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Wildfire impact: Natural experiment reveals differential short-term changes in soil microbial communities

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ABSTRACT

A wildfire which overran a sensor network site provided an opportunity (a natural experiment) to monitor short-term post-fire impacts (immediate and up to three months post-fire) in remnant eucalypt woodland and managed pasture plots. The magnitude of fire-induced changes in soil properties and soil microbial communities was determined by comparing (1) variation in fire-adapted eucalypt woodland *vs.* pasture grassland at the burnt site; (2) variation at the burnt woodland-pasture sites with variation at two unburnt woodland-pasture sites in the same locality; and (3) temporal variation pre- and post-fire. In the eucalypt woodland, soil ammonium, pH and ROC content increased post-fire, while in the pasture soil, soil nitrate increased post-fire and became the dominant soluble N pool. However, apart from distinct changes in N pools, the magnitude of change in most soil properties was small when compared to the unburnt sites. At the burnt site, bacterial and fungal community structure showed significant temporal shifts between pre- and post-fire periods which were associated with changes in soil nutrients, especially N pools. In contrast, microbial communities at the unburnt sites showed little temporal change over the same period. Bacterial community composition at the burnt site also changed dramatically post-fire in terms of abundance and diversity, with positive impacts on abundance of phyla such as Actinobacteria, Proteobacteria and Firmicutes. Large and rapid changes in soil bacterial community composition occurred in the fire-adapted woodland plot compared to the pasture soil, which may be a reflection of differences in vegetation composition and fuel loading. Given the rapid yet differential response in contrasting land uses, identification of key soil bacterial groups may be useful in assessing recovery of fire-adapted ecosystems, especially as wildfire frequency is predicted to increase with global climate change.

1. Introduction

Wildfires are notoriously unpredictable disturbances. However, fire is an important driver of ecosystem function, vegetation dynamics and nutrient cycling. The magnitude of fire impacts is determined by the interaction between the affected ecosystem, climate and the fire regime. Fire regimes are characterised by interactions between key components such as fire intensity, frequency, size, seasonality, type and severity (Flannigan et al., 2009). There has been considerable interest in understanding belowground fire impacts, especially on soil microbial communities where fire has direct and indirect impacts (Hart et al., 2005; Muñoz-Rojas et al., 2016; Neary et al., 1999). Direct effects result from heat transfer from the soil surface to lower depths, whereas

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indirect fire impacts are mediated by above- and below-ground interactions between plants and the soil environment. Soil heating affects soil microbial communities through cell death, causing reductions in biomass and diversity (Neary et al., 1999; Dooley and Treseder, 2012). In contrast, greater fire-induced impacts on soil microbial communities, in terms of spatial extent and longevity, are mediated through changes to soil organic matter quality, soil moisture retention, soil pH and buffering capacity and changes in nutrient availability. Fire also impacts rhizodeposition, plant litter accumulation, and ash and charcoal content which alter nutrient cycling and soil microbial communities (Cobo-Díaz et al., 2015). The application of molecular techniques to post-fire studies is advancing our understanding of fire-induced changes on microbial communities, especially with detailed identification of the affected communities (Ferrenberg et al., 2013; Goberna et al., 2012; Mikita-Barbato et al., 2015); however, further work is required into immediate post-fire impacts (i.e. days since fire) and time to recovery.

Fire regimes in fire-adapted biomes have led to the evolution of plant fire survival traits (Bond and Keeley, 2005). These functional traits facilitate rapid (days to weeks) post-fire regeneration, and include post-fire basal or epicormic resprouting (e.g. eucalypts) (Clarke et al., 2015; Gill, 1975); underground storage organs (e.g. acacia); and heat or smoke-stimulated flowering and seed germination (Bond and Keeley, 2005; Gill, 1975). Specific soil microbial fire adaptations have also been observed: some Australian fungi are pyrophilous and have underground storage organs which enable them to produce fruiting-bodies two days post-fire (McMullen et al., 2011). While fire-adapted systems have evolved protective mechanisms, they could still be substantially changed in the long-term, and sometimes irreparably, if predicted changes in climate and fire regime occur, i.e., increases in fire frequency combined with shorter recovery times (Flannigan et al., 2009). Furthermore, changes in management practices, such as more frequent low-intensity prescribed burning to control fuel loads, urban encroachment, and land use change place additional pressures on the ability of fire-adapted ecosystems to recover (Bardsley et al., 2015).

Because of their unpredictable nature, wildfire studies are reactive, often opportunistic, and may not have adequate control sites for comparison. The length of time since fire varies in wildfire studies, ranging from immediate and short-term (days, weeks, months) (Dannenmann et al., 2011; Ferrenberg et al., 2013; Muñoz-Rojas et al., 2016) to longer-term (years, decades) (Mackenzie and DeLuca, 2006; Smithwick et al., 2009; Stephan et al., 2015). Investigating post-wildfire recovery and resilience also presents challenges in replication, establishing ‘before-fire’ baseline conditions and locating similar, but unburnt, control sites. Despite these challenges, understanding the relationships between soil properties, microbial communities and soil function at different post-fire timescales has the potential to identify early indicators of weakening ecosystem resilience and recovery in a range of land use systems.

A wildfire which overran a site that was part of a multi-year environmental monitoring study (De Menezes et al., 2015; Prendergast-Miller et al., 2015) provided an opportunity to characterise short-term changes in soil properties and soil microbial communities in managed pasture and remnant native eucalypt woodland plots. We focused on short-term temporal variation, given the relatively rapid recovery of fire-adapted eucalypt woodland systems (Clarke et al., 2015; Gill, 1975; Shakesby et al., 2007). The objectives were to (1) monitor short-term temporal variation in soil and microbial parameters; (2) identify soil factors which related to temporal shifts in microbial communities; and (3) identify microbial groups which responded positively and negatively to fire-induced temporal change in soil properties. Finally, as it is difficult to directly ascertain the scale of fire impacts, the magnitude of fire as an environmental disturbance was determined by including a comparison of temporal (seasonal) variation at two unburnt (control) sites within the same locality as the burnt site. This study provided a rare opportunity to discuss temporal variation in the context of fire disturbance because data were also available from a sampling campaign which took place three weeks prior to the wildfire. We therefore tested the hypothesis that the temporal shift in soil properties and microbial communities would be different between burnt and unburnt sites in each land use.

2. Materials and methods

2.1. Study sites and sampling design

The wildfire occurred at one of three pastoral farms (Glenrock, Bogo, Talmo) which have been previously described (De Menezes et al., 2015; Prendergast-Miller et al., 2015). A map of the study site location is provided in the Supplementary Information (Fig. S1). The naturally-occurring wildfire spread over >14,000 ha of farmland which included the Glenrock farm (the burnt site). The farms at Bogo and Talmo were not affected and therefore provided unburnt pseudo-control sites for this study. The farms are within 15 km of each other and are located in the seasonally dry temperate region of New South Wales (Australia) on brown sodosols (Isbell, 2002). Glenrock is on volcanic and sedimentary rocks of the Silurian Douro Group. Bogo and Talmo are on Mountain Creek Volcanics of the Devonian Black Range Group (Cramsie et al., 1975). As described in Prendergast-Miller et al. (2015), the main plant species in the three pasture sites was subterranean clover (*Trifolium subterraneum* L.) with some annual and perennial grasses [e.g. phalaris (*Phalaris aquatic* L.)]. The woodlands at Glenrock and Bogo consisted of remnant native woodland areas adjacent to pasture fields: the *Eucalyptus* woodland was relatively open with a native grassy understorey; the Bogo woodland had some exotic grass species. At Talmo, the pasture lay adjacent to the Burrinjuck Nature Reserve (NSW); in this remnant native woodland, *Eucalyptus* and *Acacia* tree species had a more dense cover compared to the other two woodland plots. The three study sites were located on mature (>40 years) sheep-grazing enterprises typical of the farming landscape in rural south-eastern Australia. In this region, land clearing (by tree logging and fire) since the mid-nineteenth century, as well as soil degradation and increasing pressure on land resources has created an increasingly fragmented remnant native woodland-managed pasture landscape (Prober et al., 2002).

Monitoring sites on paired managed pasture-remnant native woodland plots were established at each farm in October 2012 (see Fig. S2). On each adjacent pasture and remnant native woodland, a plot (100 × 100 m) was gridded and 25 wireless sensor nodes were deployed (150 nodes in total). The layout of the sensor nodes was determined by spatial prediction variance (Cressie, 1993) based on the variability of soil and microbial parameters measured in De Menezes et al. (2015). The original objective of the study was to determine spatial and temporal variation in contrasting habitats using an environmental sensor network. The physical location of the nodes marked the soil sampling points to calibrate sensor- and soil-derived measurements, and the first soil samples were taken from all nodes in December 2012 (150 node samples; 25 samples per plot). The sensor nodes marked the sampling positions, and soil samples were taken within 0.5 m of the node. Due to temporal sampling, care was taken to avoid re-sampling the previous hole. Following the wildfire in January 2013, there were two sampling campaigns: (1) to collect soils at the Glenrock fire site (one adjacent pasture-woodland plot) over a period of 4 months (up to April 2013) to determine post-fire changes; and (2) to collect soils at the