FORESTS, FIRE AND ECOLOGICAL PROCESSES – MORE THAN JUST GOOD IN THEORY

A. K. York, T. L. Bell, F. J. Christie and K. E. C. Brennan
School of Forest and Ecosystem Science, University of Melbourne, Creswick, Victoria

Abstract
The interactions among vegetation, soil flora and fauna and litter- and soil-dwelling invertebrates are responsible for regulation of carbon mineralisation and immobilisation in litter and soil. Knowledge of soil biota and how these relationships are influenced by fires and fire regimes is critical for good management of forests. In managed forests and woodlands in Australia, protocols are being developed to assess compliance with Ecologically Sustainable Management (ESM) guidelines to provide robust means of monitoring activities such as timber production and conservation. While there are several well recognised strategies for monitoring forests including regular inventories and auditing of threatened and indicator species, future strategies will include monitoring of productivity and ecosystem health and functioning. For example, the relationships between functional groups and soil chemical and physical properties can be used to develop and evaluate indicators for the maintenance of soil resources in forests and woodlands managed by prescribed burning. Research currently underway aims to (i) identify functional groups of soil biota with key roles in maintaining organic matter cycling and nutrient capital, (ii) test the sensitivity of a sub-set of soil functional groups to disturbance by fire, and (iii) develop and evaluate soil functional groups as indicators of ESM.

Monitoring frameworks
The expectations of forest management are changing rapidly and public forests can no longer be managed for timber production alone. Other resources from forests such as water quality, biodiversity and public recreation are important and must be recognised in planning and conducting forestry operations (Commonwealth of Australia 1992*a*). Currently, a range of environmental prescriptions are used in Australia to adhere to the principles of Sustainable Forest Management (SFM). An example is the use of monitoring and managing for threatened or indicator species (e.g. Department of Sustainability and Environment 2005; Department of Natural Resources and Environment 1997). This is also achieved through adequate management plans and sustainable-yield harvesting practices and reserve systems for nature conservation (e.g. National Forest Inventory 2003). In addition, to comply with international forestry standards, there is currently testing and reporting of Criteria and Indicators according to the Montreal Process (e.g. Commonwealth of Australia 1998). Other relevant reporting frameworks include the United Nations Framework Convention on Climate Change, the United Nations Framework Convention on Biological Diversity, Global Statement of Principles on Forests, and, support of the International Tropical Timber Organisation. All of these strategies are limited and there is increasing need for integrated management of public and private forests and plantations for a wide range of uses including: water supply and catchment management, mining, grazing, tourism, honey and seed production, pharmaceuticals, recreation and employment, and education and training.

The three main principles of SFM as outlined in the National Forest Policy Statement (Commonwealth of Australia 1992*b*) are to:

- recognise and maintain the range of ecological processes occurring within forests including formation of soils and soil profiles, flow of energy throughout the system and cycling of water, carbon and nutrients,
- maintain biological diversity of flora and fauna, and to
- catalogue and optimise environmental, economic and social benefits of forests to the entire community.

Future management strategies include the development of a fully integrated Environmental Management System (EMS) including aspects of environmental, economic and social benefits to the community from forests but well within ecological considerations. This paper will outline how our current research aims to develop functional models that can be used for biodiversity management in the context of planning and conducting prescribed burning.

Our approach is to:

- investigate the roles played by mycorrhizal and decomposer fungi,
- determine the inter-relationships of invertebrates, plants and fungi, and to
- examine the impacts of fire as a disturbance on carbon cycling and other ecosystem processes.

Forests and ecological processes

Throughout Sustainable Forest Management there are some recurring themes. These are the maintenance of ecological processes, particularly carbon and nutrient cycles, and conservation of biological diversity and productivity. These themes are recognised to be important in all aspects of forest management yet we are still very poor in our understanding of the level of variability in a range of parameters in the forest. We know next to nothing about the effects of disturbance on ecological processes and relationships within living and non-living components of the forest.

Figure 1 provides a simple schematic of the cycling of carbon or nutrients through a forest system. Plants and animals provide inputs to the organic matter, which is in turn decomposed by a range of other plants, animals and microbes. Decomposition of organic matter leads to the release of nutrients, energy, carbon dioxide and water which are reused in primary production. Adding to the broad process of decomposition is comminution and mineralisation carried out by macro- and micro-invertebrates, such as fungivores and bacteriovores, soil micro-organisms and mycorrhizal or saprophytic fungi.

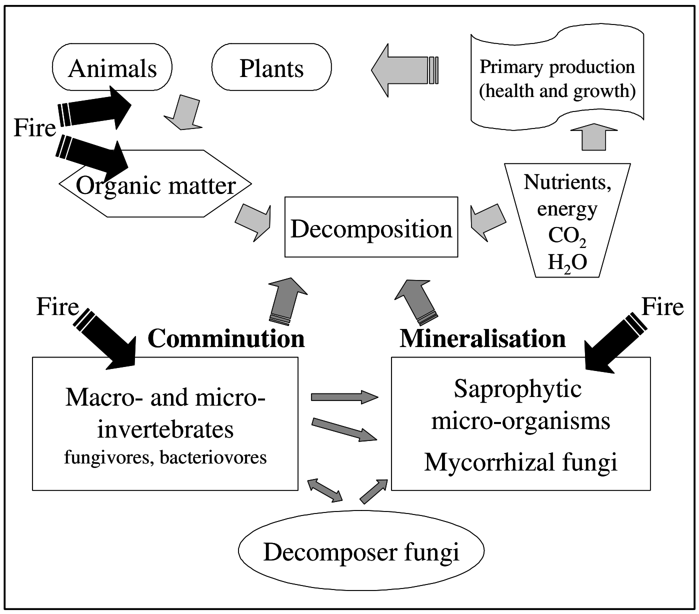

Fig. 1 Carbon and nutrient cycling in a forest ecosystem with emphasis on the decomposition processes occurring in the soil (comminution and mineralisation) by invertebrates and soil micro-organisms. Fire can impact on these processes at several points within the cycle.

In our current research, we are investigating how fire as a "process" impacts upon these other ecological processes. Through the work done by our group, there are a number of patterns that have been made concerning soil organic matter, invertebrates and fungi with fire in the form of frequent prescribed burning as a disturbance.

Fire as a disturbance

A long-term prescribed burning trial was established in Bulls Ground State Forest in 1969 on an 11 year-old, even-aged coastal Blackbutt, *Eucalyptus pilularis* Sm. regeneration forest (Van Loon 1970; York 1996). The site is located on the New South Wales coast, approximately 30 km southwest of Port Macquarie and is part of the Lorne State Forest. Small plots (approximately 1 ha) are used for each treatment, with frequently burnt plots being burned at approximately three-year intervals (1970, 1973, 1977, 1980, 1983, 1986, 1989, 1992). Litter and invertebrates were collected by litter extraction and pitfall trapping and analysed according to York (1996; 1999*a*). More recently, soil samples (n = 5) were collected and bulked from each plot and analysed for gravimetric moisture, bulk density, pH, electrical conductivity and total percentage carbon (C) according to Robertson *et al.* (1999). Research at this site is ongoing with the intention of identifying and understanding the interactions between invertebrates, plants and soil micro-organisms.

Studies at the Bulls Ground site have shown that frequent prescribed burning has had a marked effect on litter inputs (Fig. 2). At the long unburnt site, litter inputs are equal to rates of decomposition so a more-or-less steady state is achieved. Litter inputs vary at different times of the year but are generally held between 15 to 20 tonnes per hectare (Birk and Bridges 1989). In frequently burnt sites there is a much greater oscillation with decreased litter loads immediately after a burn (indicated by arrows) with gradual increases in the following years. With frequent

burning, the level of litter does not reach that in the long unburnt area and a steady state of decomposition in rarely achieved (York 1996).

A number of chemical and physical properties of soil have been measured at the Bulls Ground site and consistent differences have been found between long unburnt and frequently burnt plots (Fig. 3). For example, there is less soil moisture in the top 5 cm of soil in the frequently burnt plots compared to unburnt plots (Fig. 3A). Similarly, the electrical conductivity (Fig. 3D) and percentage total carbon (Fig. 3E) is higher in the long unburnt sites than the frequently burnt sites. The bulk density and pH of the soil at the same sites are consistently lower in the long unburnt sites than the frequently burnt sites (Fig. 3B and C).

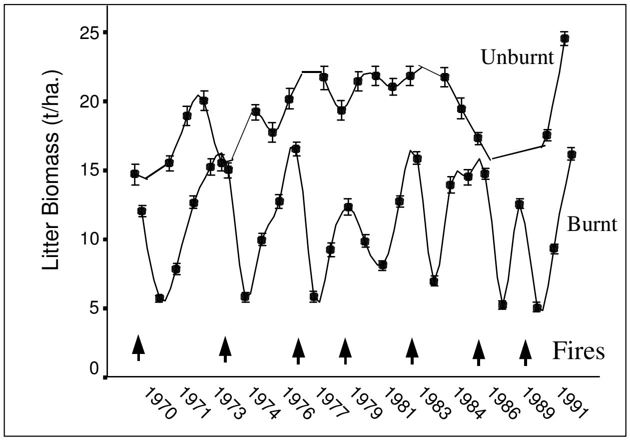

Fig. 2 Litter inputs at Bulls Ground long-term prescribed burning trials in long unburnt and regularly burnt plots. Arrows indicate the timing of prescribed fires. From York (1996).

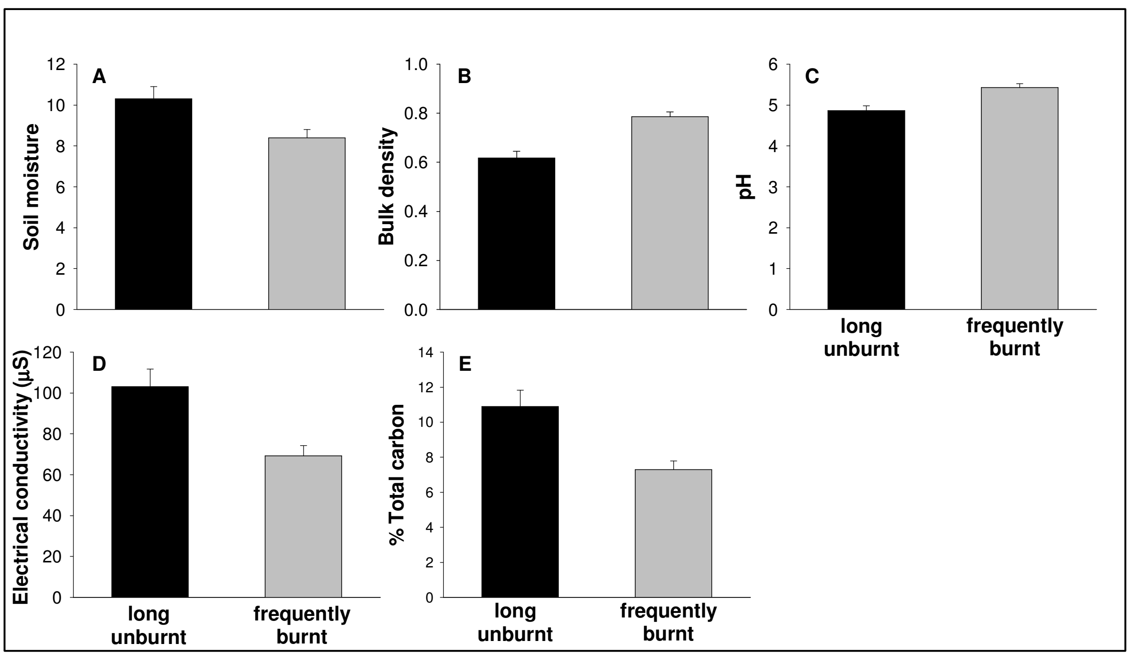

Fig. 3 Physical and chemical properties of soil from long unburnt and frequently burnt sites at Bulls Ground State Forest (a) soil moisture, (b) bulk density, (c) pH, (d) electrical conductivity, and (e) total soil carbon.

All groups of litter dwelling invertebrates collected from the Bulls Ground site also showed a significant difference between frequently burnt areas compared to adjacent unburnt areas (Fig. 4). The biggest decreases in numbers of individuals between burnt and unburnt plots included woolice (82% lower), beetles (76% lower), bugs (75 % lower) and pseudoscorpions (73% lower). Such decreases can be attributed to a reduction in the amount of litter and associated moisture levels. Frequent fires can also reduce spatial and structural heterogeneity of the habitat (Collett *et al*. 1993). Long-term consequences of frequent low intensity fires on invertebrate populations are largely unknown but are predicted to alter the composition and richness of invertebrate communities (York 1999*b*).

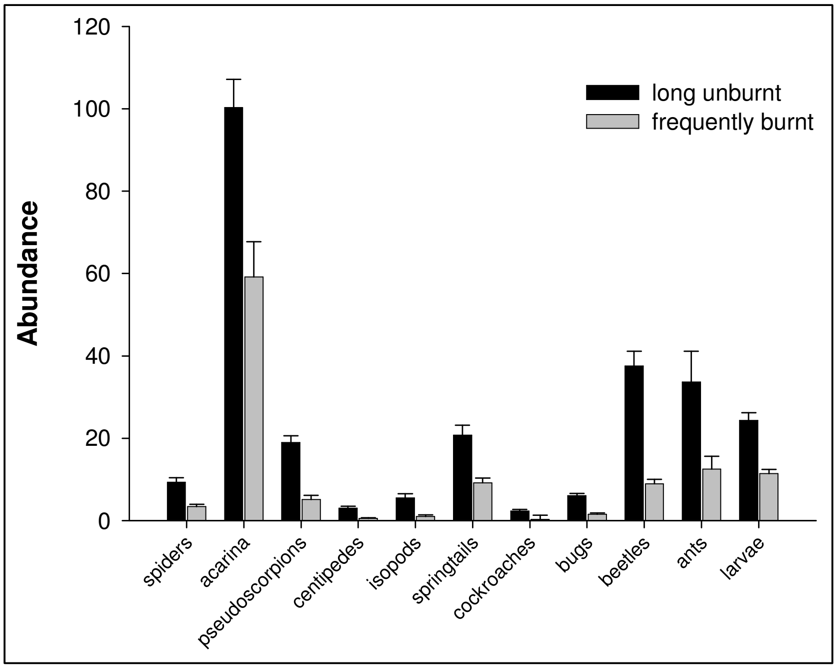

Fig. 4 Numbers of individuals in groups of invertebrates collected from litter extraction and by pitfall trapping in long unburnt and frequently burnt plots at Bulls Ground. Data from York (1999*b*).

Functional groups of forest biota

Individual species of plants animals and micro-organisms can be grouped according to the functional role they have in an ecosystem. This allows easier and potentially more meaningful comparisons between groups involved in nutrient cycling and decomposition. For example, at Bulls Ground, invertebrates living within leaf litter and feeding on the fruiting bodies of fungi (i.e. the fungal feeding guild) have been found to differ between long unburnt and frequently burnt plots at Bulls Ground (Table 1). These numbers represent the percentage of overall species present in this particular functional groups rather than the whole assemblage of invertebrates studied.

Table 1 Percentages of species of flies and beetles within the fungal feeding guild present in the leaf litter of long unburnt and frequently burnt sites (York 1999 *a*; *b*).

	Long unburnt	Frequently burnt
Flies	23.2 ± 2.5	12.9 ± 1.2 (down 44%)
Beetles	4.8 ± 0.1	3.3 ± 0.1 (down 31%)

In turn, functional groups of fungi may be affected by different burning regimes. Little research has been conducted on the effects of fire on soil fungi but some preliminary analysis of fungal patterns can give us some indication of potential changes to nutrient processes. Mycorrhizal fungi assist in the nutrient uptake for the majority of vascular plants. Arbuscular mycorrhizal (AM) associations allow their host plants greater access to ammonium and nitrate while ectomycorrhizal (ECM), ericoid and orchid fungi assist in partner plants accessing nutrients bound in organic matter.

Of the 125 species of vascular plants recorded at Bulls Ground, 62% of species have AM associations and 17% are non-mycorrhizal (Table 2). Only 8% of species have ECM associations despite this functional group being primarily associated with the eucalypts which make up over 90% of the aboveground biomass. Smaller proportions of plant species have orchid, ericoid or dual (AM/ECM) mycorrhizal associations and it is hypothesised that if these plant species are adversely affected by inappropriate fire regimes, there will be the potential for their fungal partners to also be affected. This has implications for the vulnerability of nutrient inputs and outputs for the system.

It is further hypothesised that there is less chance for the functional group of AM fungi to be disrupted by repeated fire as many more plant species are associated with this group.

Table 2 Functional groups of vascular plants found at Bulls Ground State Forest listed according to their mycorrhizal associations.

Fungal association	% species
Arbuscular	62
Ectomycorrhizal	8
Arbuscular/ectomycorrhizal	1
Orchid	9
Ericoid	3
Non-mycorrhizal	17
Unknown	30

To further enhance the interactions among fungi, plants and organic matter, evidence can be gathered from glasshouse experiments. Isotopically enriched nitrogen (^{15}N) was supplied to plants in a variety of forms including inorganic N as ammonium or nitrate or as 'organic N' incorporated into the soil organic matter fraction (Fig. 5). *Eucalyptus todtiana*, an ECM species, accessed the greatest proportion of its N from the organic N fraction (Fig. 5a). Other mycorrhizal plant species (AM and ericoid species) showed a similar pattern to *Eucalyptus todtiana*. In an N-fixing legume species (N_2 obtained from the atmosphere by symbiotic bacteria housed in nodules of the roots of the plant), there was little uptake of any form of N. If the levels of soil organic matter are affected by frequent burning, as shown earlier, it is likely that growth and productivity of the vegetation is also going to be affected.

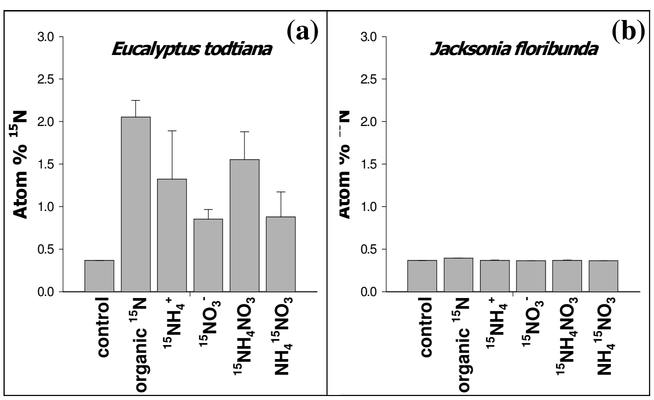

Fig. 5 Isotopic composition (atom %^{15}N) of two species grown in pot-culture with access to different labelled nitrogen sources (a) *Eucalyptus todtiana* which has an ectomycorrhizal association and (b) *Jacksonia floribunda* which can fix nitrogen from the atmosphere.

Moving from observing patterns to understanding processes

In order to move from observing patterns to obtaining a greater understanding of ecological processes, our research must take new directions. We intend to do this by:

- manipulating inputs of organic matter by using different fire regimes and other mechanisms of disturbance,
- tracking C and N cycling using isotopes at natural abundance and by using further labelling studies,
- manipulating fungal and microbial growth in culture using variable substrates and addition of nutrients,
- run decomposition trials involving exclusion of known invertebrate and fungi decomposers, and by
- manipulating communities of invertebrates and microorganisms using selective insecticides and fungicides.

References

Birk, E.M. and Bridges, R.G. (1989). Recurrent fires and fuel accumulation in even-aged blackbutt (*Eucalyptus pilularis*) forests. *Forest Ecology and Management* **29**, 59-79.

Collett, N.G., Neumann, F.G. and Tolhurst, K.G. (1993). Effects of two short rotation prescribed fires in spring on surface-active arthropods and earthworms in dry sclerophyll eucalypt forest of west-central Victoria. *Australian Forestry* **56**, 49-60.

Commonwealth of Australia (1992*a*). National Strategy for Ecologically Sustainable Development. Australian Government Printing Service, Canberra.

Commonwealth of Australia (1992*b*). National Forest Policy Statement: A New Focus for Australia's Forests. Australian Government Printing Service, Canberra.

Commonwealth of Australia (1998). A Framework of Regional (Sub-national) Level Criteria and Indicators of Sustainable Forest Management in Australia. Montreal Process Implementation Group, Canberra.

Department of Natural Resources and Environment (1997). Victoria's Biodiversity: Directions in Management. Victoria.

Department of Sustainability and Environment (2005). Victoria's State of the Forests Report. Victoria.

National Forest Inventory (2003). Australia's State of the Forests Report 2003. Bureau of Rural Sciences, Canberra.

Robertson, G.P., Coleman, D.C., Bledsoe, C.S. and Sollins, P. (1999). Standard Soil Methods for Long-term Ecological Research. Oxford University Press, New York.

Van Loon, A.P. (1970). Further investigations in the effects of prescribed burning on young even-aged blackbutt. Taree Forestry Office Research Report, Forestry Commission of New South Wales.

York, A.K. (1996). Long-term effects of fuel reduction burning on invertebrates in a dry sclerophyll forest. In: "Fire and Biodiversity: The Effects and Effectiveness of Fire Management". p163-181. Biodiversity Unit, Department of Environment Sport and Territories, Canberra.

York, A.K. (1999*a*). Long-term effects of repeated prescribed burning on forest invertebrates: management implications for the conservation of biodiversity. In: "Australia's Biodiversity – Responses to Fire. Plants, Birds and Invertebrates". p181-266. Biodiversity Technical Series 1, Department of the Environment and Heritage, Canberra.

York, A.K. (1999*b*). Long-term effects of frequent low-intensity burning on the abundance of litter-dwelling invertebrates in coastal blackbutt forests of southeastern Australia. *Journal of Insect Conservation* **3**, 191-199.