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Improving forest sampling strategies for assessment of fuel reduction burning

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ABSTRACT

Land managers typically make *post hoc* assessments of the effectiveness of fuel reduction burning (FRB), but often lack a rigorous sampling framework. A general, but untested, assumption is that variability in soil and fuel properties increases from small (~1 m) to large spatial scales (~10–100 km). Based on a recently published field-based sampling scheme, we addressed the following questions: (i) How much variability is captured in measurements collected at different spatial scales? (ii) What is the optimal number of sampling plots required for statistically robust characterisation of burnt areas? (iii) How can land managers improve their assessment of the effectiveness of FRB? We found that measurement variability does not increase with scale for all fuel components. Results showed that coarse woody debris is as variable at the small scale (plot, m) as it is at the landscape scale (km). For certain fuel components, such as litter biomass (in unburnt areas), overstorey biomass and leaf area, and soil properties such as total carbon and total nitrogen, samples taken at the small (plot) scale were indicative of variation at the larger scale of an individual FRB and more broadly across the landscape.

We then tested the hypothesis that site stratification can reduce variability between sampling plots and as a consequence will reduce the required number of sampling plots. To test this hypothesis we used Landsat Normalized Difference Vegetation Index (NDVI) across areas treated with FRB and compared the number of sampling plots required to estimate mean fuel biomass with and without stratification. Stratification of burnt areas using remotely sensed vegetation indices reduced the number of sampling plots required. We provide a model of green biomass from Landsat NDVI and make recommendations on how sampling schemes can be improved for assessment of fuel reduction burning.

1. Introduction

Low-intensity fuel reduction burning (FRB) is used to mitigate the risk of bushfires by altering fire behaviour through the temporary removal of accumulated fuel. Empirical evidence shows that FRB can reduce the incidence and extent of unplanned fires (Boer et al., 2009; McCaw, 2013). In practice, the priority for FRB is effective mitigation of risk to life and property, and integration of environmental values (e.g. capacity for carbon sequestration, provision of high quality water, and conservation of biodiversity) into fire management operations is not easily defined and requires further research and development (AFAC, 2015).

Forest inventory measurements are an important basis for fuel management (Keane, 2013; Volkova et al., 2016), prediction of fire behaviour (Sullivan et al., 2012), prioritising and post-burn characterisation of FRB in terms of severity and effectiveness (Volkova et al., 2014; Whittier and Gray, 2016), measuring forest carbon and fire emissions (Weise and Wright, 2014; Possell et al., 2015; Jenkins et al., 2016; Surawski et al., 2016), estimating risk of fire spread (McCarthy et al., 1999; Gosper et al., 2014), and assessing the impact of burning on biodiversity, nutrient cycling and the recovery of forest (Gill et al., 1999; Chatto et al., 2003; Cheng et al., 2013). In Australia, environmental effects of FRB in forested ecosystems have been investigated regularly for the past few decades using field data, often derived from inventories (e.g. Bradstock et al., 1998; Grant and Loneragan, 1999; Guinto et al., 2001; Volkova and Weston, 2013; Possell et al., 2015; Volkova and Weston, 2015; Jenkins et al., 2016) but also coming from a small

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number of long-term experimental studies in Victoria (Department of Sustainability and Environment, 2003) and New South Wales (e.g. Harris et al., 2003; Penman et al., 2009). These long term data sets are generally collected from small plots (i.e. 0.1 ha) and may have been subdivided over time (e.g. York, 2000).

Protocols for characterisation of the fuel profile and sample preparation have been based on previous practice and concepts from the literature (e.g. McKenzie et al., 2000; Gould et al., 2011). Popular methods include selection of a number of medium-size sampling plots (approximately 0.15–0.25 ha) where the understorey and overstorey biomass, litter biomass, ground cover vegetation and soil properties are assessed before and after a fuel reduction burn or in adjacent burnt and unburnt plots. Sampling over large areas with considerable vegetation heterogeneity will result in imprecise estimates of fuel load and fire spread, unless sampling schemes are developed that maximise precision over the sampling area. However, there are a limited number of studies that revise sampling procedures to check that plot dimensions and location within a landscape are effective for capturing variation in the features being measured (see, for example, Gill et al., 1999; Miehs et al., 2010). Evaluation of variability at different scales is one way for informing accurate sampling schemes (Catchpole and Wheeler, 1992; Sikkink and Keane, 2008). Knowledge about the variability is also important for upscaling measurements from smaller to larger spatial domains within the ecosystem. Upscaling would be more robust if small-scale variation is indicative of variation at larger sales (Kim et al., 2011; Marvin and Asner, 2016).

1.1. Sampling scale and spatial variability

Long-term studies (i.e. more than 10 years) show that the effects of fire on environmental values cannot be reliably measured via a few small plots within landscapes that may range in size from hundreds to thousands to tens of thousands of hectares (Tolhurst, 2003). Understanding natural variation is critical for reliable quantification of fuel and vegetation properties and of the effect scaling has on these variables. Spatial variation in soil and fuel properties makes interpretation of field measurements challenging and can obscure the effects of FRB.

A general assumption in geospatial analysis is that variability in soil properties increases from local to landscape spatial scales (Heuvelink and Webster, 2001), in the sense that samples located near each other are more similar than those far from each other (Grigdal et al., 1991; Lin et al., 2005; Martin and Bolstad, 2009). However, spatial variability in soil is at least partly a function of soil properties, some of which can be as variable at the smaller scale (1–10 m) as they are at larger scales (50–500 m) (see, for example, Garten Jr et al., 2007). Here we used measurements of a range of fuel and soil properties before and after FRB to investigate if the correct choice of sampling scale depends on the property under consideration. Fuel components included surface (litter and coarse woody debris), near-surface (ground cover and biomass), elevated (understorey) and canopy (overstorey) biomass, and, overstorey and understorey leaf area. Soil properties included soil pH and electrical conductivity (EC), total carbon (C) and total nitrogen (N). Spatial variability was assessed: (i) between points within a plot (subplot-scale), (ii) between different plots within an individual site (plot-scale), and (iii) between sites across the landscape (landscape-scale).

1.2. Optimal number of sampling plots

Inventory measurements of forest carbon pools (or fuel load) can be collected randomly, systematically (with a pre-defined distance between the plots), or along lines (Mello et al., 2015; Mitchell and Hughes, 1995). Sampling intensity (i.e. number of sampling plots) is commonly adjusted to achieve a balance between resource expenditure and confidence in the observations. For forestry applications systematic sampling (e.g. stratified sampling) is generally recommended over random sampling (Bickford et al., 1963; Scott, 1998; Jayaraman, 1999). Pre-sampling stratification is a statistically efficient approach in which sampling effort is concentrated in areas where there is great variability to most effectively minimise measurement error (McRoberts et al., 2006; Wood et al., 2006; Coulston, 2008). For stratified sampling a heterogeneous population is divided into subpopulations or strata based on maps of common grouping criteria such as biomass, foliage cover and tree height using remote sensing or interpretation of aerial photographs (Thompson, 2000; Brookhouse et al., 2010; McRoberts et al., 2014). We explored the potential for using Landsat-derived NDVI (as a proxy for vegetation biomass) in pre-sampling stratification.

Random sampling is a common strategy of land managers in major states of south-east Australia for collecting bushfire management data (SEQ Fire and Biodiversity Consortium, 2002; NPWS, 2004; Gould and Cruz, 2012). We tested if remotely sensed information could be used to complement field data and reduce costs and time of field sampling whilst achieving better precision. We tested the hypothesis that stratification of a FRB can be used to improve selection of field sites. We also provide an indication of the gain in sampling efficiency obtained through the use of stratified sampling using Landsat-derived NDVI and ground based measurements. To test our hypotheses we used two main datasets: one collected by Jenkins et al. (2016) and another collected in this study using a similar methodology.

2. Methods

2.1. Site description

Sampling sites were individual FRBs in two areas: East Gippsland in Victoria, and in the Australian Capital Territory (ACT) (Fig. 1). Sites in Victoria were classified as lowland forest (Ecological Vegetation Class 16; Department of Sustainability and Environment, 2004) dominated by Yellow (*Eucalyptus muelleriana*)

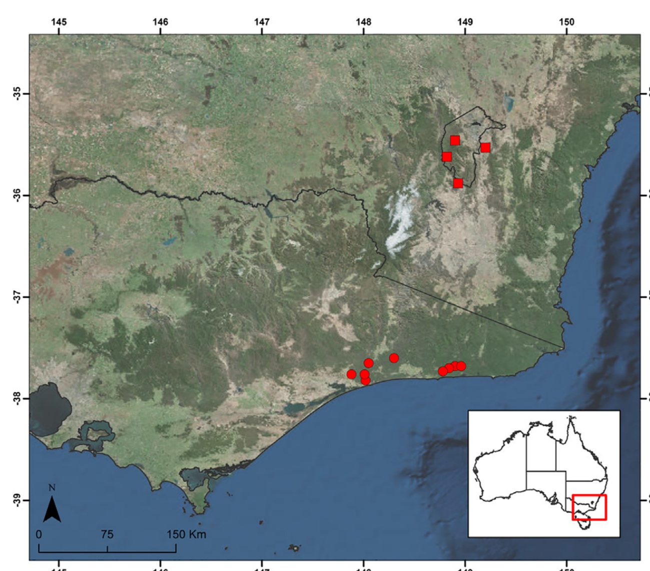

Fig. 1. Location of sampling sites in Victoria (nine sites, marked with circles, Jenkins et al., 2016) and in the Australian Capital Territory (four sites, marked with squares).