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Repeated fuel reduction burns have little long-term impact on soil greenhouse gas exchange in a dry sclerophyll eucalypt forest

Benedikt J. Fest[a,*], Stephen J. Livesley[b], Joseph C. von Fischer[c], Stefan K. Arndt[a]

[a] Department of Forest and Ecosystem Science, The University of Melbourne, Melbourne, Victoria, Australia
[b] Department of Resource Management and Geography, The University of Melbourne, Melbourne, Victoria, Australia
[c] Department of Biology and Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO, USA

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ABSTRACT

Fuel reduction burning is a widespread management tool in fire-tolerant forest systems to mitigate wildfire risk, but has the potential to impact soil greenhouse gas exchange processes. Soil disturbance often alters soil carbon dioxide (CO_2) and methane (CH_4) flux; however, the influence of repeated fuel reduction burning upon these flux processes long-term is still not well understood. In this study we measure soil CH_4 flux, soil methanotrophic activity and soil CO_2 flux in all seasons from March 2009 to February 2011 in three different fire frequency treatments applied to a dry sclerophyll eucalypt forest (Victoria, Australia) for the last 27 years. The low-intensity fire treatments are forest burnt in autumn (i) every 3 years, (ii) every 10 years, and (iii) not burned (since before 1985). Mean soil CO_2 emissions were greater in the burnt as compared to un-burnt treatments. In contrast, soil CH_4 oxidation did not show a response to repeated burning and there was no statistical difference in soil CH_4 flux among treatments. Furthermore, we did not detect changes in the relationships of soil CH_4 flux or soil CO_2 flux and key environmental controls. Our results indicate that low intensity fuel reduction burns have no cumulative negative impact on biogeochemical processes related to soil respiration or soil CH_4 oxidation.

1. Introduction

Changes in our climate system are likely to increase the risk of fire events in fire prone ecosystems. In South Eastern Australia increased temperatures and decreases in rainfall are likely to lead to an increase in the fire danger days (Clarke et al., 2011; Hasson et al., 2009) and therefore increase the risk of large-scale catastrophic fires. One management option that potentially reduces the risk of catastrophic fires is fuel reduction burning, where the fine fuel loads are regularly reduced to limit the intensity and severity of future wildfires. Recently, the yearly target for fuel reduction burns on forested public land in Victoria, Australia has been increased from around 100,000 ha per year to around 380,000 ha per year (Parliament of Victoria, 2010), in response to some severe and catastrophic wildfires. This increase in the area of forest burnt will lead to more frequent burning in any given area as compared to the historic forest fire management over the last 30–40 years (Parliament of Victoria, 2008). However, we have very little information on how increased frequent fuel reduction burning will impact long-term forest soil greenhouse gas exchange.

Well drained upland soils in temperate climates are the primary biotic sink for atmospheric methane (CH_4) as a result of CH_4 oxidation by methanotrophic bacteria. Soils in temperate forest ecosystems are estimated to contribute around 50% to this CH_4 sink (Dutaur and Verchot, 2007; IPCC, 2007). Major factors regulating and influencing CH_4 uptake (negative soil-atmosphere CH_4 exchange; F_{CH_4}) by forest soils include soil moisture, soil temperature, soil pH, soil inorganic nitrogen levels and soil physical structure (Bodelier and Laanbroek, 2004; Smith et al., 2003). A combination of environmental (soil moisture content and soil temperature) and physical (bulk density and soil porosity) factors determine soil diffusivity, a major regulator of CH_4 uptake rate (Dorr et al., 1993; King, 1997; von Fischer et al., 2009). Temperate forest ecosystems also sequester, store and release carbon (C) and are therefore of major importance to the global C cycle (IPCC, 2007; Keith et al., 2009; Martin et al., 2007; Schlesinger and Andrews, 2000). In the global terrestrial C cycle, soil CO_2 efflux (F_{CO_2}) is the second largest flux after gross primary productivity (Raich and Schlesinger, 1992). Soil CO_2 efflux is the product of autotrophic respiration (plant roots and associated mycorrhizal

* Corresponding author at: Department of Forest and Ecosystem Science The University of Melbourne 500 Yarra Boulevard, Richmond, 3121 Victoria, Australia. Tel.: +61 3 9035 6967; mobile: +61 407 342 305.
E-mail address: bfest@unimelb.edu.au (B.J. Fest).

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fungi) and heterotrophic respiration (soil microorganism and soil fauna) (Raich and Schlesinger, 1992). Factors regulating F_{CO_2} are soil temperature, soil water content, soil organic C, fine root density, and nutrient availability (Lloyd and Taylor, 1994; Schlesinger, 1984; Smith et al., 2003).

Depending on their intensity, fuel reduction burns have the potential to alter some, if not all, of the factors regulating soil-atmosphere exchange of CH_4 and CO_2 over different timescales (Certini, 2005; Close et al., 2011; Inbar et al., 2014; Raison, 1980; Raison et al., 1986; Smith et al., 2008; Switzer et al., 2012; Williams et al., 2012; Wüthrich et al., 2002). A shift in forest burning policy therefore raises concerns that frequent burning of forest ecosystems may lead to changes in the forest soil source and/or sink strength for greenhouse gases.

Studies on the effect of fuel reduction burning on soil-atmosphere CH_4 and CO_2 flux in different ecosystems have so far focused on short- and medium-term responses following single experimental burns. The results from these studies range from an increase in soil CH_4 uptake (Jaatinen et al., 2004), temporary or long-term increases in soil CO_2 efflux (Jia et al., 2012; Tufekcioglu et al., 2010; Wüthrich et al., 2002), a decrease in soil CH_4 uptake (Prieme and Christensen, 1999), a decrease in soil CO_2 efflux (Kim et al., 2011; Ryu et al., 2009), or no detectable change (Concilio et al., 2005, 2006; Kim et al., 2011; Meyer et al., 1997). However, the studies above considered the short-term effects of a single burning event and there is currently a lack of studies into the cumulative, long-term effects of repeated fuel reduction burning on soil atmosphere CH_4 and CO_2 flux. Changes in soil factors such as nutrient availability, pH, soil moisture, soil bulk density and soil organic C content have been linked to burning frequency (Campbell et al., 2008; Scharenbroch et al., 2012; Williams et al., 2012) and it is therefore possible that a long-term increase in the frequency of planned burning may have significant long-term impacts on the greenhouse gas fluxes of CH_4 and CO_2 between the soil and the atmosphere within our forest systems.

In our study we measured soil CH_4 flux, methanotrophic activity and soil CO_2 flux at forest sites that have been burned at various frequencies of low intensity fire over the last 27 years (planned burning every 3 years, planned burning every 10 years, and unburnt). Our main objectives were to (i) measure any cumulative long-term effects of planned fire regimes on soil CH_4 flux, methanotrophic activity and soil CO_2 flux in a dry sclerophyll Eucalyptus forest system–the predominant forest type in Victoria (Australia) and (ii) to investigate if the relationship between CH_4 flux, or soil CO_2 flux, and key environmental/edaphic controls has changed as a consequence of the fire treatment.

2. Material and methods

2.1. Site description

The study was based within the Victorian 'Fire Effect Study Areas' (FESA) the longest ongoing Australian study to investigate the ecological impacts of low intensity fuel reduction fires in dry sclerophyll forests (Tolhurst et al., 1992; Tolhurst, 2003; Tolhurst and Kelly, 2003). The three areas included in this study (Barkstead, Blakeville and Musk Creek) are located in the Wombat State Forest (approximate distance between sites = 10 km) north-west of Melbourne close to the township of Daylesford (Table 1). The forest is dominated by *Eucalyptus obliqua* (L. Hér), *Eucalyptus rubida* (H. Deane & Maiden) *and Eucalyptus radiata* (Sieber ex DC) with an approximate overstorey height of 25–28 m and a basal area ranging from 29 to 43 $m^2\ ha^{-1}$. The climate is classified as between cool-temperate and Mediterranean, as it has cold, wet winters and warm, dry summers (Fig. 1). The annual rainfall range is 814–901 mm (1987–2011) and the mean monthly minimum temperatures range from 2 °C (July/August) to 12 °C (January/February; Table 1) with daily summer temperatures often exceeding 35 °C. Mean monthly maximum temperatures range from 7 °C (July) to 24 °C (January/February).

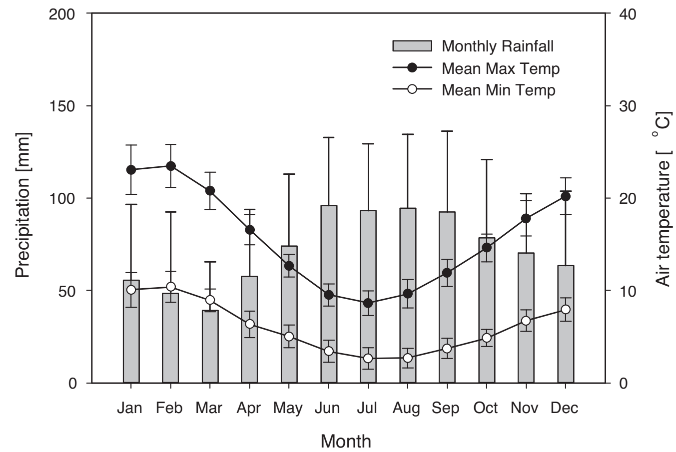

Fig. 1. Climate data 1987–2011 for the Wombat forest in South Eastern Australia. Data were compiled from weather stations at the three FESA's and surrounding Bureau of Meteorology weather stations.

The soils in the southern part of the Wombat State Forest derive from weathered sandstone and shale. The surface texture is fine sandy loam to clay loam. Soils are classified as Acidic-mottled, Dystrophic, Yellow Dermosol after Australian soil classification (Robinson et al., 2003). Bulk density at the study sites averaged around 0.75 $g\ cm^{-3}$ and pH was 4.8.

Following experimental burning treatments are applied in a fully replicated design across all FESAs:

- Low intensity burn approximately every 3 years in autumn (AH).
- Low intensity burn approximately every 10 years in autumn (AL).
- control, fire exclusion (CONTROL).

Treatments were established in 1985 and are ongoing, with only a short interruption 'no burn' period between 1998 and 2002. The burning treatments at the three chosen sites were last applied between March 2003 and October 2008. More detailed information about treatment history and frequency is presented in Table 1.

2.2. Experimental design

Three plots (upslope, mid-slope, bottom of slope), each 25 m^2, were established in each treatment (CONTROL, AH, AL) at each of the three FESA sites (Barkstead, Blakeville and Musk Creek). Beginning in March 2009, we sampled trace gas fluxes with five manual chambers in each plot. When possible we sampled all plots on consecutive days (3–5 days per sampling cycle). We sampled trace gas fluxes seasonally between March 2009 and February 2011, a total of 135 chamber flux measurements per sampling cycle.

2.3. Flux measurements

The manual closed chamber method (Hutchinson and Mosier, 1981) was used to quantify the spatial and seasonal variation in soil-atmosphere exchange of CO_2 and CH_4. Manual chambers were made of dark PVC inspection pipe fittings (diameter 15 cm, height 15 cm, volume 2.8 L, basal area 0.018 m^2) with a PVC screw-on-lid incorporating a butyl-rubber septum and a rubber O-ring to form a gas tight seal. Chambers were fitted with low voltage fans to ensure good headspace mixing. PVC anchors (height 100 mm), for