditions" is meant to "represent the long-term degree of visibility that is estimated to exist in a given mandatory Federal Class I area in the absence of human-caused impairment" (U.S. EPA 2003; pg. 1-1). States must show they are making "reasonable progress" toward achieving this goal. The Regional Haze Rule sets up the period of 2000 to 2004 as the baseline visibility conditions and "reasonable progress" will be tracked for that period onward. States currently are coordinating through the RPOs to determine the necessary level of reductions in haze forming emissions to achieve this. State Implementation Plans (SIPs) will need to be developed to outline strategies and schedules for emission reductions. Prescribed fire emissions are to be included in the suite of emission sources that potentially impact visibility. Most states will need to have a SIP in place by 2008 to cover a period of 10-years. While this program is aimed at Class I areas, visibility will improve throughout the country by reducing regional emissions.

Because the pollutants that lead to regional haze can originate from sources located across broad geographic areas, the EPA has encouraged the states and tribes across the U.S. to address visibility impairment from a regional perspective. Therefore, Regional Planning Organizations (RPO's) (Fig. 6) have been formed to address regional haze and related issues. These organizations are

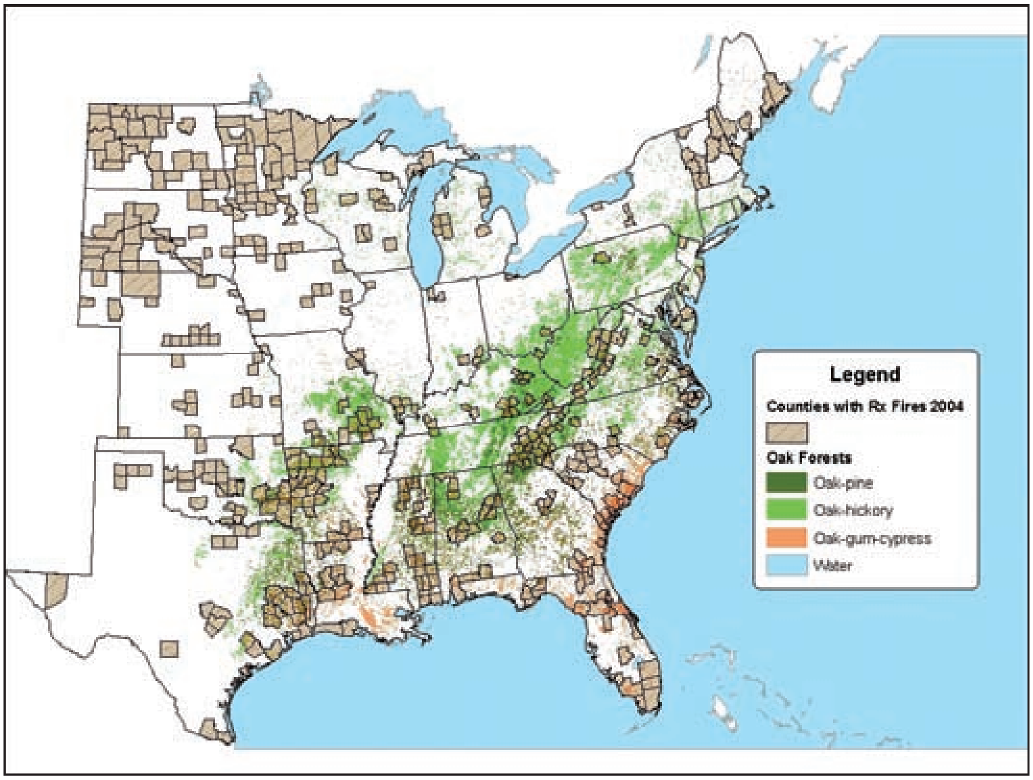

Figure 7.—Counties reporting prescribed fire activity in 2004 overlaying locations of oak forests in the eastern United States.

evaluating available technical information to better understand how the sources within their states and Tribal lands impact Class I areas across the country. This technical information can then be used by the states and tribes to develop regional strategies to reduce emissions of pollutants leading to regional haze (from: http://www.epa.gov/air/visibility/regional.html).

5. *Where and when does burning typically occur?*

Figure 7 shows the counties in the eastern United States that reported federal prescribed burn activity in 2004 (http://www.nationalatlas.gov/natlas/Natlasstart.asp). In addition to the locations indicated on this map, additional prescribed burn activity undertaken by state and local organizations occurs throughout the region.

4. *Where does smoke typically go?*

Smoke from prescribed burns has local, regional, and national impacts. Local impacts, such as those to sensitive receptors (homes, schools, businesses) directly downwind of a burn site are routinely addressed in burn plans.

Regional impacts are sometimes included in burn plans, as some plans account for population centers away from the burn site. Additionally, there is evidence that smoke from prescribed burns can impact specific sites hundreds of miles away from the burn location, contributing to impacts more on a national scale. Figure 8 shows

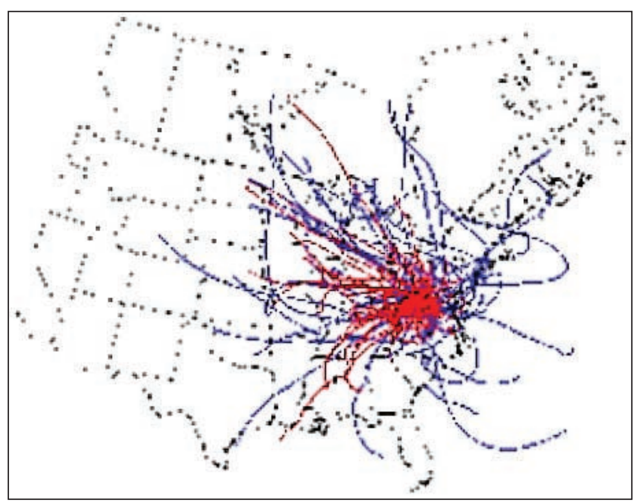

Figure 8.—48-hour back trajectories for 20% best (blue) and 20% worst (red) haze days in the Shenandoah National Park, 1997-1999 (from Regional Haze and Visibility in the Upper Midwest. Midwest Regional Planning Organization, (http://www.ladco.org/tech/monitoring/docs_gifs/rhreport.pdf).

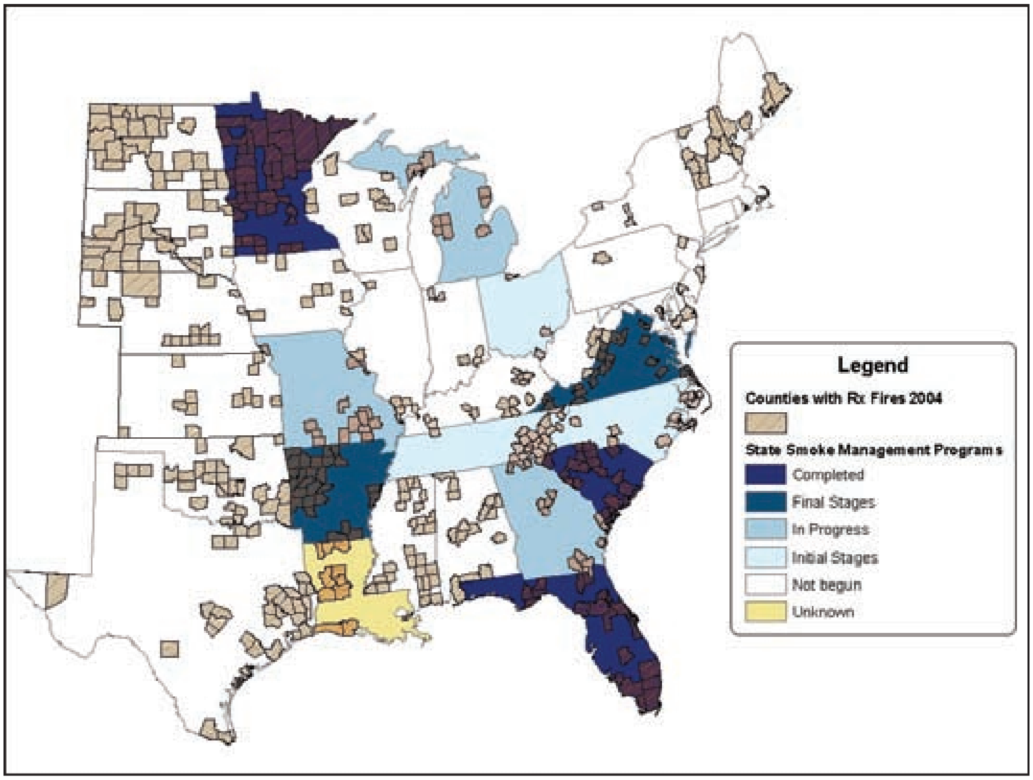

Figure 9.—Status of efforts to design and implement state Smoke Management Programs overlaying counties reporting prescribed burn activity in 2004 in the eastern United States.

a 48-hour trajectory analysis for the best and worst visibility conditions measured at Shenandoah National Park from 1997-1999 (Midwest RPO, 2001). This analysis indicates that the source air a given location, such as a sensitive receptor or a national park can come from locations all across the eastern United States. The implication here is that any prescribed burn activity has the *potential* to impact air quality and visibility conditions on a regional and national scale. As states implement smoke management programs designed to monitor and, if necessary, alter burn programs to control air quality at specific sites, prescribed burn planning will become increasingly dependent upon modeling tools that assess the potential for smoke to influence regional and national air quality.

3. *Where is burning expected to increase/decrease?*

The USDA Forest Service Region 9, which stretches from Minnesota south to Missouri and east to the Atlantic Coast, treated (using prescribed fire and other fuel treatments) approximately 96,473 acres in FY 2005 (USDA Forest Service 2006). Nationally, the USDA Forest Service in 2005 had a target of treating 2.5 million acres of hazardous fuels through a variety of prescribed fire and other vegetation treatments. In FY 2007 the target is approximately 3.2 million acres of hazardous fuels treatments. Each state also has treatment plans that include prescribed burning as an activity. Prescribed burning in mixed oak forests, and throughout the United States, is expected to increase in the near future.

2. *Where are there coordinated Smoke Management Programs?*

There is a wide variety in the type or existence of state Smoke Management Programs (SMPs). Florida has perhaps the best-established SMP in the East, with daily burning coordinated through a central clearinghouse in the Florida Department of Forestry. South Carolina and Minnesota likewise have SMPs in place. But many other states throughout the region are in the early stages of developing SMPs or have nothing at all (Fig. 9). As these programs become established and smoke management regulations are more clearly defined, the impact of smoke management on prescribed burn planning and execution will become more apparent.

1. *What does all this mean to fire and smoke managers?*

When all of the elements listed above are considered together, it becomes clear that smoke management in the Oak forests can be extraordinarily complex. This burn activity takes place in a part of the country with the greatest population (compared to the west) and in states with existing air pollution problems and an extensive transportation system. Additionally, forest managers are hoping to increase the number and size of prescribed burns in the near future. Finally, coordinated SMPs designed to account for the cumulative effects of burning are few and far between in the region.

SMOKE MANAGEMENT TOOLS

There are many smoke management tools available to fire and smoke managers to aid in planning for a burn. The tools indicate how readily smoke will disperse from the fire area, and where the smoke will go in the ensuing hours. The National Weather Service provides forecasts of the Ventilation Index (VI) (Hardy et al. 2002; and others) in routine fire weather forecasts and spot forecasts requested by fire managers. The VI provides an assessment of the extent to which smoke produced by a fire will be effectively transported (ventilated) from the fire area. However, while the VI indicates how readily smoke will disperse, it does not indicate where the smoke will go once it leaves the burn site. A smoke dispersion model is necessary to determine where smoke is likely to go and what the pollution concentrations (mainly PM 2.5) will be downwind of the burn.

The model that a fire or smoke manager employs depends strongly on what questions need to be answered. For questions concerning smoke concentrations within a few miles of a fire, dispersion models driven by single observations take at or near the fire location are often sufficient. VSMOKE (Lavdas 1996) is arguably the most advanced model that is currently in operational use in the eastern United States. VSMOKE is designed to help smoke and fire managers predict the smoke and dry weather visibility impact of a single fire at downwind locations. VSMOKE contains a plume rise model, a steady-state trajectory model, and other components that provide predictions of concentrations, visibility and other factors. Additional examples of dispersion models in use include: 1) the EPA's Industrial Source Complex (ISC3) model, which is used for predicting dispersion of pollutants from industrial facilities mainly for permitting purposes (U.S. EPA 1995); 2) the Smoke Impact Spreadsheet (SIS), a simple planning puff model for calculating particulate matter emissions and concentrations downwind of wildland fires (Wickman and Acheson, 2005), and 3) The Simple Approach Smoke Estimation Model (SASEM), which predicts ground level particulate matter and visibility impacts from single sources in relatively flat terrain (Sestak and Riebau, 1988). All of these models can be used to assess smoke concentrations immediately downwind of a fire on time scales of a few hours. Additional details about the applications and relative merits of these and other smoke dispersion models can be found in Breyfogle and Ferguson (1996).

The Smoke Management Team at the USDA Forest Service's Southern Research Station in Athens, GA is developing more advanced smoke transport models, the so-called Planned Burn (PB) models (Achtemeier, 2001). PB smoke movement and dispersion models are designed to address the following questions: 1) if I burn tomorrow, will I smoke up a road?; and 2) I just burned, where is my smoke going to be tonight? The PB models address the problem of terrain and landscape features that can cause smoke plumes to diverge, split, merge, and evolve over complex local topography. The models predict smoke movement as a mixture of independent particles similar to smoke actually flowing downwind from a burn site. Smoke that becomes trapped in a localized area gradually dissipates over time. The "bleedoff" of smoke is simulated by allowing the model to occasionally create new smoke particles from existing particles that can then disperse over time (Achtemeier, 2001). One of the major advantages of the PB modeling framework is that it is designed to incorporate highly detailed gridded weather information both at the ground and aloft. This detailed weather information allows the model to account for temporally and spatially varying

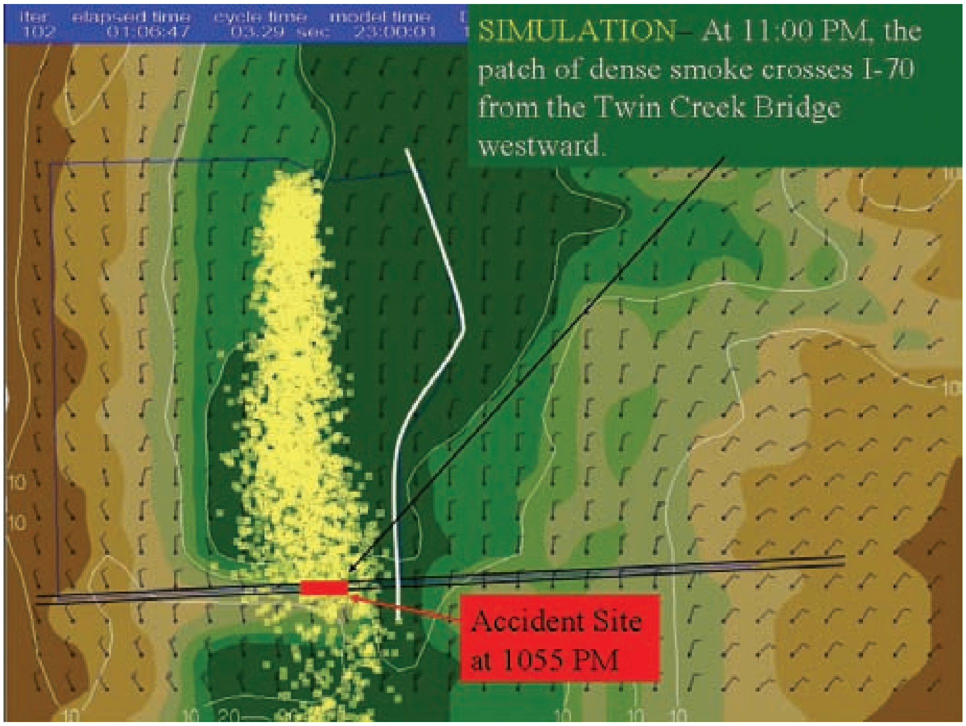

Figure 10.—PB-Piedmont simulation of smoke from burning a pile of Christmas trees at a refuse site near Lewisburg, OH in the Twin Creek Valley between 8:00 AM and 3:00 PM on 7 February 2000. Smoke from this fire, in addition to local dense fog, was implicated as a factor in a vehicle pileup on I-70 at approximately 10:55 PM on 7 February.

wind and stability conditions, and to predict how surface features (terrain, coastlines, etc) impact the smoke plumes as they evolve and disperse.

The first PB model to be developed was PB-Piedmont, which was designed to simulate smoke transport in the complex terrain of the southeastern United States Piedmont region. Two newer incarnations of the PB models have since been developed. PB-Coastal Plain incorporates land use data and land-water information, along with small variations in elevation, to model smoke movement over the lower Coastal Plain. Finally, PB-Mountain is designed to simulate smoke transport in the mountains of the Southeast. The Eastern Area Modeling Consortium (EAMC) is working to implement one or more PB models for the northeastern United States and eastern oak forests, and to make this smoke prediction tool available to fire and smoke managers across the region. Figure 10 shows an example of a one-time use of the PB-Piedmont model to simulate smoke from burning timber in Ohio.

The smoke dispersion models outlined above are generally applicable only to smoke management concerns in the immediate vicinity of a fire. None of the models are designed to address how smoke from fires could affect regional air quality. However, in Section 2 we indicated that state smoke monitoring programs designed to address regional air quality issues will soon begin to impact smoke management decisions throughout the Eastern United States. Currently, there is no well-established tool that can help fire and smoke managers make regional smoke management decisions. However, researchers in the USDA Forest Service's Pacific Northwest Research Station, in cooperation with universities and other research facilities, have developed the BlueSky Smoke Modeling Framework (O'Neill, 2003) to address this need.

BlueSky is a modeling framework that brings the latest state-of-the-science fuels, fire, smoke, and weather models into one centralized processing system. It is designed to provide fire operations and air quality management communities easy access to sophisticated emission, dispersion and weather prediction models and model output. The modeling framework predicts the cumulative impacts of smoke from prescribed fire and wildfire on regional concentrations of PM2.5 and other particulates (Fig. 11).

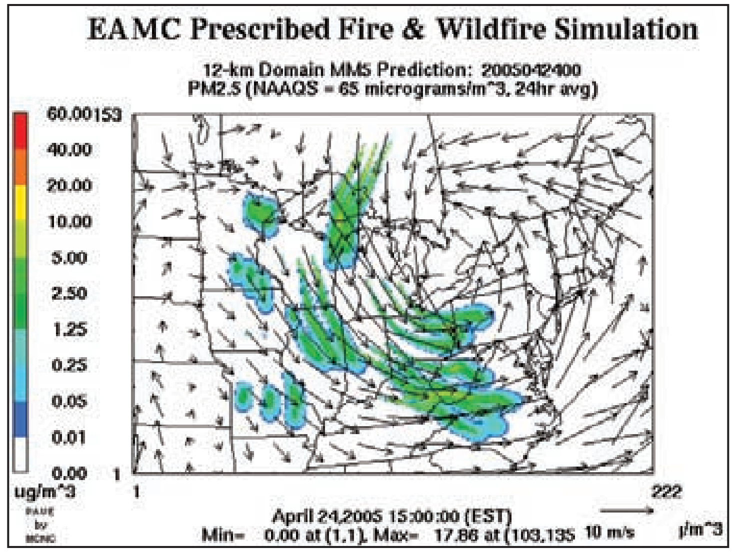

Figure 11.—BlueSky output using the weather conditions on April 24th, 2005 and a hypothetical distribution of prescribed burns across the Great Lakes, Ohio Valley, and southern Canada.

The BlueSky system was designed as a tool to aide land managers in making go/no-go/go-slow decisions relative to smoke management from prescribed burns. The system produces hourly PM2.5 predictions based on input from the user and 209 wildfire reports. By employing centralized collection and processing of model data, the user does not need to download data and learn to use complex modeling systems. It also allows for analysis of multiple burns and wildfires so that air quality managers can see the combined impacts of prescribed burns within shared airsheds. BlueSky output is posted to the web daily for easy access by burners, air resource specialists, and the public.

Sample BlueSky output for the Pacific Northwest United States and publications are available at http://www.fs.fed.us/bluesky. The Eastern Area Modeling Consortium (EAMC) maintains BlueSky for the northeastern United States. The user interface for submitting a prescribed burn to the EAMC implementation of BlueSky can be found at http://www.ncrs.fs.fed.us/eamc/products/bluesky/.

CONCLUSION

This paper has outlined the pertinent smoke management questions that fire and smoke managers in the Central Hardwoods will face in the near future. As prescribed fire becomes a more common practice in ecosystem management, the potential for the resultant smoke to impact human health and public safety will have a correspondingly greater impact on burn plans and go/no-go/go-slow decisions on the day of the burn. We have outlined what we see as the main questions that land managers in eastern oak forests should be aware of as they develop forest management plans, as states implement smoke management plans, and as federal regulations that could affect smoke management decisions are being established. Additionally, we have provided an introduction to the existing tools and some of the new tools that are becoming available to aid in smoke management decisions. Clearly, prescribed burn planning in eastern oak forests will continue to become more complex as additional regulations are implemented and sensitivities both in the physical and social aspects of the problem become apparent. By remaining aware of the air quality regulations affecting prescribed burning programs and utilizing the tools available to assist them in meeting those regulations, land managers can be fully prepared for the changes that are certain to come.

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