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Prescribed fire increases pyrogenic carbon in litter and surface soil in lowland *Eucalyptus* forests of south-eastern Australia

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ABSTRACT

Low intensity prescribed fire is widely practiced in seasonally dry forests in many countries to reduce fuel loads and the risk of uncontrollable wildfires. Associated with low intensity fire is the heating and alteration of organic matter of the litter and surface soil to create pyrogenic carbon (PyC). This study reports changes in total carbon (TC) and PyC in the litter (as char particles) and the top 2 cm of soil (as oxidation resistant carbon, PyC) in *Eucalyptus obliqua* forests in south-eastern Australia. Litter and surface soil were sampled and carbon (C) measured before and immediately after low intensity prescribed fire on the same sites. Post-fire, lightly burnt (FIRE-300) and heavily burnt (FIRE-600) forest floor areas were sampled separately. On average, net loss of 1.55 Mg ha^{-1} C (10% of initial) from litter was largely offset by increase of 1.67 Mg ha^{-1} C in soil (which was restricted to the 0–2 cm layer) with no net change in the initial litter + soil C stock of 21.9 Mg ha^{-1} C. Concurrently, fire increased PyC by 0.3 Mg ha^{-1} in litter and 0.4 Mg ha^{-1} in surface soil, which together were equivalent to about 11% of the 6.1 Mg ha^{-1} C emitted to the atmosphere as a result of the prescribed burn.

1. Introduction

Prescribed fire is important in forest management to reduce the risk of uncontrollable wildfires by reducing fuel loads, particularly in Australia, the most fire-prone continent (e.g. McCaw, 2013; Knapp et al., 2015). The impact of prescribed fire on forest carbon (C) stock is an important consideration for land managers as globally millions of hectares are treated annually and fire is a key driver of change in C stock (Boerner et al., 2008; Loehman et al., 2014). The extent to which fire alters both the amount and properties ('quality') of litter and soil C depends mainly on the intensity and duration of fire (González-Pérez et al., 2004; Knicker et al., 2006; Knicker, 2007; Mastrolonardo et al., 2013; Faria et al., 2015). Changes in litter and soil C following fire also derive from the accession of organic C, including pyrogenic carbon (PyC), from aboveground biomass that influences both the size range of litter particles as well as the total pool size (González-Pérez et al., 2004; Knicker, 2007). Biomass and litter C, added to the post-fire soil surface, can subsequently be redistributed into the soil (Certini et al., 2011; González-Pérez et al., 2004; Alexis et al., 2012).

The PyC in litter and soil, produced by combustion and pyrolysis during burning (e.g. Abiven et al., 2011; Bird and Ascough, 2012; Jenkins et al., 2014), is a continuum of combustion products ranging from slightly charred degradable biomass to highly condensed, refractory soot (Masiello, 2004). The chemical characteristics of PyC in fire impacted forest soils are described by Otto et al. (2006) and De la Rosa et al. (2008). PyC is of interest because of its importance in the global C cycle (Kuhlbusch, 1998; Santín et al., 2015b), its potential role as a C sink (Knicker, 2009), its role in influencing microbial activity and decomposition (Steiner et al., 2008; Lehmann et al., 2011; Jenkins et al., 2014) and for its impact on soil properties including cation exchange capacity (Liang et al., 2006). Techniques for quantification of PyC in soils and sediments rely mainly on resistance to oxidative degradation, with a high degree of variability in results reported, so that each technique is an index of PyC within a specific region of the combustion continuum (Hammes et al., 2007; Knicker, 2007). Hence it is not feasible to account for the complete combustion continuum using one single method. We employed a chemo-thermal oxidation method proposed by

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Kurth et al. (2006) in which wet-oxidation of soil with a weak nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) solution removes labile organic C but not PyC. The refractory nature of PyC is the basis for chemical and thermal oxidation techniques. Both over- and under-detection of PyC while applying chemical and thermal oxidation methods have been reported (Masiello, 2004; Knicker et al., 2007). For this reason standard soil-char mixtures are used to examine the associated uncertainties (Pingree et al., 2012; Soucémarianadin et al., 2014).

Fire influences the global C cycle by releasing CO_2 to the atmosphere and by transferring otherwise decomposable organic C to more stable PyC forms, effectively a transfer of C from short-term bio-atmospheric turnover to longer-term cycling more akin with the geological C cycle (Clay and Worrall, 2011). Although the importance of PyC in the global C cycle is generally recognised, there are few quantitative studies of fire effects on forest floor and soil surface organic matter that include the production or loss of PyC. Specifically, for the extensively fire-managed and fire-affected Australian *Eucalyptus* forests, the impact of prescribed fire on litter and soil C is not well described in the literature and there are few robust quantitative assessments. Given that more than 0.5 million ha of *Eucalyptus* open forests in Australia are managed with low intensity fire annually (ABARES, 2013), this is an important gap in knowledge. An earlier study in *Eucalyptus obliqua* forests of southern Victoria reported the redistribution and emission of C following prescribed burning (Volkova and Weston, 2013). In the present study we aimed to determine in greater detail the impact of prescribed fires on the forest floor litter and surface soil, including the loss of litter C or transformation to more recalcitrant PyC, and the redistribution of C to the surface soil.

2. Materials and methods

2.1. Study area

The forests studied are in the Otway Ranges of Victoria about 160 km southwest of Melbourne, Victoria, in south-eastern Australia (Fig. 1). The forests are dominated by *Eucalyptus* species, predominantly messmate (*E. obliqua* L.Hér.) with some narrow-leaf peppermint (*E. radiata* Sieb. ex DC.) and brown stringybark (*E. baxteri* (Benth.) Maiden & Blakely ex Black), and the understorey is often dense comprising low shrubs, ferns and grasses. Classified as Lowland Forests (EVC 16) in the Ecological Vegetation Classification System (DEPI, 2014), these are floristically diverse forests typical of lowland plains in the state of Victoria (Anderson and White, 2000). Long-term mean annual rainfall is 1020 mm with mean maximum temperature of 18.5 °C and minimum 6.8 °C. Soils of the Otway Ranges are developed from lithic sedimentary rocks of the lower Cretaceous. Soils at the study sites are yellow podzolic, predominantly of sandy loam to sandy clay loam A-horizons over clayey B-horizons (Robinson et al., 2003). The soils are Kurosol in the Australian soil classification (Isbell, 2002) and Alisol according to IUSS Working Group WRB (2006), with acidic profiles (pH 4.5–5.2) and strong texture contrast between A and B horizons. Forest floor litter and soil properties are given in Table 1 and further site characteristics and weather conditions at the time of burning are detailed in Volkova and Weston (2013).

2.2. Experimental design and sampling protocol

Three sites were established across the 80 km north to south extent of the Otway Ranges, within areas scheduled for prescribed

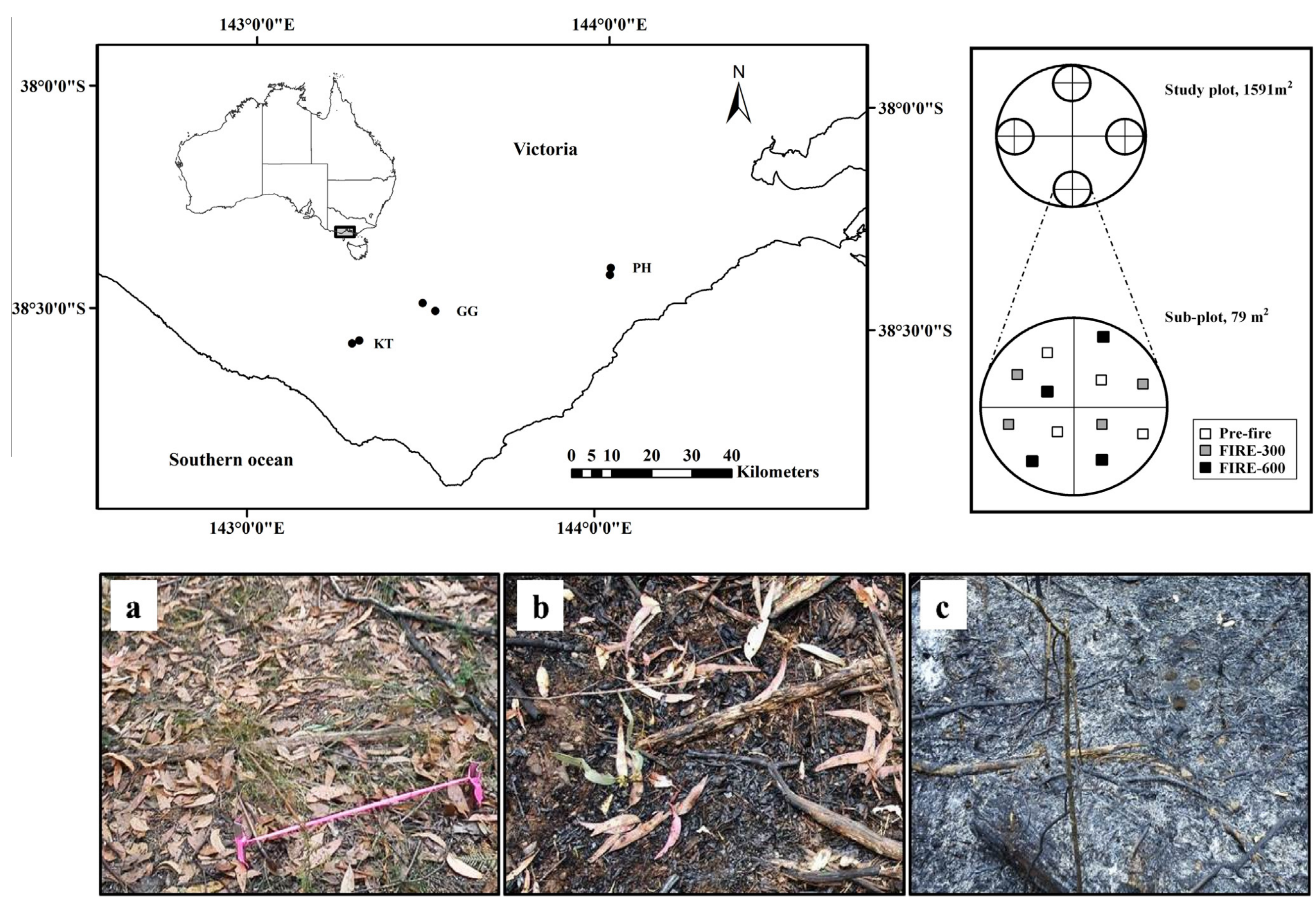

Fig. 1. Location of the study area and sampling design of plots and subplots (top) and photos of the forest floor (a) pre-fire, (b) post-fire (FIRE-300) and (c) post-fire (FIRE-600).