



Full length article

Do fungi have a role as soil stabilizers and remediators after forest fire?

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ABSTRACT

The functional roles of fungi in recovery of forest ecosystems after fire remain poorly documented. We observed macrofungi soon after fire at two widely separated sites, one in the Pacific Northwest United States and the other in southeastern mainland Australia. The range of species on-site was compared against macrofungi reported after the volcanic eruption at Mount St. Helens, also in the Pacific Northwest. Each of the three sites shared species, particularly representatives of the genus *Anthracobia*. Soon after disturbance, we noted extensive mycelial mats and masses of fruit-bodies of this genus, particularly at heavily impacted microsites. The mycelial mats appeared to play an important functional role on-site, possibly aggregating soil particles in otherwise highly erodible landscapes. We hypothesise that fungi such as *Anthracobia* are pivotal species in early system recovery after disturbance, helping minimize the movement of soil in the absence of plant roots. As plant root systems recover, the importance of these fungi in soil stabilization may diminish. Other functional roles of early postfire fungi might include nutrient acquisition, leading to the reestablishment of vegetation. These potential roles need to be experimentally tested and relevant findings incorporated into programs aimed at restoring forest ecosystems after disturbance.

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1. Introduction

Forest ecosystems around the Pacific are variously shaped by wildfire, particularly in North America and southeastern Australia, which are characterized by hot, dry summers and associated lightning events that serve as excellent ignition sources (Agee, 1993; Pyne, 2001, 2006). The postfire recovery of these systems has been relatively well documented in the scientific literature, particularly for better-known organisms within the animal and plant kingdoms (see Cary et al., 2003). In contrast, much remains to be learned about the response of fungi to disturbances such as wildfire, in part because few scientists per capita work on this significant component of biodiversity. Moreover, despite a general understanding of the types of roles of fungi in ecosystem functioning, including nutrient acquisition, water transfer and

carbon and nutrient cycling, the precise ecological roles of many species after fire remain undetermined.

Cairney and Bastias (2007) in Australia and Hart et al. (2005) in the western United States have extensively reviewed literature relating to the many and varied effects of fire on fungi, including studies that have documented recovery of these organisms several years after disturbance, saving us the need to do that here. The consensus of these studies to date is that fire, particularly of high intensity, is detrimental to the majority of fungal species at least in the short-term and sometimes in the long-term (i.e. Claridge and Trappe, 2004; Vernes et al., 2004; Hart et al., 2005; Cairney and Bastias, 2007; Jiménez Esquilin et al., 2007). In this brief paper, we focus on fungi that appear to benefit from disturbance, combining our field observations in southeastern mainland Australia and Pacific Northwestern America with review of selected literature relevant to the first 6 months after wildfire. Although the immediate postfire activities of such fungi are transient (Hart et al., 2005), our observations indicate they may be important in stabilizing soils and setting the stage for subsequent, longer-term forest recovery processes. For that reason, we consider it useful to integrate the literature with our own field observations as a

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baseline for fire ecologists to test hypotheses on fungal roles in the immediate aftermath of fire, especially because we can report that postfire fungal phenomenon occur similarly halfway around the world in forest types as dissimilar as Pacific Northwestern conifers and southeastern Australian eucalypts.

We have specific experience with postfire fungi following large scale intensive wildfires in southeastern mainland Australia in 2003, and a smaller scale though locally intensive wildfire in Washington State, USA, during 2006. One of us (Trappe) collected fungi within a month after the explosive eruption of Mount St. Helens in Washington State in 1980. The parallels between the fires in these far removed and markedly different forests were striking, as was the similar mycological aftermath of the Mount St. Helens eruption (Carpenter et al., 1987). In this paper we compare some of the fungal activity observed soon after these events and discuss their possible broader ecological meaning.

2. Definition of postfire fungi

The term “postfire fungi” as we use it here refers specifically to species that fruit as a result of fire or eruption effects (e.g. heat, ashing of organic matter), but generally not to fire survivors, (i.e. fungi that were active in the prefire habitat and escaped fire effects by being deep in soil or in patches of unburnt habitat). Some postfire fungi are carbonicolous, fruiting on charcoal or partially burned organic debris; others are terrestrial, fruiting on ash or heated soil; still others appear to be mycorrhizal symbionts with or pathogens on tree roots (Egger and Paden, 1986). Whereas some species produce only microscopic fruiting structures, others form fruit-bodies visible to the naked eye. Most postfire fungi are ascomycetes, but basidiomycetes and zygomycetes are also represented (Petersen, 1970; Warcup, 1990; Dahlberg, 2002).

Postfire fungi normally fruit during the first significant rain event following disturbance and are not the product of spores dispersed during that season, because the same species fruiting elsewhere have yet to produce spores or have only begun to. Their source is usually the spore bank in the soil built up over time since previous fire. Spore longevity in the soil is known for only a few species, but spores of terrestrial fungi in general retain viability for many years. Some fungal spores are strongly dormant and require heat treatment to germinate (Jalaluddin, 1967; El-Abyed and Webster, 1968; Wicklow and Zak, 1979; Izzo et al., 2006). Repeatedly deposited on the soil, the spores are carried over time to various depths in upper soil profiles by infiltrating water. When a site burns, the heat from the fire may kill spores near the surface, but at some depth the soil temperature will climb to the range that, rather than killing spores, breaks their dormancy.

We are aware of only two recent studies on effects of fire on fungal activity in the soil during the first year following fire. Hart et al. (2005) reported that the variation of functional diversity of bacteria in the top 5 cm of soil in a New Mexican *Pinus ponderosa* pine stand was greater than that of fungi. A severe wildfire subsequently burned the site, 1 month after which the soil was resampled. At that time, the variation of bacterial functional diversity had decreased while fungal functional diversity increased. These data reinforce that fungi can be particularly active soon after wildfire and are potentially important to postfire recovery of forests.

In the Rocky Mountains of Colorado, Jiménez Esquilin et al. (2007) sampled soils for microbial populations and activities at different time intervals after burns of slash piles following logging. Lethal temperatures in the top 5 cm of soil under the middle of piles were reached within an hour after ignition and maintained for more than 24 h. Soil fungal biovolume and respiration in the top 5 cm of soil were significantly reduced compared to nonburned

control samples up to at least 15 months. At 15 cm depth under piles, fungal biovolume did not differ from nonburned controls, although fungal respiration was reduced over a similar timeframe. While these observations are relevant to understanding postfire responses of fungi *per se*, they are not directly comparable to the present study since the authors did not record fungal fruiting activities.

3. Functions of postfire fungi

Postfire fungi have many potential functions with either positive or negative importance to stabilization of soils, restoration of habitat, recovery of damaged plants or replacement of dead vegetation. They decompose organic matter, including woody debris (Egger, 1986), thereby incorporating it into the soil and releasing organically bound nutrients. Mycelial networks bind soil particles into aggregates, thereby improving aeration and water infiltration (Bond and Harris, 1964; Tisdale and Oades, 1982; Hallett, 2007). Simultaneously, however, mycelium near or on the surface may increase water repellency, either or both by production of hydrophobic substances or a hyphal network dense enough that the surface tension of water may prevent quick infiltration. Fungal-induced repellency may increase surface runoff and thereby risk of erosion.

Other factors may also play a key role in increasing repellency. For example, Mataix-Solera and Doerr (2004) reported that fire-increased soil hydrophobicity was accompanied by improved soil aggregation. They attributed this to heating and distillation of plant litter, which subsequently condensed in the organic and mineral soil profile. Moreover, as pointed out by Hallett (2007), seasonal water repellency may switch off during soil water recharge in autumn and winter but return in surface soils during dry months. At that time, the repellent layer could act as a barrier minimising evaporative water loss. In Australia, fire-adapted hypogeous fungi may survive fire to be dug up by mammal mycophagists (Claridge et al., 2001; Claridge and Trappe, 2004). The resulting excavations break through the repellent layer and act as catchments of surface runoff that then infiltrates to the fungal colony and its associated host root system (Garkaklis et al., 1998).

Some fire-surviving fungi also act as postfire fungi, because they fruit only after fire, even though they may have formed mycorrhizae with surviving trees prior to fire (Egger and Paden, 1986; Vrålstad et al., 1998; Dahlberg, 2002). These fungi importantly facilitate regrowth of trees requiring mycorrhiza formation to survive (e.g. eucalypts and pines). Finally, a few postfire fungi are pathogenic on plant roots (Egger and Paden, 1986).

One overlooked function of fungi soon after fire would be sequestration of nitrogen. Nitrogen is lost through combustion, the loss generally being proportional to quantity of forest litter and upper soil organic layer consumed (Little and Ohmann, 1988; Wan et al., 2001). However, when combustion is incomplete, soil NH_4^+ may increase substantially and NO_3^- may increase somewhat through pyrolysis of organic matter (Wan et al., 2001). As nonpareil scavengers, fungi undoubtedly capture much of those newly released, highly leachable nitrogen ions plus any newly biologically fixed and released nitrogen and convert them to organic compounds needed for continued growth and fruiting. As fungal hyphae and fruit-bodies die the nitrogen released through decomposition becomes available to other organisms. That turnover can be rapid: fruit-bodies may begin to decompose within weeks of their formation. It is this activity that we had in mind when suggesting above that fungi ‘set the stage’ for further recovery of a site following fire. The importance of restoring nitrogen and organic compounds to an impoverished substrate

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