FIRE NOTE

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Figure 1: Jarrah forest in the Perth Hills six months after a wildfire in January 2005. a) unburnt reference adjacent to burnt areas, b) low intensity, c) high intensity.

SPATIAL PATTERNS OF SOIL CARBON AND NITROGEN AFTER EUCALYPT FOREST FIRE

SUMMARY

This research provides land managers with a better understanding of the impacts of fire on ecosystem processes and the resilience of the forest with respect to the impacts of bushfires and prescribed burning. Geostatistical analyses were used to examine spatial patterns of soil nitrogen and carbon in jarrah (*Eucalyptus marginata*) forest that has been burnt at low and high intensity by wildfire in 2005. The research provides an indication of recovery of the below-ground community and how it functions, thereby providing a means to assess recovery much quicker than plant and animal communities. This will allow land managers to better apply fire in the landscape with greater knowledge that the application of fire is not fundamentally altering the community.

ABOUT THIS PROJECT

This research is from project B4.2: Multi-scale patterns in ecological processes and fire regime impacts, within Bushfire CRC Program B: Fire in the Landscape.

The authors: all are based at the University of Western Australia's School of Plant Biology, where Jaymie Norris (pictured) is a PhD candidate and recipient of a Bushfire CRC scholarship (now working with the Department of Sustainability and Environment, Victoria), Dr Matthias Boer is Research Fellow (Bushfire CRC) and Dr Pauline Grierson is Senior Lecturer and leads Bushfire CRC Project 4.2.

CONTEXT

Fire plays a critical role in releasing nutrients from organic material in the forest ecosystems of southern Australia but the effect of fire intensity on subsequent patterns of nutrient availability are not well known. Spatial patterns of soil resources for plants play a crucial role in the structure, composition and productivity of many terrestrial ecosystems because of their influence on processes at the individual, population and community levels.

BACKGROUND

Knowledge of how fire impacts different levels of ecological organisation is critical if we are to predict the consequences of fire regimes. Fire creates spatial patterns in nutrients and vegetation and is in turn affected by the spatial patterns of past fires.

These patterns have implications for the regulation of key ecological processes of water, carbon and nutrient cycling, and may also help regulate biodiversity. Productivity, carbon and nutrient cycling are also linked to fuel loads and patterning of litter (fuel) within the landscape and therefore to the spread of future fires.

All key cycling processes are mediated by the microbial community, which is particularly important in forests with nutrient poor soil, such as the jarrah forests of Western Australia (Hingston *et al.*, 1979). However, the processes and feedback mechanisms that drive and control the recovery of vegetation, litter, and fuels after fire are only partly understood and remain poorly quantified in terms of their link to fire intensity.

Many previous studies have studied changes in soil nutrient availability and microbial biomass after fire (e.g. Romanyà *et al.*, 1994, Rutigliano *et al.*, 2007), but few have focused on how fire intensity affects spatial variability therein. Spatial changes in soil nutrient composition directly affect soil microorganisms (Hart *et al.*, 2005), which, in turn, changes the spatial distribution of soil fertility (Wardle, 1998).

Figure 2: Geostatistical sampling grid at the 10 x 10 m scale used to sample within the jarrah forest. The plot shown here was in jarrah forest burnt at high intensity, with the photo taken 6 months post-fire. Replicate soil samples are taken at the grid intercepts (n = 121).

Consequently, this research has focused on understanding changes in the patterns of microbial communities (diversity, function and activity) in relation to soil carbon and nutrients as the most sensitive indicators of shifts in nutrient cycling processes across the landscape after fire.

BUSHFIRE CRC RESEARCH

Prescribed and wild fires result in spatial patterns at multiple scales that have implications for key ecological processes of water, carbon and nutrient cycling. Fires do not burn uniformly across a broad landscape or even at smaller scales. Consequently, micro-scale spatial patterns can exist for organic matter distribution, which, in turn, has implications for estimation of carbon and nutrient fluxes. For example, the consumption of forest-floor litter varies considerably according to moisture content, fuel load and fire intensity.

CHARTING REGENERATION PATTERNS

Fires can also create nutrient-rich patches of ash that, in turn, influence patterns of regeneration. Here, the researchers sought to assess the impacts of fire intensity on the pools and processes that underlie the controls of forest productivity and structure in the microbial community at fine (metre) scales. The main objective was to describe the impacts of variable fire intensity on the spatial patterns of soil organic labile-N and C (soil microbial biomass and dissolved organic carbon and nitrogen), nitrate and ammonium, as well as total nitrogen (N) and total carbon (C). The hypothesis was that shortly after a fire of low intensity, the spatial pattern of labile nutrients (nutrients that are more easily decomposed) would become more variable or patchy because of ash accumulation and post-fire deposition of litter around individual plants. At high fire intensities a more uniform distribution of C and N fractions was expected. The researchers measured changes in spatial pattern by quantifying patch size and spatial variance.

DEFINITIONS

Labile: more easily decomposed

Microbial biomass: Microbial biomass is a measure of the total quantity of living organisms of all the species in surface soil (soil biomass), commonly referred to as a unit weight of the soil. As microbes are difficult to measure, the total weight of biophysical carbon and nitrogen components are used as a proxy. As the two nutrients are intrinsically linked, the C/N ratio of the microbial biomass can also help to detect changes in the community constituents. For further detail, please refer to Vance *et al.*, (1987).

The research sites were within 27,000 hectares of jarrah forest in the Perth Hills burnt by a bushfire in January 2005. The fire resulted in a landscape mosaic of forest burnt at different intensities (Boer *et al.*, 2008). For this study, the researchers sampled (i) unburnt forest, (ii) forest burnt at low intensity, where the understorey was largely consumed but overstorey crowns were not fully scorched, and (iii) forest burnt at high intensity, where there was significant scorching and leaf loss of the crowns of overstorey trees (Fig. 1). Six months after the fire, the researchers used a geostatistical sampling design to collect 121 soil samples (0-5 cm) across a 10 x 10 metre (m) grid at each site (Fig. 2). Soils were then analysed for a range of C and N fractions, including microbial C and N. The analysis of spatial patterns was used to determine the average variance between samples collected at increasing distances from one another (lag interval) using ARC-GIS (Environmental Systems Research Institute (ESRI), 2006) and VESPER (Minasny *et al.*, 2005) software and produced surfaces based on the observed patterns.

RESEARCH OUTCOMES

Fire can either increase or decrease the spatial variability of soil C and N, depending on its intensity and the pool measured. With respect to soil microbial biomass, it was found that at the plot scale, high intensity fire tended to reduce patchiness and homogenise the distribution of microbial biomass C and N, while soil burnt at low intensity showed increased patchiness compared to unburnt forest. Forest stands classed at landscape scale as low intensity included patches varying in area between 2-20 m^2 that had burnt at either low or high intensity, next to patches that remain largely unaffected by fire. Consequently, overall spatial variability of soil resources at the plot scale tends to be greatest with low intensity fires.

Niche variability creates complex landscape

The development of finer scale patterns of soil nutrients creates greater niche variability, and therefore a more complex landscape at multiple scales. Spatial variability of the microbial biomass is also greatest with low intensity fires, but it is difficult to assess whether the patterns that develop are a consequence of the direct influence of temperature or a ‘trickle-down’ effect of changed resources as a result of the fire.

Fire affects soil carbon and nitrogen pools differently. During low intensity fire, soil may remain below or near the critical temperature (~220°C, Knicker *et al.*, 1996) for nitrogen volatilisation resulting in greater loss of carbon lost relative to nitrogen. High intensity fire has the opposite effect: soil temperatures may greatly exceed 220°C, meaning that the loss of carbon relative to the loss of nitrogen is small. These differences in sensitivity of soil C and N fractions to temperature have major implications for assessments of the stability and resilience of carbon in burnt forests, as well as for the quantification of carbon sequestration in fire-prone forests.

This research found that while the overall pool sizes of carbon (Fig. 3a) and nitrogen (Fig. 3b) were reduced by fire irrespective of intensity, particulate organic carbon was preferentially burnt off at high intensities (Fig. 3c), which resulted in a decrease in the soil C/N ratio.

Charcoal may be the key

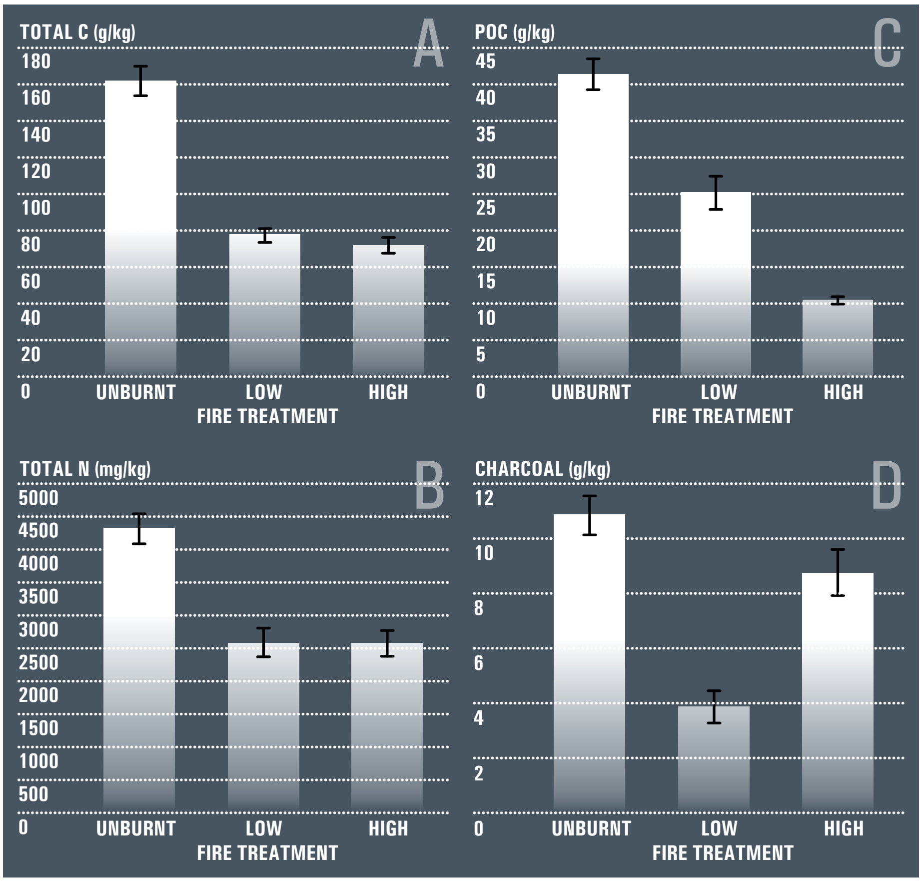
However, at high fire intensity, most N is lost but C may remain in the soil at concentrations > 260 mg C/kg soil. In severely burnt sites, this may mean that the remaining C is protected in the form of charcoal rather than unburnt particulate organic carbon. Apart from changes in C pool sizes, fire also changes the relative proportions of the different C fractions (Fig. 4), with the result strongly depending on fire intensity. For example, we found that soil burnt at high intensity had a significantly greater proportion of charcoal than soil burnt at low intensity.

Prescribed burning in the jarrah forests is generally at low intensities and is likely to generate similar spatial patterns as those observed in our study at the plot scale. The development of finer-scale patterns of microbial biomass supports ideas that both the absence of fire or fires of higher intensity, often wildfires, creates less complex landscapes at multiple scales. The results suggest that there is greater niche development and therefore microbial biomass 'insurance' for recovery of key processes with low intensity fire.

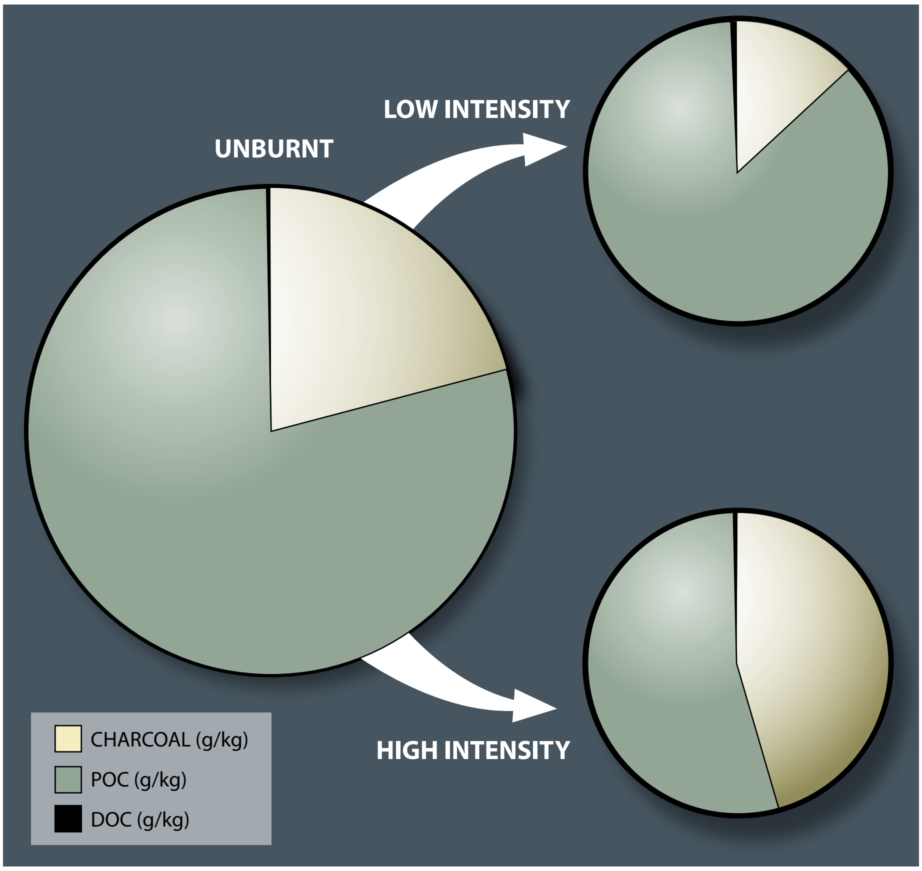
The research results support the idea that fine-scale patch mosaic burning is, to an extent, self-managed and represents ecologically appropriate management beyond simply maintenance of species diversity.

HOW THE RESEARCH COULD BE USED

A continuing challenge for fire management agencies is determining the appropriate level of spatial variability that ensures conservation of ecosystem structure and function. The results of this research enhance current knowledge of fire impacts on soil carbon and nitrogen pools beyond short-term changes in nutrient availability. The findings demonstrate that variation in fire intensity sets off a chain reaction: it drives space and time-related patterns of carbon and nitrogen which directly interact with post-fire plant productivity and fuel accumulation patterns and, therefore, with the potential behaviour of future fires. By quantifying the relationship between fire intensity and spatial variation in soil resources, the research also contributes to a better understanding of the long-term impacts of fire regimes dominated by prescribed burning on key ecological functioning of the jarrah forest.



▲ **Figure 3:** Mean (+/- standard error) total carbon and nitrogen (121 samples), charcoal (30 samples), and particulate organic carbon (POC) (30 samples) in forest soils burnt at increasing fire intensity (unburnt, low and high).



▲ **Figure 4:** Relative sizes of charcoal, particulate organic carbon (POC) and dissolved organic carbon (DOC) pools within the total C pools in soil as measured by Mid-Infrared spectroscopy (MIR) analysis. The sizes of the circles on the right represent total soil C pool sizes relative to the unburnt site (left circle).

END USER STATEMENT

"Understanding the relationship between fire regimes and soil nutrient processes is important to fire managers, particularly in nutrient-limited ecosystems such as the jarrah forest. This study contributes to a better understanding of how soils respond to fires of different intensity, and how this may affect patterns of regeneration after fire. The interaction of fire regimes and carbon cycling is an emerging issue for fire management and this research has drawn attention to the need to better understand the role played by soil charcoal."

– Dr Lachie McCaw, Principal Research Scientist, Department of Environment and Conservation, Manjimup, WA

Carbon cycling is recognised as a fundamental component in global climate change. Within this context a better understanding of the carbon cycle of fire-prone ecosystems is particularly relevant due to the large areas involved and potentially strong impacts of fire on carbon pools. The study's findings support management strategies aimed at minimising carbon losses from fire-prone eucalypt forests. Incorporating this knowledge into existing models such as the National Carbon Accounting Toolbox (NCAT), FullCAM model (Richards & Evans, 2000) will further improve our understanding of how regional carbon cycles are linked to fire, management, and climate change.

FUTURE DIRECTIONS

A greater understanding of the role of charcoal in eucalypt forest soil is required in order to understand the processes that govern carbon flux and forest productivity (Attiwill & Adams, 2008). The project found that charcoal content in burnt soil (< 2 mm) was less than in unburnt soils, and that soil burnt at low intensity was only ~50 % of soil burnt by high intensity fire (Fig. 3d). This somewhat counter-intuitive result is probably due to incorporation of charcoal fragments into the soil from larger charcoal pieces, such as branches and logs that were broken down over many years since the previous fire (Hopmans *et al.*, 2005). We observed that large charcoal pieces were most abundant in the jarrah forest burnt at high intensity. This charcoal component should be quantified across a range of forest sites burnt at varying intensity in order to explain its ecological function.

The ecological role that charcoal plays remains unknown, with debate in the scientific literature largely inconclusive. Further, the assessment of impacts of fire and soil will be of increasing importance with the adoption of Article 3.4 of the Kyoto Protocol (IPCC, 1998), which introduces requirements towards full accounting and the need to differentiate between human-caused and other emissions.

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AFAC is the peak representative body for fire, emergency services and land management agencies in the Australasia region. It was established in 1993 and has 26 full and 10 affiliate members.