Soil Biology & Biochemistry 86 (2015) 67–76

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

# Wildfire effects on the properties and microbial community structure of organic horizon soils in the New Jersey Pinelands

Robyn A. Mikita-Barbato [a, *], John J. Kelly [b, 1], Robert L. Tate III [a]

[a] Department of Environmental Sciences, Rutgers, The State University of New Jersey, New Brunswick, NJ 08901, USA
[b] Department of Biology, Loyola University Chicago, Chicago, IL 60660, USA

ARTICLE INFO

*Article history:*
Received 3 December 2014
Received in revised form
13 February 2015
Accepted 22 March 2015
Available online 2 April 2015

*Keywords:*
Wildfire
Bacteria
Archaea
Fungi
Organic horizon

ABSTRACT

The frequency and intensity of wildfires are expected to increase in the coming years due to the changing climate, particularly in areas of high net primary production. Wildfires represent severe perturbations to terrestrial ecosystems and may have lasting effects. The objective of this study was to characterize the impacts of wildfire on an ecologically and economically important ecosystem by linking soil properties to shifts in microbial community structure in organic horizon soils. The study was conducted after a severe wildfire burned over 7000 ha of the New Jersey Pinelands, a low nutrient system with a historical incidence of fires. Soil properties in burned and non-burned soils were measured periodically up to two years after the fire occurred, in conjunction with molecular analysis of the soil bacterial, fungal and archaeal communities to determine the extent and duration of the ecosystem responses. The results of our study indicate that the wildfire resulted in significant changes in the soil physical and chemical characteristics in the organic horizon, including declines in soil organic matter, moisture content and total Kjeldahl nitrogen. These changes persisted for up to 25 months post-fire and were linked to shifts in the composition of soil bacterial, fungal and archaeal communities in the organic horizon. Of particular interest is the fact that the bacterial, fungal and archaeal communities in the severely burned soils all changed most dramatically during the first year after fire, changed more slowly during the second year after the fire, and were still distinct from communities in the non-burned soils 25 months post-fire. This slow recovery in soil physical, chemical and biological properties could have long term consequences for the soil ecosystem. These results highlight the importance of relating the response of the soil microbial communities to changing soil properties after a naturally occurring wildfire.

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## 1. Introduction

Wildfires are common perturbations in our environment that can have devastating ecological and economic repercussions (Janzen and Tobin-Janzen, 2008). Areas of moderate to high net primary production have been found to be especially prone to frequent wildfires, which impact both the local ecology and economy (Bowman et al., 2009). With the expected increase in wildfires due to the changing climate, particularly in areas of high net primary production (IPCC, 2013), understanding the potential ecological effects of wildfires is critical.

Wildfires and prescribed burns can have significant effects on soil physical and chemical properties, although currently available data indicate that the specific effects can vary dramatically. For example, previous studies have revealed both increases (Fernández et al., 1997; Murphy et al., 2006b) and decreases in soil pH (Hamman et al., 2007) as a result of wildfires. Many studies have reported losses in soil carbon (Fernández et al., 1997) and nitrogen following fires (Fernández et al., 1997; Murphy et al., 2006b); however, in others there were no changes in these parameters (Johnson et al., 2007). Similarly, changes in micronutrient concentrations following a fire can vary, with both increases and decreases being reported (Murphy et al., 2006b; Johnson et al., 2007).

Most studies examining the effects of fires on soil properties have focused on the soil mineral horizon, with limited data available for the organic soil horizon. The organic horizon of a soil is the surface layer of the soil, usually occurring above the mineral horizon, and is typically subjected to variations in soil temperature and

* Corresponding author. Engineering Research and Development Center, Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03257, USA. Tel.: +1 603 646 4388; fax: +1 603 646 4437.
*E-mail address:* robyn.a.barbato@erdc.dren.mil (R.A. Mikita-Barbato).
[1] Tel.: +1 732 932 9800x3217; fax: +1 732 932 8644.

http://dx.doi.org/10.1016/j.soilbio.2015.03.021
0038-0717/Published by Elsevier Ltd.

moisture (Howard and Howard, 1993). At the surface, these soils are also more likely to be significantly impacted by disturbance events such as fires.

Fire effects on microbial communities have been well reported for mineral horizon soils. Data are more limited for the organic horizon. Several recent studies have shown declines in total soil microbial biomass in the mineral horizon after a fire (Choromanska and DeLuca, 2001; Yeager et al., 2005; Smith et al., 2008; Dooley and Treseder, 2012) while others have reported increases in microbial biomass post-fire (Goberna et al., 2012) or no significant difference in microbial biomass between non-burned and burned soils (Hamman et al., 2007). Similarly bacterial community structure in the mineral horizon has also been shown to be sensitive to fire, as exemplified with an experimental fire in a Mediterranean shrubland, which revealed a shift in bacterial community structure (Goberna et al., 2012). Related studies have revealed bacterial diversity decreases after a wildfire of red pine in Japan (Mabuhay et al., 2006) and after prescribed burning of an upland oak forest in the USA (Williams et al., 2012). Fungi have been shown to be even more sensitive to fire events than bacteria, possibly due to the elevated soil temperatures associated with fires (Bárcenas-Moreno and Bååth, 2009) or to the newly established alkaline soil pH resulting from fires (Dunn et al., 1985; Smith et al., 2008), both of which could negatively affect fungal communities. Wildfires in a Mediterranean pine forest (Gassibe et al., 2011) and in an Alaskan black spruce forest (Waldrop and Harden, 2008) resulted in reduced fungal yields in the upper soil horizons during the early stages of fungal community secondary succession. Archaea are also are also significant components of soil microbial communities, but there are limited data available on fire effects on soil archaeal communities. Jurgens and Saano (1999) showed that Crenarchaeota dominated boreal forests that were subjected to both clear-cutting and prescribed burning. Additionally, archaeal community structure shifted immediately following a prescribed burn in Mediterranean shrublands, correlating with changes in ammonium nitrogen and soil pH (Goberna et al., 2012).

These variable impacts of wildfires reported in the current literature may be explained in part by differences in the types of fires studied. For example, many prior studies have assessed fire effects based on prescribed or experimental burns (Jurgens and Saano, 1999; Choromanska and DeLuca, 2001; Tuininga and Dighton, 2004; Certini, 2005; Murphy et al., 2006a; Chief et al., 2012; Williams et al., 2012), which are less intense than wildfires and thus might be expected to have less dramatic effects (Neary et al., 1999; Janzen and Tobin-Janzen, 2008). However, these varied effects of wildfires on soil biological populations also suggest that fire responses may be site specific, demonstrating a need for studies focused on specific ecologically and economically significant ecosystems. Lastly, prior studies have often been limited to single sampling events (e.g. Hamman et al., 2007; Smith et al., 2008), so questions remain about the duration of wildfire effects and the time course of soil ecosystem recovery post-fire.

The Pinelands is a large pine oak forest covering approximately 450,000 ha in southern New Jersey, which represents 22% of the state's total land area (http://www.state.nj.us/pinelands/reserve/). The plant composition of the Pinelands is relatively homogenous compared to other forest systems (Collins and Anderson, 1994). Typical soil properties include a low soil pH of 3.5–4.0 and a predominantly sandy soil texture (Zhu and Ehrenfeld, 1996; Ehrenfeld et al., 1997). The sandy soil is dominated by quartz ($SiO_2$), which contributes to the low cation exchange capacity, low pH, and poor nutrient status of the soils in this region (Forman, 1979). The Pinelands also contain over 4800 ha of pygmy forest, composed of mature pine and oak trees less than 3.4 m in height. Due to its unique features, the Pinelands region was classified as a National Reserve by the United States Congress under the National Parks and Recreation Act of 1978. In 1983 it was designated as a United States Biosphere Reserve by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (http://www.state.nj.us/pinelands/reserve/). The Pinelands Reserve is also economically significant, as it includes over 700,000 permanent residents and is used extensively for the production of blueberries and cranberries, as well as for recreation (http://www.state.nj.us/pinelands/reserve/).

Wildfires and prescribed burns are common occurrences in the Pinelands (Forman, 1979; Collins and Anderson, 1994). Previous research has explored a variety of topics related to the effects of fires in the Pinelands, including the regeneration of vegetation (Matlack et al., 1993; Ehrenfeld, 1994), fire suppression and survey studies (Skowronski et al., 2007; LaPuma et al., 2013), reduction in evapotranspiration due to prescribed fire (Clark et al., 2012), loss of phosphorus due to leaching in burned soils (Gray and Dighton, 2009), the impact of heat on forest litter (Gray and Dighton, 2006), and the effects of prescribed burns on fungal diversity (Tuininga and Dighton, 2004). Missing, however, are studies focused on the impact of naturally occurring wildfires on soil properties and soil microbial communities in the Pinelands.

To explore the effects of fire on the Pinelands soil ecosystem, we collected soil samples from a burned and an adjacent non-burned region of the Pinelands after a severe natural wildfire that occurred in 2007. We collected soil samples periodically over a two year period and assessed soil physical and chemical properties as well as the composition of bacterial, fungal and archaeal communities in the soil organic horizon. We hypothesized that the wildfires have significant impacts on soil physical and chemical properties and microbial community composition, but that these impacts would be short term, therefore not persisting two years post-fire. The objectives of our study were to examine the impact of wildfire on microbial community structure and to assess the relationships between microbial community dynamics and soil chemistry.

## 2. Materials and methods

### 2.1. Study site

In May of 2007, a wildfire burned approximately 7284 ha of a pine–oak forest in the Warren Grove region of the New Jersey Pinelands (correspondence with Nicholas Skowronski, USFS). A severely burned section of forest (SB; N39° 43′ 39.3″ and W74° 22′ 14.3″) and an adjacent non-burned section of forest (NB; N39° 44′ 25.3″ and W74° 22′ 8.6″) were selected for sampling. SB and NB contained similar vegetation, climate, and topography (0% slope). The dominant plant types within both sites included *Pinus rigida*, *Quercus alba*, *Quercus marilandica*, *Quercus ilicifolia*, *Gaylussacia baccata*, and *Vaccinium angustifolium*. Invasive plant species were not observed within the sampling sites during the study. The mean annual precipitation in the region is 1123 mm and mean monthly temperatures in January and June are 0.3 and 23.8 °C, respectively (1930–2004; NJ State Climatologist). The soils at the sampling sites were xeric, sandy soils from the Woodmansie series, a siliceous, mesic Typic Hapludults (USDA, 1971). Indications of the crown fire at SB included charred trees, absence of an understory, and a visible ash layer.

### 2.2. Soil sampling

Soil was collected from SB 2, 5, 13, 17, and 25 months after the fire and from NB 2 and 25 months after the fire. At each sampling time, nine replicate soil samples were collected from each site