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Smoldering Combustion in Organic Soils: Peat and Muck Fires in the Southeastern U.S.

Adam C. Watts and Leda N. Kobziar

INTRODUCTION

Although fires in wetlands would seem to be rare or impossible by definition, these ecosystems do occasionally experience fire. In the southeastern U.S., where frequently-burned uplands commonly occur adjacent to wetlands (e.g., pine flatwoods, Abrahamson and Hartnett 1990) wetland fires can occur with surprising frequency—as often as every decade in small wetlands that show greater variability in hydrology, for example (Wade et al. 1980, Snyder 1991). Most often, fires that occur in wetlands burn aboveground fuels. However, during prolonged drought conditions, the highly organic soils found in some wetlands may dry sufficiently to ignite and burn (de Groot 2012). Such fires, variously called ground fires, peat fires, or muck fires, are the result of smoldering combustion in organic soils. Different in many ways from the dramatic conflagrations often pictured in the news, these slow-motion wildfires pose unique challenges and hazards that make them worthy of special consideration.

SMOLDERING COMBUSTION

In contrast to flaming combustion, which typically lasts a fraction of an hour at a given location, smoldering is a flameless form of combustion that occurs when oxygen reacts with the surface of solid fuels (Ohlemiller 1995, Hadden 2011). Smoldering ground fires can continue in organic soils, such as peat[1]—soil developed from accumulated biomass (Joosten and Clarke 2002; Hurt et al. 2003)—for many days, or even months in cases such as the Kalimantan peat fires in Indonesia in 1997 (Page et al. 2002, Usup et al. 2004), and Georgia's Okefenokee Swamp (Florida Times-Union 2012). Despite typically lower temperatures for smoldering combustion compared to flaming combustion (500 to 700 °C versus 1500 to 1800 °C; Rein et al. 2008), smoldering fire persistence can eventually transfer more heat to surrounding soils and plants than flaming combustion (Kreye et al. 2011), and can produce significant ecological effects both because of the long residence time and their occurrence in the rooting zone, where plants have few adaptations to withstand fire.

When ground fires do become established, they are notoriously difficult to control. One reason is the tendency of smoldering to proceed deep into the soil (depending on such conditions as soil moisture and organic content), and to spread laterally far underground (Rein 2009). The result may be extensive burning of soil far below the surface, with little indication of the extent or location of smoldering (Rein et al. 2008). Additionally, the tendency of organic soils to become hydrophobic (i.e., repel water) when desiccated means that application of water, foam, or other agents often results in pooling on the surface, with only slow percolation downward toward the site of combustion. Regardless of their ability to penetrate, any suppression agent must be applied in logistically prohibitive amounts to be effective: one supervisory forester in northern Florida reported that the equivalent of more than three inches of rainfall were needed to extinguish a ground fire that had been smoldering for months (the Olive Fire), an equivalent of nearly 90,000 gallons per acre.

Practically speaking, it is therefore usually not feasible to deliver sufficient water to extinguish ground fires. A number of additional control techniques are employed, but all have their potential drawbacks. Heavy equipment is often used to cut firelines in desiccated muck or peat (Figure 1). However, the depth of the organic layer—sometimes meters deep—means that this can be time-consuming and expensive, and hard on both equipment and operator. Extensive firelines can also result in deleterious environmental impacts, such as landscape and habitat fragmentation. Firelines in deep organic soils also can have long-lasting effects, since these soils develop at very slow rates. Also, the integrity of the fireline can be compromised if the smoldering front passes underneath it in

[1] The question often arises of whether a particular ground fire is occurring in duff, peat, or muck. Duff is the least-decomposed form of accumulated organic matter on the forest floor (see Varner 2005), and muck is sufficiently decomposed to contain no recognizable plant matter and few or no fibers. Although fires in each type of fuel vary in their spread rates and the maximum moisture content sufficient for sustained combustion, they are treated together in this document.

Figure 1. At the Olive Fire (Levy Prairie, Putnam County, Florida), many passes of this bulldozer were required to cut a fireline to mineral soil through the thick muck.

undetected organic soil. Specialized lance-shaped nozzles are sometimes used on hoses to deliver water laterally from the end of a pointed tip, which is shoved into the ground in an attempt to access the site of smoldering. This method requires much time and water as well. Additives such as guar gum or chemical fire retardants, and even household dishwashing detergent, have been employed by firefighters to quench ground fires by improving the ability of water to penetrate organic soil profiles to reach the smoldering front or adhere to fuel surfaces.

HUMAN AND ENVIRONMENTAL HAZARDS

There are many reasons to attempt to control or extinguish ground fires, the most obvious of which are the costs to human health and smoke-related impediments to transportation. The smoke from ground fires is produced abundantly day and night, in contrast to wildfires consisting primarily of flames—the latter type of combustion being heavily influenced by diurnal weather patterns. With its production independent of atmospheric convection, ground fire smoke can accumulate at ground level during periods of stable atmospheric conditions (and especially during temperature inversions), causing dangerous reductions in visibility on roadways (Figure 2). Low-lying areas are particularly susceptible to the accumulation and even mixing of smoke and fog, and rapid visibility reductions encountered by vehicles entering accumulated smoke may cause tragic accidents (Abdel-Aty et al. 2011).

Smoke from ground fires is a concern for human health in addition to motorist safety. Although smoke from fires is only one source of atmospheric pollutants, wildland fire smoke contains various classes of particulate matter (Monroe et al. 2009). Among these, particulate matter with average particle sizes of 2.5 microns or smaller—referred to as $PM_{2.5}$—is considered particularly harmful for cardiovascular health, because of the ease with which these particles pass into the body and their large surface area on which toxic compounds may be adsorbed (See et al. 2007). Ground fires produce more of this class of airborne pollutant than other types of wildfires (Muraleedharan et al. 2000); this characteristic, along with the persistent nature of the fires themselves and the tendency of the smoke to remain near the ground, makes smoke from ground fires a threat to smoke-sensitive populations such as elderly, children, and asthmatics (Rappold et al. 2011).

The environmental effects of ground fires extend beyond immediate and direct impacts to humans at local scales. Organic soils are the result of accumulation of plant biomass over many decades to centuries or longer, and ground fires can consume much of this in a matter of weeks. The enormous carbon stocks found in organic soils can result in ground fires releasing substantial amounts of carbon to the atmosphere (Page et al. 2002, Mack et al. 2011)—indeed, Langmann and Heil (2004) estimate that peat fires may produce emissions 75% higher per acre than fires consuming standing vegetation alone. Existing efforts to quantify the potential for carbon sequestration on public lands as a means of mitigating anthropogenic CO_2 emissions (e.g., Depro et al 2008, Failey and Dilling 2010) will further increase interest in soil-consuming fires among managers who may be charged with preventing them or accounting for their effects on ecosystem carbon pools.

ECOLOGICAL EFFECTS

The combination of heating, direct consumption of roots embedded in organic soils, and organic soil loss to combustion (Figure 3) can result in significant damage and mortality to trees (Ewel and Mitsch 1978, Hartford and Frandsen 1992, Stephens and Finney 2002, Watts et al. 2012). In the case of some ecosystems, such as cypress swamps, ground fires may leave some pondcypress (*Taxodium distichum* var. *imbricarium*) or baldcypress

Figure 2. Smoke from ground fires often dissipates slowly, and contributes to serious degradation of visibility on roadways.

(*Taxodium distichum* var. *distichum*) alive, while killing potential competitors. In this way fires of moderate severity can be a mechanism of continued dominance by cypress in swamps, or (in the case of severe ground fires) a disturbance that can cause shifts in community composition from forested ecosystems to marshes (Gunderson 1977, Duever et al. 1984, Casey and Ewel 2006).

In areas of low topographic relief, ground fires can change the volume of depressional isolated wetlands by changing soil elevation, with hydrologic consequences for the surrounding landscape. Given a particular amount of water delivered via precipitation or overland flow each year, a change in the storage volume of a wetland following fire (due to changes in the basin depth caused by consumption of soil) may provide increased water availability in the wetland, while water availability to higher-elevation areas of the landscape may be more limited as it more rapidly is drawn to the depressions. Additionally, greater water storage or longer hydroperiod may mean that small wetlands may be able to serve for longer periods of time as watering holes for wildlife, or as habitat for their prey, during droughts. In southern Florida, for example, two Federally-listed endangered species (the wood stork, *Mycteria americana*, and the Florida panther, *Felis concolor coryi*) may depend on the existence of standing water late in the region's dry season (Fleming et al. 1994, Cox et al. 2006, Benson et al. 2008). To the extent that soil-consuming ground fires maintain open water by lowering soil elevations and reducing encroachment of vegetation, there may be an indirect ecological benefit of low-frequency ground fires.

CONCLUSION

The determinants, behavior, and effects of smoldering combustion in ground fires are far less understood than those of flaming fires. Most of the work that has occurred focuses on organic soils in areas such as Canada and the Arctic, where vast expanses of peat soils occur (de Groot 2012, Benscoter et al. 2011). However, work in the southeastern US, where environmental conditions differ considerably, has been limited to pocosin soil in North Carolina (Reardon et al. 2007) and cypress soils in Florida (Watts 2012). Because future climate change scenarios predict drought events of greater severity and frequency in many areas (IPCC 2007), including those with the potential for ground fires to occur (Running 2006, Liu et al. 2010), the potential for an increase in ground fires demands a greater understanding of their ecological and human heath effects, as well as their control. Of particular importance are investigating the ecological impacts of control techniques (such as traditional line-cutting and chemical additives), and determining whether a balance must be sought between the known risks and hazards associated with ground fires and the potential for these events to produce ecologically beneficial results under certain circumstances.

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Figure 3. Consumption of organic soil around the root zone of this tree indicates the depth of burn, and soil loss. Hydroperiod in the consumed area will be longer due to the elevation change caused by the fire.

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Authors

Adam C. Watts, School of Natural Resources and Environment, University of Florida (acwatts@ufl.edu)

Leda N. Kobziar, School of Forest Resources and Conservation, University of Florida

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