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Filling in Knowledge Gaps in North Carolina

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Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Flaming combustion in pocosin vegetation during prescribed burning conducted in the Green Swamp, Brunswick County, NC. Credit: Roger Hungerford, RMRS Fire Sciences Laboratory.

Filling in Knowledge Gaps in North Carolina

Summary

North Carolina is divided into three broad physiographic regions, from the low-lying Atlantic Coastal Plain, to the mid-elevation foothills—the Piedmont Plateau—to the higher elevation Blue Ridge and Appalachian zone. Understanding the behavior of fire in these widely different regions, as in much of the southeastern United States, presents challenges that differ sharply from those common in the West, where the emphasis on fire science research has been greater. An ambitious project has helped fill in local and regional knowledge gaps, as researchers gathered data and assessed the relevance and limitations of existing tools, including remote satellite sensing, weather station information, fire behavior models, and drought indices commonly used to make management decisions. This study focused on pocosin swamp ecosystems of the Coastal Plain, longleaf pine plantations of the Piedmont/Sandhills and Coastal Plains, and rhododendron and laurel communities in mixed hardwood forests of the Appalachian Mountains. Over a three-plus year time period, data were collected on a number of parameters: live foliar moisture, dead woody fuels, moisture content of litter and duff, and soil moisture content. In the pocosin systems with deep organic soils, the researchers also measured root mat moisture, muck, and water table depth. Results suggest that existing fire behavior tools and predictive models need to be modified to better fit regional and local conditions. In addition, interpretation of the data collected needs to be fine tuned to better reflect conditions specific to local systems, especially for the poorly understood contribution of live fuel moisture and soil moisture content to fire behavior.

Key Findings

- Assumptions about the contribution of live fuels to fire behavior based on western models are not necessarily valid in eastern forests.
- Significant local knowledge gaps make predicting wildfire behavior and planning for controlled burns difficult.
- In coastal pocosin wetlands, a commonly used regional drought index and localized estimates of water table depth are poor indicators of potential ground fire behavior.
- Better field monitoring tools are needed, particularly in pocosin habitat with deep organic soils, to estimate soil moisture content and the potential for smoldering ground fires.

Introduction

From the Great Dismal Swamp to the Great Smoky Mountains, the terrain of North Carolina rises gradually from low to high elevation, and across a wide gradient of soil and vegetative communities. Pocosin swamp land with deep organic soils and a few remnant longleaf pine ecosystems dominate much of the low-lying Atlantic Coastal Plain. The Piedmont Plateau, with gently rolling foothills rising to an altitude of 1,000 feet (300 meters), still harbors remnant communities of longleaf pine savannahs and generally has drier, well drained mineral soils. To the west, the Appalachian Mountains soar to nearly 7,000 feet (2,000 meters) and are home to mixed conifer and hardwood forests in relatively moist sandy loam and clay soils.

In each of these communities, the forest floor and midstory vegetation play a distinct and critical role in the behavior of fire. In addition, the deep organic soils of the swampy pocosin habitat pose significant risks of producing smoldering ground fire. Until recently, little research has been conducted on the contribution of live foliar moisture and soil moisture content on fire behavior in the Southeast. A study supported by the Joint Fire Science Program has begun to fill in local and regional knowledge gaps for these three ecosystems.

Smoldering combustion of root mat soil in pocosin vegetation continues after flaming combustion has ended. Credit: Jim Reardon.

Regional variations

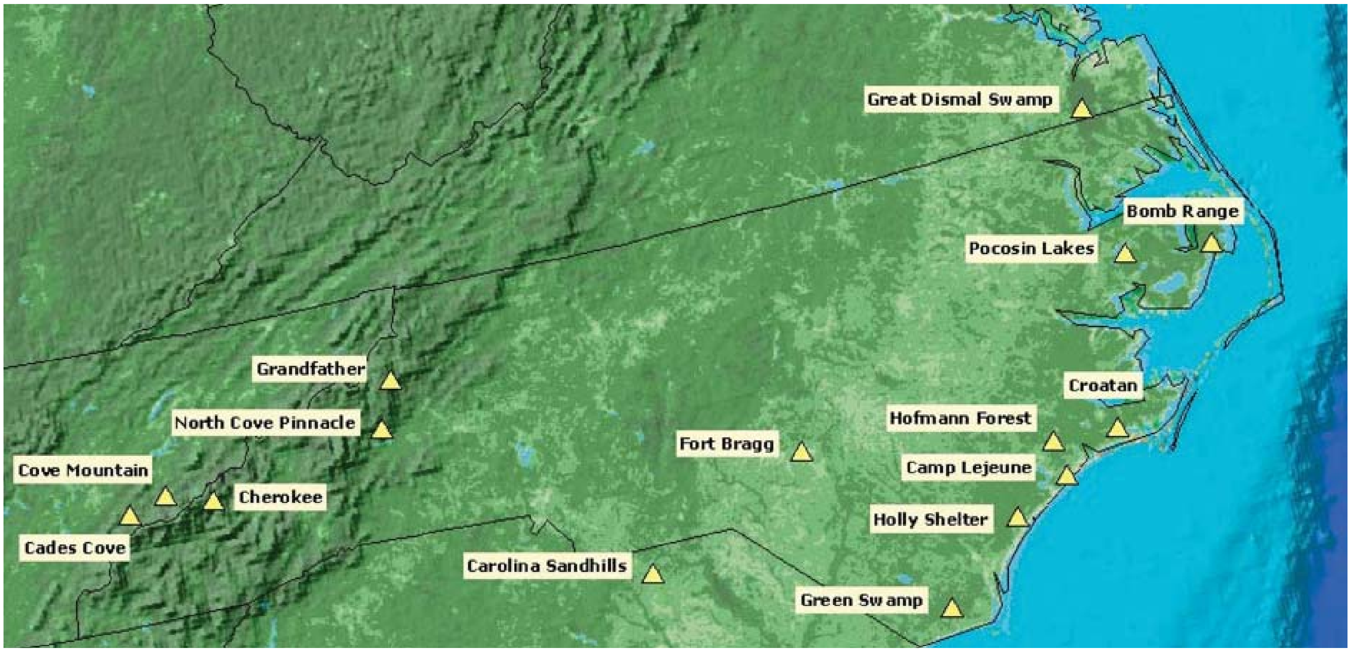
Much of the knowledge of fire behavior has been gathered primarily on forests in the more arid western United States. "There is much that we don't understand about the Southeast," says Roberta Bartlette, a retired forester from the Missoula Fire Sciences Laboratory, Rocky Mountain Research Station. "It is a more complex system, and we have less information." Remote sensing of vegetation greenness from space, for example, is often complicated by the many layers of lush vegetation that make it difficult to assess conditions beneath the canopy. "Satellite remote sensing to identify areas that are drying out works better in more arid climates," says Bartlette.

Moreover, dead downed fuels in the humid climate quickly rot, changing from sound or solid to decayed wood. Fire spread models were developed to account for the behavior of solid woody dead fuels with the relatively narrow range of moisture content typically found on western lands. "One thing I find interesting about dead wood in the Southeast is that it decays so rapidly, it doesn't react to weather changes or burn the way our models were set up to interpret," says Bartlette. Decaying dead wood can hold more water for its diameter class than fire danger rating models predict, and it can burn at a higher moisture content than fire behavior models predict. "Fire managers in the Southeast observe sustained burning at moisture conditions beyond those that would extinguish fire in western environments."

Bartlette and James J. Reardon, a forestry ecologist also with the Fire Sciences Laboratory, have spent nearly four years gathering seasonal data in three vegetative communities across the state in an effort to refine knowledge of the behavior of fire using multiple parameters, including live foliar moisture, downed woody fuels, litter and duff, soil moisture content and temperature, and in the Coastal Plain, water table depth.

Filling in data gaps

The study, conducted from late 2004 through August 2007, was ambitious in scope, entailing cooperation among eight federal, state, and nonprofit stakeholders. The research covered 30 sampling sites at 15 locations and documented three different vegetative communities: shrub-dominated pocosin swamps with gallberry (*Ilex glabra*) and fetterbush (*Lyonia lucida*) evergreens, and some longleaf pine stands, of the Atlantic Coastal Plain; frequently burned longleaf pine/savannah communities of the Piedmont Plateau/ Sandhills region with surface vegetation of turkey oak (*Quercus laevis*) and wiregrass (*Aristida stricta*); and mixed hardwood/conifer stands with laurel (*Kalmia latifolia* L.) and rhododendron (*Rhododendron* sp.) understories of the Appalachian Mountains.



The study's 15 research sites.

Moisture content of hand-gathered samples was measured on a seasonal basis throughout the multi-year project using conventional oven drying and weighing in the lab. Foliar samples of the dominant vegetative types included new and mature leaves and small, dead, attached twigs. Dead woody fuels in the one to 10-hour class (0 to ¼ and ¼ to 1 inch in diameter), litter, and duff were also sampled. Spring through fall sampling was done on a weekly or biweekly schedule, depending on the availability of personnel, and in winter as weather permitted.

Moisture sensing probes were inserted into the soil, and moisture content was monitored with data loggers on an hourly basis. In the deep organic soils of the pocosin communities, ground water depths were recorded with automated water level monitors, which have historically been used to estimate the potential for ground fire.

Technician Justin Bennett conducting maintenance and downloading of soil moisture and ground water well monitoring equipment (Dare County, NC). Credit: Roberta Bartlette.

The researchers used standard fire danger rating system outputs based on information from local weather stations located near the sample sites, including a commonly used regional drought index, the Keetch-Byram Drought Index (KBDI), to compare actual measurements with estimates and with remote satellite sensing of the greenness index.

In the Appalachian Mountains, managers have identified mountain laurel and rhododendron vegetation in mixed hardwood/conifer forests as an area of concern due in part to the difficulty of assessing the role of live foliar moisture in the evergreen midstory. "Areas dominated by shrubby live fuel, like those in the Appalachians, are tricky," says Bartlette. Identifying triggers between burning or not is difficult. The vegetation appears moist and dense, and can be too wet to carry fire, but if conditions are dry enough, the fire will rapidy consume the rhododendron and laurel."The leaves have a lot more substance, more waxes and carbohydrates than most mountain shrubs, so more heat energy is given off when they do burn." This makes suppression of wildfire difficult and dangerous.

Gary Curcio in a typical mixed pine/hardwood overstory with laurel/shrub understory, North Cove Pinnacle site, Appalachian Mountains, NC. Credit: Jim Reardon.

The study sites in the Piedmont and Sandhills consist of a few remnant longleaf pine ecosystems that have been maintained by The Nature Conservancy, the U.S. Fish and Wildlife Service, and the Department of Defense with a frequent rotation of prescribed fire, which has kept the understory quite open. In that respect, they are not typical of other Piedmont forest communities or longleaf pine stands that have not been frequently burned and may have a denser vegetative understory. They were chosen because of the importance of the species *Pinus palustris*, which today occupies not more than 3 percent of its original range and is considered one of the most threatened ecosystems in the United States.

Wiregrass, a common, fire-dependent perennial bunchgrass, and turkey oak, a small, fire-intolerant hardwood, are the dominant forest floor vegetation in the longleaf forests. Live fuel moisture sampling showed the widest range of moisture content of all study sites, with the highest levels coinciding with the spring fire season. “As with western open pine fuel types, you can have dead grass and pine needle litter from the previous year with green grass growing up through it,” says Bartlette. “If it’s hot and dry for a day or so, it’s going to burn.” Energy from the larger amount of dry dead fuel overrides the effects of moist, but low coverage, grasses and emerging shrub leaves.

A wide range of moisture content was also recorded in 1 and 10-hour fuels, from 10 percent in late spring to 75 percent in winter. Again, it can be difficult, using models based on sound dead wood more typical of western forests, to assess fire hazard. “A cool fire from dead grass and litter may ignite decaying woody fuel at higher moistures than our models predict for sound wood. This is true across all of the habitats we studied,” Bartlette says. “The large amount of dead fuel that is present, along with the fact that it can burn at higher moisture contents than we currently would predict, creates the potential for live fuel to be ignited.” On the other hand, the fact that a high percentage of the dead fuel is likely to be at least partially decayed leads it to potentially be wetter than models predict. Without sampling, prescribed burns plans based only on modeled moisture content could miss windows of opportunity.

Pocosin sites

Research sites in the Atlantic Coastal Plain ranged from the Great Dismal Swamp National Wildlife Refuge on the Virginia border to The Nature Conservancy’s Green Swamp Preserve just north of the South Carolina border. The 10 sampling locations included pocosin pond-pine (*Pinus serotina*) swamp characterized by deep organic soils.

As expected, moisture content of live foliar samples of the two dominant evergreen species in the bay family, fetterbush and gallberry, gradually increased during spring green-up, and slowly declined over the course of the summer. Somewhat paradoxically, here, as in other southern forests, land managers have noted that this increase in live fuel moisture historically coincides with the late spring and early summer fire season.

Close up of fetterbush with aerial and suspended dead fuels (Brunswick County, NC). Credit: Gary Curcio, NCDFR.

By applying the Rothermel fire spread model to correlate potential fire behavior with foliar moisture, the researchers concluded that foliar moisture has only a small dampening effect on the predicted fire behavior due to the relatively larger amount of dead fuel present. Fire behavior observations show that fire in these fuels can behave in unexpected and sometimes extreme ways. “We have guidelines for estimating live fuel moisture based on appearance or season, but it is easy to be fooled,” says Bartlette. The best method is to collect the sample and dry it in the lab, a field exercise that is time consuming and labor intensive.

The complexity of the vegetation, a mixture of live and dead fuels, also makes prediction of fire danger difficult. The researchers therefore included samples of suspended dead vegetation from October 2006 through August 2007. “So much of it has needle drape or dead fuel,” says Bartlette. Even if the canopy is moist, these aerial fuels, including fine dead stem wood, may increase fire potential. “Aerial fuels dry out in a matter of hours,” says Bartlette. “In an afternoon of drying it can easily burn.”

Soil and fuel moisture sampling site with a large amount of aerial and suspended dead fuels. Credit: Gary Curcio, NCDFR.

Moisture contents derived from hand measurements in the 1- and 10-hour fuel classes were much higher than expected. For sound dead wood typical of the West, the fiber saturation point is about 35 percent. “We found moisture contents from 50 percent to 70 percent,” says Reardon. This poses a challenge to managers planning prescribed burns. If prescribed burns are conducted with higher fuel moistures than anticipated, the fire behavior and fuel consumption will not meet planned objectives, and managers may need to go back and burn again. On the other hand, burning opportunities are somewhat limited because of the limited understanding of the factors influencing the moisture thresholds at which these fuels will burn. “If we wait too long, we will never be able to burn it, but if we burn it while it’s green, we may have to go back and burn again,” says Reardon.

Another challenge in pocosin swamp land is the complexity of the subsoil. The root mat, which is technically the OA1 soil horizon, is the matter that lies beneath the litter layer. "It's a lot like duff," says Reardon, "partially decomposed and fluffy, with a lot of air space. You can cut it like a brownie, and it has tiny roots woven through it, live roots, dead roots, and leaves."

Root mat from pocosin swamp land. Credit: Jim Reardon.

The litter layer and root mat produce irregular, or hummocky, terrain. "Nothing is homogeneous, duff depth or moisture content," Bartlette says. An uneven surface leads to a wide range of moisture contents across the surface and within the forest floor.

The researchers hand sampled litter and root moistures using commercially available probes to estimate moisture in the muck or sapric horizon, which are the highly decomposed soils beneath the root mat. The probes logged moisture content data on an hourly basis. A comparison of the information gathered with sensors to moisture measurements by hand sampling revealed that the probes were poor indicators of actual moisture content in the root mat. "It's very difficult to monitor moisture conditions in the field because soil properties and moisture contents are highly variable even within small areas," says Reardon.

A major concern for fire managers in pocosin habitat is the potential for significant smoke emissions from the smoldering combustion of organic root mat and muck soils. "When I stand in preburn briefings, a major concern is smoke management and the associated wind speed and direction," says Reardon. In pocosin habitat, managers have often used water table levels to plan for prescribed burn or assess fire hazard, assuming that higher levels are correlated with soil moisture content and thus the potential for smoldering fire. In this study, water level monitors were installed to measure the depth of the water table. When compared with the measured moisture content of these organic soils, however, the study showed that "water table isn't a reliable indicator of anything other than the level of the water table," Reardon says.

Managers in the southeast also make decisions based on the KBDI. The Keetch-Byram Drought Index, created in 1968, is a climatological system that estimates moisture levels in the soil and duff based on precipitation and evapotranspiration using a numerical system from 0 to 800. Higher numbers indicate more severe drought. Local and regional guidelines suggest that prescribed burns are not recommended when the KBDI is above 350–400. Reardon notes a couple of problems with KBDI. First, it does not account for inputs from groundwater and the surrounding topography, and it may at times overestimate the potential for smoldering fire in root mat and muck soil. This shortcoming may reduce opportunities for prescribed burn. "Without going out there and measuring the actual conditions, you may shut yourself out of a lot of possible burning days," he says. Moreover, the weather stations that gather climatological information may be located many miles from an area targeted for prescribed burn and may not truly reflect local conditions. "In our research we wanted to open up more opportunities to conduct prescribed burns."

In the future, Reardon hopes to see refinements of the monitoring equipment that measures soil and fuel moisture in the field and incorporation of data analysis and new information into existing models. The ultimate challenge is communicating information to managers confronting varying conditions in the field. "I would like to see the point where the information from models and data from field samples can end up on a cell phone," he says. "Research is a lot like gardening or fishing, if you are not an optimist, you probably won't do it."

Management Implications

- Drought indices based on meteorological inputs are not a reliable indicator of potential smoldering in wetland organic soils. Managers planning prescription burns should, to the extent possible, augment information from common drought indices with field measurements of live and dead fuel and soils.
- Meteorological information may not be a reliable indicator of actual conditions on sites that may be several miles from the weather station.
- Regular sampling and delivery of local information on soil and foliar moisture content to researchers can improve understanding of soil and live fuel moisture's effect on fire behavior.
- Researchers seek feedback from managers who can describe conditions when wildfire fire exceeded their expectations or prescribed fire did not spread according to predictions.
- More accurate information on soil and foliage moisture levels can open the windows of opportunity for prescribed burning.

Further Information: Publications and Web Resources

Fire Fuel Moisture Regimes website:
http://www.firefuelmoistures.org/

Reardon, J., G. Curcio, and R. Bartlette. 2009. Soil moisture dynamics and smoldering combustion limits of pocosin soils in North Carolina, USA. International Journal of Wildland Fire. 18, 326-335.

Reardon J., R. Hungerford and K Ryan. 2007. Factors affecting sustained smouldering in organic soils from pocosin and pond pine woodland wetlands. International Journal of Wildland Fire 16, 107–118.

Scientist Profiles

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NOTE: We would like to acknowledge the contribution to this project of co-investigator Gary M. Curcio, whose work experience has concentrated in the area of prescribed burning and wildland fire. He is a leading Division Fire Behavior Analyst and represents the Southeast as a state member on the National Advisory Group of Fire Danger Rating and the Interagency Airtanker Board. Recently his research time has been devoted to Fire Danger and Aviation Projects, making the National Fire Danger Rating System more meaningful to fire fighters.

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.

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