Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

View of smoke and emissions field monitoring equipment as aerial ignition begins. Credit: Tom Crews.

Where There's Fire, There's Smoke

Smoldering Combustion from Wildfire Poses Serious Threats to Public Health in the Coastal Plains

Summary

The Coastal Plain of North Carolina contains some of the last remaining vestiges of a wetland forest ecosystem characterized by organic soils ranging from a few inches to eight or more feet deep. When fire occurs in this system, it can result in smoldering combustion far down into the peat-like soil, which may burn for weeks or even months. Carefully planned and implemented prescribed fire can reduce the fuel load and risk of wildfire, but it also creates emissions of pollutants, including particulate matter and trace gases. Computer models that predict smoke behavior were developed in western lands with mineral, not organic soils. Recent research in the North Carolina Coastal Plain has begun to fine tune the models to account for the flat topography of the area, the unique meteorological conditions created by the interface between the ocean and land, and the organic soils found throughout the Coastal Plain of the eastern and Gulf coasts. These adapted models will help managers minimize the hazards of smoke and trace gases, which can blanket nearby roadways, be transported long distances, and present a health hazard to people. Ideally, prescribed fires consume fine litter and small diameter fuels without igniting the organic soil horizon, during times when meteorological conditions will send the smoke high into the atmosphere.

Key Findings

- North Carolina's Coastal Plain has been radically altered through more than two centuries of timber harvesting and hydrological draining to support agriculture.
- When wildfire ignites the deep organic soils characteristic of this system, it can produce smoldering combustion that is difficult to extinguish.
- Prescribed burns are designed to consume fine litter and small fuels, producing fewer, and less toxic, emissions than long-duration, smoldering ground fires.
- Computer models that predict smoke emissions from wildfire or prescribed burning developed for western terrain are now being adapted to the unique ecosystems of the Coastal Plain.

"The land was smelt before it was seen."
Journal entry from a European sailor seeking docking sites in the southeastern United States.

Introduction

The Coastal Plain ecosystem has been altered over more than two centuries by logging, ditching, and draining of wetlands for agricultural and forestry purposes. "The ditch network is extensive," says Robert Mickler, principal investigator with Alion Science and Technology in Research Triangle Park, North Carolina. "At first ditches were built by slave labor as a means of clearing land for agriculture and forestry uses and moving crops via boat to markets, but the process went much faster when people began using heavy mechanized equipment and light rail."

Draining these wetlands dries out the organic soil and makes it prone to ignition. "Organic soil is like peat moss when it dries out," says Mickler. "When it ignites, the fire produces tremendous heat, which further dries the organic soil and extends the combustion process down and outward into the soil like underground coal fires."

In a recent research effort supported by the Joint Fire Science Program, Mickler and colleagues from the Forest Service and the U.S. Environmental Protection Agency (EPA) set out to track smoke and trace gas emissions from prescribed fires and to improve and validate smoke dispersion models adapted to the unique conditions of the Coastal Plain. "We are basically studying and modeling fire processes on organic soils that are poorly understood and not previously described in the scientific literature," Mickler says.

"What is new about this project is that it takes into account the fire dependent vegetative communities fairly common to the Coastal Plain of the eastern and Gulf coasts," says David Brownlie a fire ecologist with the U.S. Fish and Wildlife Service, Southeast Region. "The Coastal Plain is flat as a pancake; it has more fuel as measured in tons per acre—especially when organic soil is present—and it has a very unusual meteorology that results from the interface between land and ocean," says Brownlie.

Predicting smoke behavior

To model smoke dispersion, prescribed burns were conducted and ground level smoke monitored on a network of research plots in the Alligator River and Pocosin Lakes National Wildlife Refuges, Croatan National Forest, and the Air Force Dare County Bombing Range in fall and spring of 2005 and 2006. The fuel load was characterized using the Forest Service's Forest Inventory and Analysis protocol to measure live biomass and down deadwood by size class. In this study, the researchers used information on vegetation specific to the forest ecosystems located in the prescribed fire tracts. "We put field plots on the ground to measure the pre-burn fuel load prior to burns and then measured the same transects post-burn to determine how much fuel and what size classes were consumed," Mickler says.

Fuel loading transects. Credit: Robert Mickler.

This information was used to validate the BlueSky modeling framework of existing fuel loading, consumption, and smoke prediction models designed for rural and agricultural non-point sources. BlueSky is a national modeling system that uses a number of factors—including weather, fuel loads, and fire location—to predict the effects of ground level smoke and allow land managers and air quality regulators to anticipate the impacts of smoke from multiple sources. BlueSky incorporates all known burns into the modeling framework, including wildfires and planned prescribed burns. "This allows land managers and air quality regulators to anticipate the impacts of smoke from multiple sources, in addition to predicting the effects from their individual burns. BlueSky can also be used 'after the fact' to determine where smoke originated when populated areas have been affected by smoke emissions" says Miriam Rorig with the Forest Service's AirFire Team. A second model being validated in the project is Prescribed Burn (PB) model PB-Coastal Plain.

BlueSky and PB-Coastal Plain basically provide burn bosses with information on the trajectory and concentration of smoke from a fire ignited on a particular day and how the smoke will behave overnight, when inversion tends to keep smoke low to the ground. "With prescribed fire, you want the smoke wafted up and away from populated areas," says Mickler. "Typically you don't get the same lofting at night as during the day due to the evening inversion."

Prescribed burn at Pocosin Lakes National Wildlife Refuge on a day with a moderate breeze and excellent lift in the smoke column. Credit: Andrew Baily.

Emissions samples downwind from the fires were measured using portable monitors provided by U.S. Fish and Wildlife Service, Forest Service, and EPA and deployed in the study area. Meteorological information from portable weather stations was used to forecast weather, predict smoke behavior, and to validate the weather components of BlueSky and PB-Coastal Plain. Portable weather stations with particulate samplers were stationed in areas where smoke was predicted to travel downwind from the fire.

Overall, the information showed that prescribed fire applied during the wetter fall and spring seasons burns litter and fine fuels and produces more efficient combustion than wildfires under drier conditions, which can ignite the deep organic soil and result in smoldering combustion, releasing more smoke and gaseous emissions.

Health concerns

The EPA is responsible for setting the National Ambient Air Quality Standards (NAAQS) for criteria pollutants such as particulate matter, volatile organic compounds, and ozone precursors, and each state is required to devise a plan to comply with those standards. If an area exceeds the NAAQS, it is designated as "non-attainment," and the state is required to devise a plan to achieve attainment.

The majority of criteria pollutants are emitted by stationary sources, such as industrial plants, or mobile sources, from the tailpipes of cars and trucks. But wildfire and prescribed fire also emit primary pollutants, those that represent a threat to public health especially to sensitive individuals, and secondary pollutants that may cause impaired visibility or damage to plants, animals, and buildings.

In the southeastern United States, about 6 million acres (2.5 million hectares) of forest and agricultural land are burned each year, contributing from 2 to 15 percent to overall emissions. Monitoring in the rural environment, however, reveals that open burning of biomass can cause a spike, or transient emissions, of particulate matter, ozone, and ozone precursors from 50 to 150 percent higher than median values. Of increasing concern to EPA are emissions of fine particles, 2.5 microns or less (PM2.5), which can penetrate deeply into the lungs.

The researchers measured particulates PM2,5 and PM10 and other air quality parameters including ozone precursors and volatile organic compounds, some of which are known carcinogens, and as yet unregulated greenhouse gas emissions such as carbon dioxide, carbon monoxide, and methane. Relative to greenhouse gas emissions, Brownlie says, combustion from controlled burns is chemically comparable to decomposition of organic matter in the woods. "Both release a good bit of CO_2."

Go/No go decisions

While EPA sets the NAAQS for criteria pollutants, it's up to each state to devise a plan to comply with those standards. If an area exceeds the NAAQS, it often is subject to stricter regulatory requirements to achieve attainment of the standards.

Gary Curcio, a fire staff specialist with the North Carolina Division of Forest Resources, says that no county in North Carolina currently exceeds the standard for particulate matter, but some counties, mainly in the Interstate I-40/Piedmont corridor, exceed the standard for ozone. Prescribed fire and wildfire, however, can cause transient exceedences. "Working with our sister agency, the

Division of Air Quality, under the exceptional event rule, we petitioned EPA to remove what we call smoke intrusions that affect a federal reference monitor if these exceedences were caused by prescribed burns or wildfire where we could demonstrate we were using the right techniques." Essentially, this means that exceedences from fire are not included in the national database EPA maintains to monitor compliance with the NAAQS.

The state issues burning permits, which are required for anyone burning outdoors for any reason, and land managers and property owners are encouraged to submit a smoke management plan to the Division of Air Quality before conducting a burn. In North Carolina, the smoke management plan is voluntary for now. "Most people including federal land managers and all our cooperators comply with the program as if it were mandatory," Curcio says. "Not to follow a fire plan is suicidal."

To determine when conditions are favorable for a burn, North Carolina currently uses V-Smoke, an atmospheric smoke dispersion model designed for the southeastern United States. V-Smoke uses the Ventilation Climate Information System (VCIS), which is based on 40 years of historical data collection on wind speed and direction and mixing height—the distance above ground that a smoke plume disperses into the atmosphere.

Landscape scale prescribed burn at Alligator River National Wildlife Refuge. Credit: Tom Crews.

The dispersion model helps burn bosses evaluate the impact of smoke dispersion downwind. Curcio finds, however, that V-Smoke can overestimate emissions and reduce the number of days when controlled burns could be applied. "That is the kind of information Bob Mickler's research project is trying to validate."

"We have one of the toughest jobs in terms of burning because we have a high frequency, day after day, of inversion, when the air just sits there," says Curcio. The state's population is also one of the fastest growing in the nation, which puts more people in the wildland/urban interface. "That really puts burn bosses on notice. When we burn we have to do it right, and any kind of tool to help us is extremely useful."

Landscape scale fires

On June 1, 2008, a wildfire was ignited by a series of lightning strikes on private land adjacent to the Pocosin Lakes National Wildlife Refuge. By the end of August, when it was finally contained, the Evans Road Fire had burned a total of 41,000 acres (17,000 hectares) of public and private land, including 25,000 acres (10,000 hectares) of Pocosin Lakes National Wildlife Refuge. The fire burned two or three feet deep into organic soil in many places, and smoke from smoldering combustion blanketed large areas as far as 100 miles (160 kilometers) away. People in the Raleigh-Durham area could smell smoke from the fires, and tourists fled the Outer Banks, while others cancelled or postponed vacations there. In several counties, EPA issued air quality advisories in the highest ranges.

Sue Wilder, U.S. Fish and Wildlife Service Fire Ecologist, (approximately 5' 2" tall) stands in front of a stilted tree to show the depth of the burn. Credit: Vince Carver.

A large wildfire fire like the Evans Road Fire not only affects public health, it also damages the state's economy. Tom Crews, a fire management officer with the U.S. Fish and Wildlife Service's Alligator River National Wildlife Refuge in Dare County, hopes that better modeling systems will increase the number of prescribed burns to reduce heavy fuel loads. "The guidelines in North Carolina are so strict they have at times impeded our fuel reduction prescribed burning," he says. Dare County alone, where the Alligator River refuge is located, has nearly 200,000 acres (81,000 hectares) of land managed by the U.S. Fish and Wildlife Service. "We have large chunks of real estate unbroken by roads or fire breaks. A fire on the Dare County peninsula could burn the entire peninsula."

Landscape scale prescribed burn at Alligator River National Wildlife Refuge. Credit: Tom Crews.

In fact, a summer wildfire in 1957 nearly did just that, burning half the Dare County peninsula. "It was a slow spreading fire that burned deep pockets in the soil and wouldn't go out," says Crews. Wind caused the fire to spread along the shore of the Croatan/Pamlico Sound, and local residents, many of whom were elderly and unable to drive, had to be evacuated. Large fires occurred again in 1970, 1971, and 1980. For Crews and other fire management officials, large prescribed burns are critical to reducing fire hazard.

"We are trying to implement a controlled burning program to reduce fuels and break them up, creating a conflagration barrier to fire," Crews says. "To do this you have to burn large sections of landscape." The state of North Carolina's original smoke management guidelines restricted the burning of heavy fuels on larger units of land, such as we have on the National Wildlife Refuges in North Carolina. Crews thought it was possible to conduct larger burns safely, "so when Bob Mickler approached us asking about our needs for forest research and fire management, we told him our primary need was smoke management modeling," says Crews. "Although V-Smoke is widely used in the southeastern United States, it has not been validated for our area and seems to over predict impacts in many cases, especially on days with lower surface wind speeds." This limits the windows of opportunity for controlled burns. "This type of research is needed to get a better understanding of the V-Smoke and BlueSky models and fine tune them so we can make more accurate predictions of the concentration and trajectory of smoke and gaseous emissions. The more we burn, the better we get at safely re-introducing prescribed fire to restore and maintain the ecosystems that evolved with wildfires."

Management Implications

- Prescribed fire is a vital tool for reducing fuel loads in the Coastal Plain forests. Land managers, however, have to balance multiple goals, including protecting public health and meeting national air quality standards.
- More accurate models fine-tuned to local meteorological conditions will allow land managers to increase the number and size of controlled prescribed burns without violating air quality regulations.

"The more we burn, the better we get at safely re-introducing prescribed fire to restore and maintain the ecosystems that evolved with wildfires."

Further Information: Publications and Web Resources

Bailey, A.D. and R.A. Mickler. 2007. Fine scale vegetation classification and fuel load mapping for prescribed fire. In: Butler, W., Cook, W. comps. The fire environment-innovations, management, and policy. 26–30 March. Destin Florida. Proceedings RMRS-P-46. Fort Collins, CO; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. pp. 1–13.

BlueSky Web Resource: http://www.blueskyframework.org/uses/daily-smoke

Mickler, R.A., M. Rorig, C.D. Geron, G.L. Achtemeier, A.D. Bailey, C. Krull, and D. Brownlie. 2007. Development and demonstration of smoke plume, fire emissions, and pre- and postprescribed fire fuel models on North Carolina coastal plain forest ecosystems. In: Butler, W., Cook, W. comps. The fire environment-innovations, management, and policy. 26–30 March 2007, Destin Florida. Proceedings RMRS-P-46. Fort Collins, CO; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. pp. 1–18.

PB–Coastal Plain Web Resource: http://shrmc.ggy.uga.edu/

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Special Acknowledgement

While coordinating the BlueSky smoke dispersion modeling of the JFSP research project outlined in this article, Co-Principal Investigator Dr. Sue A. Ferguson died while battling cancer. In fire research, Sue helped found the Northwest Regional Modeling Consortium (NWRMC), a multi-agency effort to develop improved weather forecasts for the northwest. Through the National Fire Plan and the JFSP, she created the BlueSky smoke modeling framework, a tool that for the first time allows users to see real-time predictions of cumulative smoke impacts from prescribed, wildland, and agricultural fire.

Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

The information in this Brief is written from JFSP Project Number 04-2-1-80, which is available at www.firescience.gov.

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