

ESTIMATED SMOLDERING PROBABILITY: A NEW TOOL FOR PREDICTING GROUND FIRE IN THE ORGANIC SOILS ON THE NORTH CAROLINA COASTAL PLAIN



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In the Southeastern United States, fires in pocosin wetlands and other similar vegetation communities with deep organic soils are a serious concern to fire managers. Highly flammable shrubs, such as gallberry and fetterbush, and small evergreen trees, such as red and loblolly bay, create the potential for extreme surface fire behavior. Moreover, deep organic soils allow excessive ground fire smoldering in these communities. The combustion of organic soils produces large amounts of persistent smoke, which is linked to health concerns and increases the potential for vehicle accidents due to reduced visibility.

Wetland Ground Fires: A Challenge to Suppress

Ignitions in pocosins can quickly “blow up,” creating major fire runs that defy control efforts until weather or fuel conditions change. In May of 1986, the Topsail Fire made several major runs and remained uncontrolled for a week in eastern North Carolina. A successful backfire operation involved the mass firing of 10,000 acres (4,000 ha) and created a convective plume reaching 15,000 feet

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(4,500 m) and fire spread rates of 2 to 2.5 miles per hour (3.2 to 4 km per hour). More recently in North Carolina, the Evans Road Fire of

June 2008 made major fire runs encompassing 7,000 to 12,000 acres per day (3,000 to 5,000 ha per day). In the aftermath of these runs,



Fireline preparation and back-firing on the Evans Road Fire. Photo: U.S. Fish and Wildlife Service.

Smoldering combustion and organic soil consumption on the Evans Road Fire. Photo: Bonnie Strawser, U.S. Fish and Wildlife Service.



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ground fire in the organic soils consumed up to 36 inches (91 cm) of organic soil and generated massive smoke plumes that impacted communities along the eastern coast for 2 months (Bailey and others 2009).

Suppression of smoldering ground fires presents serious challenges to fire managers. In these wetlands, suppression alternatives are often limited by accessibility, and soils often cannot support the weight of heavy equipment. Frequently, the extent and severity of smoldering makes flooding the only viable option for dealing with ground fires. For example, the ground fire on the Evan's Road Fire was contained by over 2 billion gallons (8 billion L) of water. The water was moved through existing drainage networks, with some water sources more than 35 miles (56 km) from the fire.

Assessing Ground Fire Potential

Tools for evaluating the potential for ground fire in organic soils are limited. Managers commonly use water levels in shallow water table wells and drainage ditches as indicators of local ground fire risk. Intermediate or regional scale estimates of potential are commonly evaluated using the Keetch Byram Drought Index (KDBI). However, our previous research has reported that the KDBI and water level measurements are inconsistent estimators of ground fire risk in these soils (Reardon and others 2009).

Currently, a network of fire danger stations monitors surface fire conditions, but they do not monitor ground fire potential. Due to the lack of suitable methods to evaluate ground fire risk, fire managers

often must rely heavily on broad guidelines developed from local knowledge and past experiences. Their judgments are often based on visible characteristics, not on other, more subtle changes in fuel characteristics, such as moisture changes. Although their decisions often result in positive outcomes, fire managers are sometimes surprised by extreme surface fire behavior and unexpected smoldering in what were initially considered benign fuels.

An efficient means of evaluating ground fire potential in organic soils would help managers use prescribed fire with minimal or limited resources and would increase the effective use of wildfire personnel and equipment resources during suppression activities.

Estimated Smoldering Probability

Ground fire in pocosin soils is associated with a porous root mat layer that is dominated by moderately decomposed organic material and fine to small roots (fig. 1), as well as a dense muck layer composed of highly decomposed organic material. The ability to predict ground fire in these soil layers is limited by our understanding of the moisture levels supporting smoldering combustion. To determine the moisture threshold between smoldering and nonsmoldering conditions, we collected soil samples from several sites on the North Carolina Coastal Plain and burned the soils in laboratory experiments. The laboratory burning experiments simulated common field conditions during



Figure 1—Root mat soil layer. This layer was between 12 and 18 inches (30 and 45 cm) thick on the burn units. Photo: Jim Reardon, Forest Service.

which an ignition source establishes a ground fire in the root mat and continues smoldering into adjacent soil.

Based on this laboratory work, we developed the Estimated Smoldering Probability (ESP) model as a predictive tool for use in the organic soils of these shrub-dominated wetland communities (Reardon and others 2007). This probability model reflects the chance of continued smoldering after a successful ground ignition, when smoldering becomes dependent on soil moisture and soil properties. Model scenarios represent common ignition situations such as lightning strikes, a flaming combustion front, or burning embers. At low probabilities, continued smoldering is not likely and control may require limited resources. At high probabilities, there is a good chance that most ignitions will be sustained and control will be more difficult.

Organic soils, including the root mat and muck layers in these wetlands, often have high moisture contents due to their ability to absorb and hold relatively large amounts of water. The percent moisture content of organic soils is determined based on the weight of water in the soil and the weight of the soil when it is dry. When the weight of water in the soil is greater than the soil dry weight, the percent moisture content exceeds 100 percent. Moisture contents of greater than 400 percent are common for saturated muck soils in North Carolina, and moisture contents greater than 800 percent have been reported for saturated feather moss soils in boreal black spruce forests.

Our analysis shows that the ESP of the root mat soil is related to moisture content and soil mineral content (fig. 2). For example, in root mat soils with a moisture content of 93 percent and an average mineral content of 4.5 percent, there is an estimated 50 percent probability of sustained smoldering. The ESP decreases to less than 10 percent in soils with moisture contents above

145 percent with the same mineral content (fig. 2). Although the ESP of the muck soils is also related to moisture content, it is insensitive to mineral content (fig. 3). Muck soils at moisture contents less than 140 percent have an ESP of 91 percent or greater, while muck soils at moisture contents greater than 250 percent have an ESP of less than 13 percent.

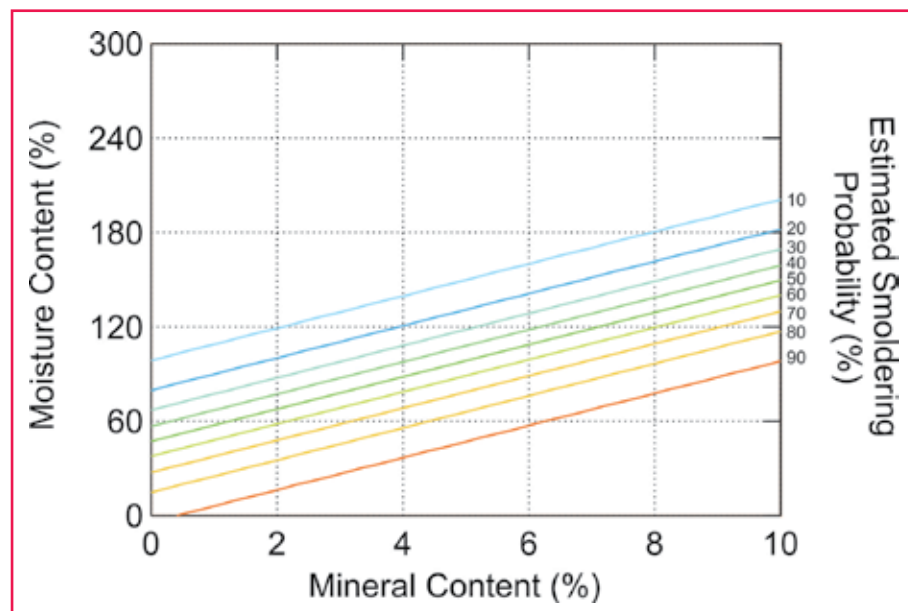


Figure 2—The estimated smoldering probability in root mat soils as a function of soil moisture and soil mineral content.

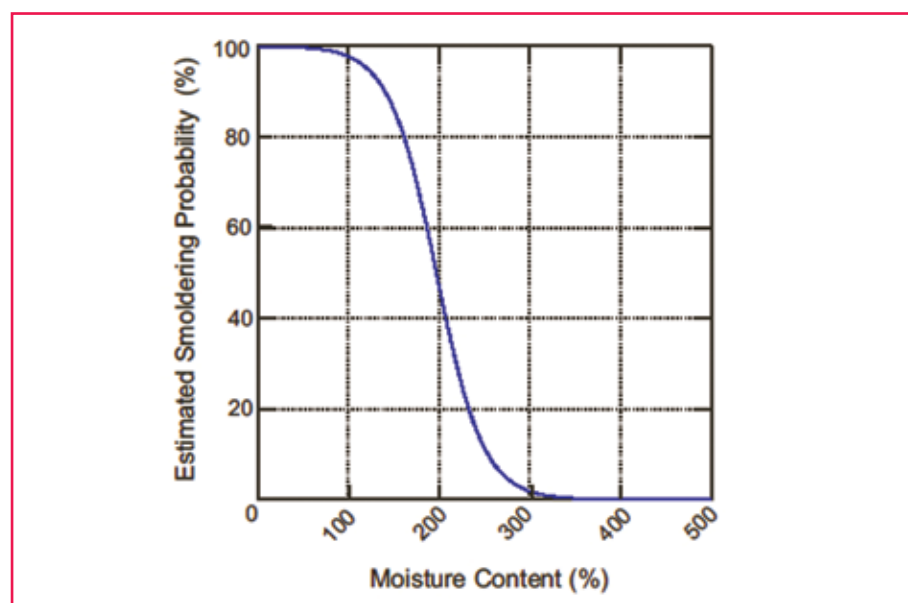


Figure 3—The estimated smoldering probability in muck soils as a function of soil moisture.

Small-Scale Field Tests

We conducted field tests of the ESP model using a series of small-scale research burns of approximately 4 to 6 acres (2 ha) and larger scale operational prescribed burns of approximately 100 to 800 acres (40 to 300 ha). We designed the small-scale burns to test the dry and wet moisture content limits of smoldering in these soils. In addition, we evaluated some widely accepted assumptions about smoldering combustion that were based on fire managers' past experiences and observations during these burns.

One burn, conducted during a period of extended drought and dry soil conditions, replicated laboratory observations of a ground fire that established in the dry root mat and spread downward into the muck soil. On the day of burning, the local water table was more than 30 inches (76 cm) below the soil surface and the water level in the ditches surrounding the burn unit was more than 3 feet (1 m) below the soil surface. The average root mat ESP was 84 percent, while the ESP was less than 10 percent at depths greater than 18 inches (46 cm) below the surface. Post-burn consumption measurements showed that ground fire consumed the root mat and stopped in the muck soil at moisture levels not expected to support smoldering.

The water depth in shallow water table wells and the water level in the adjacent drainage network are measures commonly used by managers to evaluate the risk of ground fire. Although conventional wisdom regarding the relationship between water table levels and the depth of smoldering consumption based on these measures suggested that smoldering would continue until

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constrained by the water level, neither the laboratory results nor the depth of soil consumption during this burn supported this assumption.

Additional small-scale burns conducted during wet burning conditions replicated observations of laboratory experiments during which the ignition of the surface litter layer initiated smoldering in the upper root mat layer, but the vertical spread of smoldering was constrained by high moisture contents of the lower root mat layer. Again, this contrasts with the accepted assumptions that once smoldering was established, it would not be constrained by soil moisture content.

Large-Scale Field Tests

Although we conducted the small-scale research burns with limited soil and fuel variability, the larger scale burns included levels of variability normally encountered during operational burning and wildland fires. The larger scale burns tested the influence of soil characteristic variability on the application of the ESP model. We conducted these larger burns as part of the North Carolina Division of Forest Resources Operational Research Evaluation Burn Project, which was created to facilitate the use of new research findings and fire management tools to advance prescribed fire.



Wet burn in the Green Swamp, Brunswick County, NC. Photo: Gary Curcio, NC Division of Forest Resources.

The monitoring and evaluation of pre-burn ground fire potential or risk was an important part of the planning of these larger burns. A concise way of incorporating our research results into the decisionmaking process was a simple “Burn–No Burn” moisture content threshold based on an acceptable ESP level. We set the decision point at a moisture content threshold of 170 percent for the root mat soil horizons on these sites. This moisture threshold represents a probability of sustained smoldering of less than 5 percent with an assumed average mineral content of 5 percent (fig. 2). Burning at lower moisture contents and correspondingly higher ESP levels was considered an unacceptable risk due to the uncertainty of soil mineral content combined with the potential for long-lasting residual emissions from smoldering and the costs of suppressing a smoldering ground fire.

On the day of burning, the measured root mat soil moisture was above the moisture content threshold on all sites. The burns were successful, and the absence of sustained smoldering following the burns supports the use of ESP on a wide range of sites.

The Future of ESP

The thick organic soils along the southeastern Coastal Plain are a unique resource that is not well integrated in the burning decisionmaking process. Future increases in burning opportunities in these wetland communities are dependent on better, finer scale tools to evaluate the potential for organic



A pine woodland burn site with a thick root mat soil layer above a mineral soil layer was characterized by the presence of a pine overstory and a heavy shrub understory. Photo: Gary Curcio, NC Division of Forest Resources.

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soil consumption. Tools such as ESP can provide valuable insight on burning conditions that support the decisionmaking process and can ultimately help managers use fire with more confidence.

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