Background briefings on emerging issues for fire managers from AFAC and Bushfire CRC.

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FIRE NOTE

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FIRE AND CO_2 EMISSIONS IN SUB-ALPINE WOODLANDS AND GRASSLANDS

▲ **Figure 1:** A grassland/woodland transect on the Snowy Plain.

SUMMARY

This ground-breaking research examines the critically important role of soil carbon dynamics in Australian sub-alpine ecosystems. Soil respiration – the release of carbon dioxide (CO_2) by decomposer microorganisms in the soil – contributes more to the pool of atmospheric CO_2 than any other single process. Soil respiration (referred to hereafter as 'respiration'; see 'Key Terms' box) adds an order of magnitude more CO_2 than industrial emissions every year.

The boundaries between, and the total areas of, three major plant communities in Australia's sub-alpine landscapes are largely determined by fire-topography interactions. These plant communities are: snow gum woodland with a shrub understorey (SGS); snow gum woodland with a grass understorey (SGG); and sub-alpine grassland (G). Soil respiration in these communities is a major carbon flux and at least partly fire-determined.

The research presented addresses the hypothesis that vegetation type dictates rates of soil respiration. The possible implications of changes in vegetation patterns leading to increased rates of respiration are discussed.

Characterising the effects of future climatic regimes on soil-stored carbon is critical to explaining feedbacks (see 'Key Terms') to changes in the atmospheric pool of CO_2. Models of future carbon cycles need to include changes in soil chemistry and rates of respiration driven by changes in vegetation as well as those that are temperature- and moisture-driven. The research outcomes from this experiment make a significant contribution toward the evidence required to predict outcomes of bushfires and prescribed fires for the carbon balance of ecosystems.

ABOUT THIS *FIRE NOTE*

This is a summary of a scientific paper currently in press for the journal *Global Change Biology* and is based on research within Bushfire CRC Program B: Highfire (Jenkins & Adams, 2009).

The authors: Meaghan Jenkins and Professor Mark Adams are both at the Faculty of Agriculture, Food and Natural Resources, at The University of Sydney, where Meaghan is a Bushfire CRC PhD candidate and Professor Adams is the Dean.

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Increasing CO_2 leads to increased temperatures (climate change) and results in changes in frequency of extreme weather events, bushfire risks and major changes in vegetation type. This research investigates the likelihood that, along with climate change, fire-promoted changes in the distribution of vegetation types across the Australian sub-alpine landscapes could result in increased rates of respiration and a positive feedback (see 'Key Terms' box) to further increase atmospheric CO_2.

BACKGROUND

Alpine and sub-alpine areas of Australia have been emphasised as among those most likely to be affected by changing climates (Hughes, 2003). Increased summer temperatures will be likely to increase bushfire risk. However, the implications of climate change for alpine and sub-alpine ecosystems may well include a positive feedback from increased soil respiration.

Soils are the largest store of carbon in the biosphere and cool-cold climate ecosystems, such as those in the alpine and sub-alpine

regions, are notable for their carbon-rich soils. The carbon in soil is released via respiration by heterotrophic organisms (organisms that cannot synthesise their own food) and rates are known to vary among vegetation types. Variations are linked to plant metabolism and to recent contributions of plant carbon (Hartley *et al., 2006*) and are sensitive to temperature changes. Rising temperatures have the potential to dramatically increase respiration and this could have significant and positive feedback effects on atmospheric CO_2.

Distributions of communities in these sub-alpine areas are dynamic and respond over relatively short time-frames (decades) to changes in fire regime and, possibly, to changes in climate. Shifts in boundaries among communities and possible changes in species composition as a result of direct and indirect climatic effects, such as fire regime, are also likely to significantly alter rates of respiration through plant-mediated changes in soil chemistry. This experiment measured rates of respiration in soil from the mosaic of three major vegetation types that dominate the landscape.

BUSHFIRE CRC RESEARCH

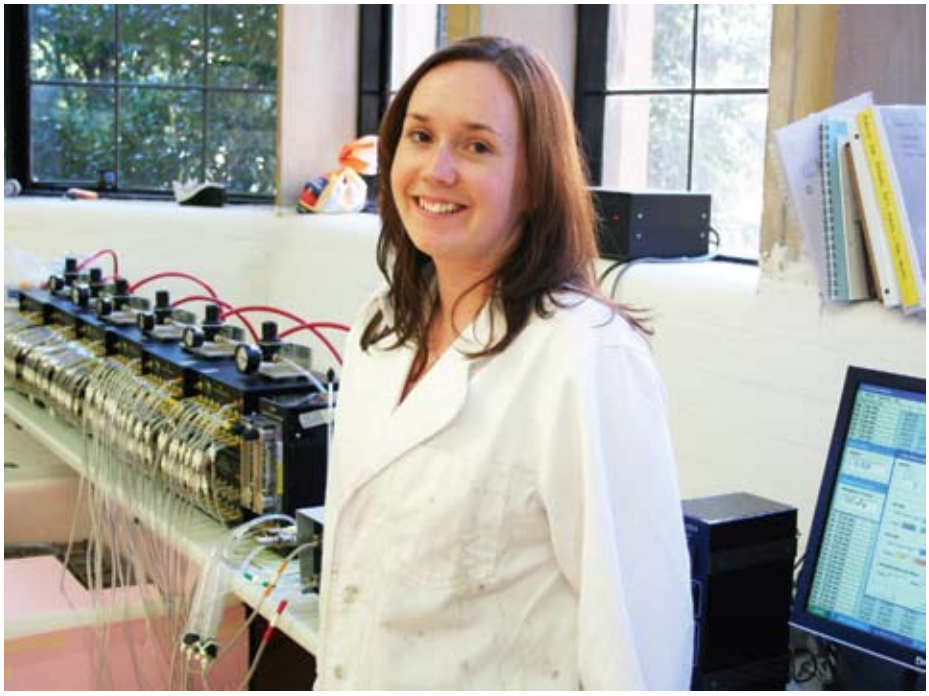
Soils were collected from sites within the Snowy Plains region of the Kosciusko National Park, in NSW Australia.

This study focused on three vegetation types:

1. Sod tussock grassland (G)– dominated by *Poa* spp.
2. Sub-alpine woodland (SGG)– *Eucalyptus pauciflora* (snow gum) woodland typically with a herbaceous understorey dominated by *Poa* spp.
3. Sub-alpine woodland (SGS) – *Eucalyptus pauciflora* (snow gum) woodland typically with an understorey dominated by shrubs, that is, *Bossiaea foliosa*, *Leucopogon* spp. and *Tasmannia xerophila*.

Each vegetation type was replicated on each of five separate transects (Figure 1). Within each site triplicate soil samples were collected. Soil was analysed for water content, pH, total nitrogen and carbon, oxidizable organic carbon, available phosphorus and microbial biomass carbon (see 'Key Terms' box).

Soil respiration was measured in the laboratory using a novel, flow-through, gas monitoring system (Figure 2) capable of measuring up to 48 soil samples simultaneously. Cylinders packed with 100 grams of fresh soil were incubated and monitored for CO_2 using an infra-red gas analyser (IRGA) (Qubit Systems Inc, Kingston, Ontario, Canada). Respiration measurements were made continuously at a range of temperatures, from 5^0 Centigrade (278 Kelvin) to 40^0C (313K) over a 10-day period.



▲ **Figure 2:** Bushfire CRC PhD candidate Meaghan Jenkins, of the Faculty of Agriculture, Food and Natural Resources at The University of Sydney, with a flow-through, gas monitoring system.

KEY TERMS

Positive feedback
Any increase in concentrations of greenhouse gases in the atmosphere are set to accelerate the rate of warming that may in turn change net primary productivity, inputs of carbon to the soil, soil microbial activity and eventually the release of further CO_2 from soil to the atmosphere.

Heterotrophic respiration
Decomposition of organic matter (non-living, ranging from fresh plant litter to carbon from parent rock) in soil from the surface to depths of several metres, mainly by soil microbes; a process resulting in the release of CO_2.

Microbial biomass carbon
An estimate of the size of the microbial component of the soil which is key to understanding the transfer and turnover of nutrients within and between ecosystems.

Net Primary Productivity (NPP)
The rate at which plants accumulate biomass (organic matter) via photosynthesis, minus the mass of carbon used during respiration.

Abbreviations

SGG: Snow gum [woodland] with grass understorey

SGS: Snow gum [woodland] with shrub understorey

RESEARCH OUTCOMES

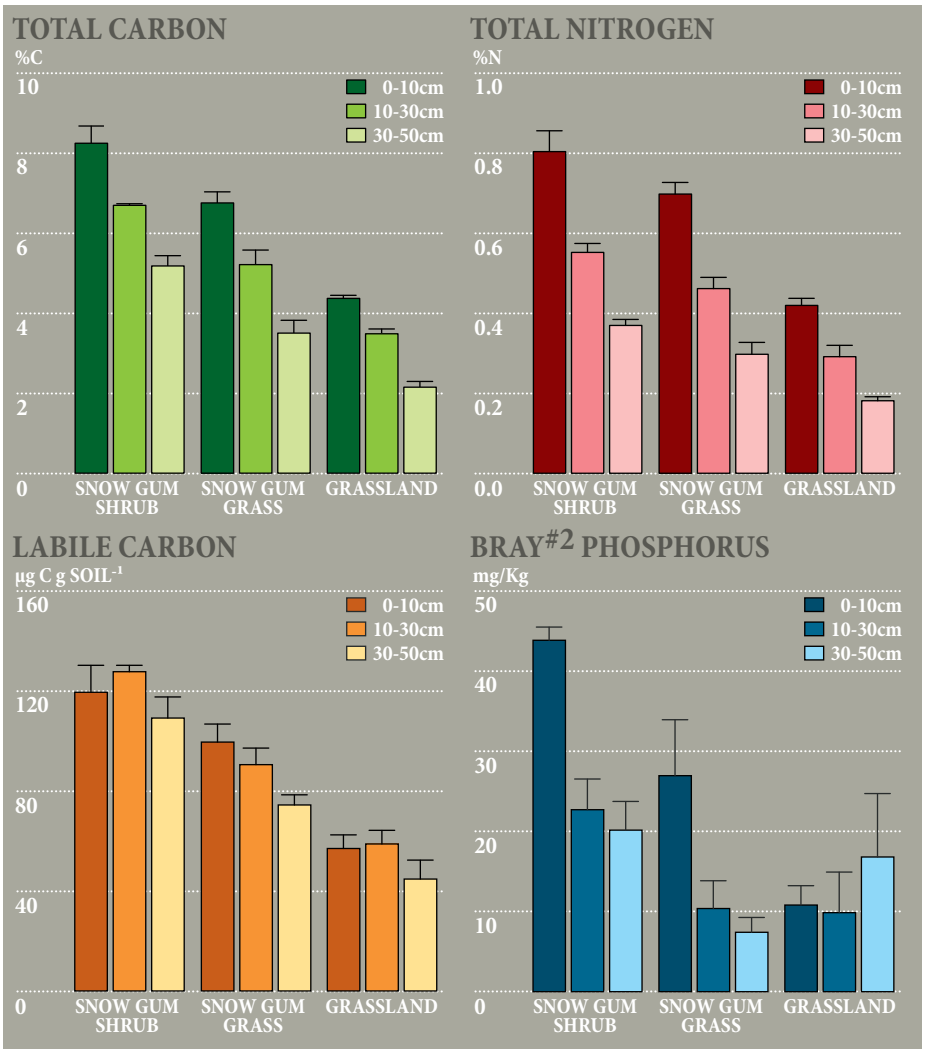
Respiration and temperature

Rates of respiration in soil from all vegetation types increased with rising temperature (from 5°C to 40°C). This result is consistent with well known temperature sensitivities of respiration (Lloyd & Taylor, 1994). Overall, these results support the likely increase in CO_2 emission from sub-alpine soils with rising temperatures.

Respiration, soil carbon and vegetation type

Rates of respiration were fastest in SGS, slowest in the grassland, and intermediate in SGG. Additionally, soils from SGS were consistently richer in carbon and nitrogen and available phosphorus, at all depths, than soils from either SGG or grassland (Figure 3).

These results strongly suggest that vegetation type has a strong influence on soil chemistry, rates of carbon turnover and net primary productivity (NPP – see 'Key Terms' box). For example, the dominance of the nitrogen-fixing shrub, *Bossiaea foliosa* in SGS is clearly associated with greatly reduced carbon:nitrogen in litter when compared with the grassland. Carbon:nitrogen ratios are almost invariably and inversely related to rates of carbon turnover.



▲ **Figure 3:** General soil characteristics for three sub-alpine vegetation types at three soil depths, mean (n=10), bars indicate standard error.

In addition, many native Australian legumes can produce specialised roots to mobilise forms of phosphorus (e.g. Adams *et al.*, 2002). The coupling of increased availability of phosphorus with that of nitrogen in SGS vegetation type may well serve to increase NPP and rates of carbon turnover, including rates of respiration.

Clearly, changes in vegetation type and species composition can result in a shift in physiological dominance and have a significant effect on carbon dynamics. In the Australian sub-alpine ecosystems, a shift from grassland to shrub-dominated ecosystems in the absence of fire would result in greater rates of respiration and amounts of CO_2 released into the atmosphere from the soil.

Soil carbon and temperature

Soil carbon concentrations were greater in the warmer, upland woodland communities (SGG and SGS) and less in the valley bottom grasslands that are reportedly maintained by cold air drainage (Williams & Ashton, 1987). However, this result is not consistent with the widely held assertion that soil carbon generally increases as mean annual temperature decreases. Rather, our result suggests a unique relationship in this Australian context that implicates plant physiology and fire regime.

The data reported here seem to have two likely explanations. First, the balance of NPP and respiration lie strongly with the former – lesser concentrations of carbon in grassland soils in the coolest parts of the landscape might be explained by reduced NPP relative to woodlands at higher elevation, rather than reduced heterotrophic activity. Secondly, fire regime is one of the major influences on species and community distribution in the Australian high country and elsewhere (e.g. Bond *et al.* 2005). Grasslands and other herbaceous species seldom persist in fire's absence and much of the present day distribution of plant communities in the Australian high country is undoubtedly dictated by past fire regimes.

Cold adaptation

The carbon content of microbial biomass was generally greater in soils from the grassland and SGG compared with SGS. These data support the work of others (Lipson, 2007) who have suggested that microbial communities in alpine meadows were cold-adapted throughout the year, whereas their counterparts in sub-alpine forest soils changed their temperature responses over the course of a year. In our example from the Australian sub-alpine ecosystems, the consistently colder temperatures in grassland communities would be expected to produce a thermally adapted microbial flora and biomass. Nevertheless, there was no relationship between microbial biomass and rates of respiration.

END USER STATEMENT

"The changing nature of vegetation in the high country in south-eastern Australia has long been noted by land and fire managers. Increased abundance of woody shrubs, in particular, is of concern due to the resultant increased quantities of fuel. This research shows that there are major differences among the vegetation types in rates of release of CO_2 to the atmosphere from soils, with the shrubby understorey being the greatest contributor and grassy systems the least. This offers a potential win-win for land managers in as much as by applying an appropriate fire regime, we might also improve the carbon outcomes. Further work is obviously needed."

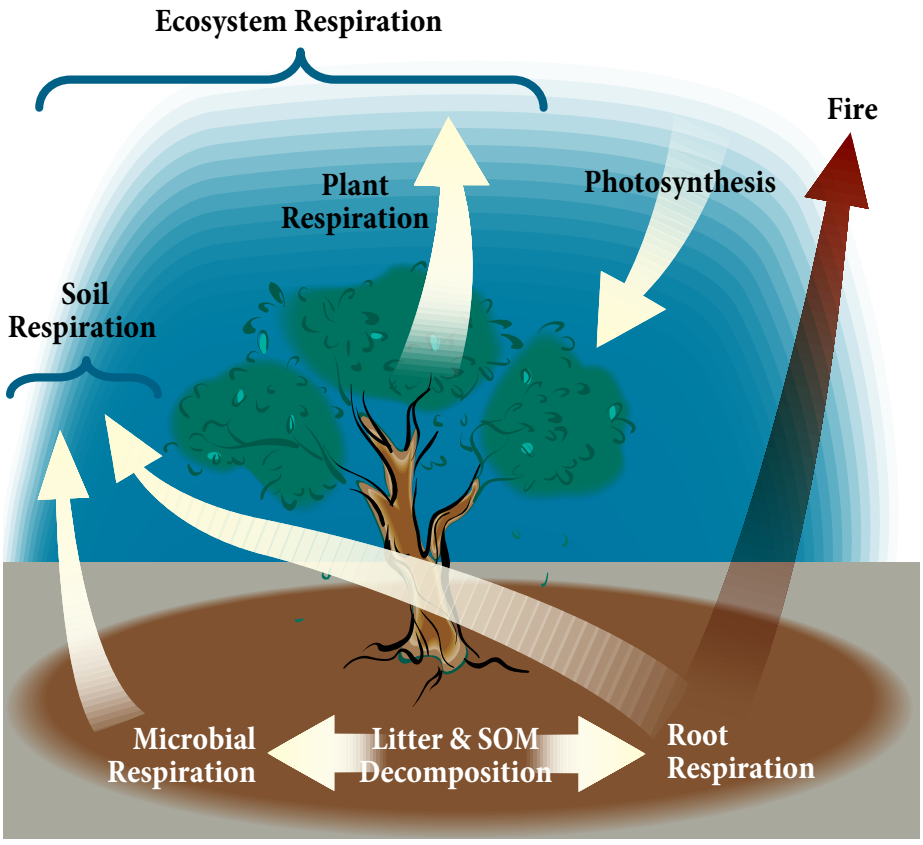
– Mr Jim Darrant, Team Manager, NSW Rural Fire Service, Monaro Team

Fire and the carbon balance in Australian sub-alpine communities

With the exception of landscape-scale fires, such as those seen in 1939, 2003 and 2006/7, we lack the detailed knowledge of fire regime required to definitively attribute the causes of the differences in soil carbon and rates of respiration among vegetation types. Significant circumstantial evidence – lower field temperatures, slower rates of respiration, valley bottom locations – suggests that soil carbon should be *greater* in grasslands than in the woodlands, if fire were not involved. Most likely, fire regime *and* the differential effects of temperature on NPP and respiration, are both involved. Knowledge that fire has direct effects such as volatilisation of soil organic carbon, as well as its indirect effects on distribution of species with contrasting growth forms (grasses versus woody shrubs and trees), makes extremely difficult any prediction of future pools of soil carbon and rates of CO_2 outflow to the atmosphere.

Data from Australian ecosystems

The results from this work highlight the difficulty of relying on work from outside Australia. The relationships reported here for



▲ Diagram of the Carbon cycle (Trumbore 2006).

Australian communities differ significantly from those in the Northern hemisphere from which most previous research was derived.

PUTTING THE RESEARCH TO WORK

This research contributes significantly to our understanding of the dynamics of soil carbon in Australian sub-alpine ecosystems. It significantly expands our understanding of the potential impacts of climate change on these ecosystems. Moreover, it exposes the impacts that these ecosystems may have on atmospheric CO_2 via positive feedback, in response to changes in temperature. Such knowledge will be an important consideration for land managers making decisions on policy and practice.

In the short and longer term, these research outcomes will be used to drive models to predict how climate change will affect carbon and water fluxes in sub-alpine ecosystems. The positive feedback effect reported by this research reveals the complicated nature of climate change impacts on sub-alpine ecosystems, given the carbon-rich soils and potential for major vegetation changes. This data will contribute significantly to underpinning the success of future modelling aimed at combating the potential deleterious impacts of climate change on the Australian sub-alpine ecosystems.

The key findings of this and other related studies will be disseminated via a series of four or five peer-reviewed, published papers on the carbon dynamics of sub-alpine ecosystems. In addition, summaries of key findings will be made available to CRC partners and the public via Fire Notes.

FUTURE DIRECTIONS

This work is ground-breaking in its examination of soil carbon dynamics in Australian sub-alpine ecosystems. Modelling required to make predictions on future changes must be underpinned by data, adequate in quantity and quality, from field and laboratory work. While the use of laboratory-based systems for respiration measurements allow for direct and controlled comparisons of soils from a range of vegetation types and depths, further field studies are required to validate likely responses of soils to changed climatic conditions

In particular though, much further work is needed to clarify the influence of carbon substrates, available phosphorus and microbial community composition on respiration in the Australian alpine and sub-alpine ecosystems. Additionally, as recently noted by Attiwill and Adams (2008), there is an obvious need for further research in the areas of climate and fire interactions, that is, the impact of longer, hotter drier summers in increasing bushfire incidence, and their impact on ecosystem carbon fluxes. This information will be critical if reliable models of the effects of changing climates are to be prepared.

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