Macrofungi in early stages of forest regeneration in Tasmania's southern forests

D.A. Ratkowsky[1,2*] and G.M. Gates[1,2]
[1]School of Plant Science, University of Tasmania, Private Bag 55, Hobart, Tasmania 7001
[2]School of Agricultural Science, University of Tasmania, Private Bag 54, Hobart, Tasmania 7001
*e-mail: D. Ratkowsky@utas.edu.au (corresponding author)

Abstract

The present study compares the macrofungi at three study sites in the lowland wet eucalypt forest of southern Tasmania, all in early stages of regeneration, two from silvicultural treatments and one from wildfire. Although not part of a designed experiment, the three areas provided an unbroken, partially overlapping time-line in which macrofungi were recorded during the first 38 months of their development after disturbance and/or fire. Two of the three regenerating units had adjacent mature forest, the macrofungi of which were markedly different from those in the regeneration, the latter being dominated by opportunistic, predominantly saprotrophic species and very low in the symbiotic basidiomycetous ectomycorrhizal species that are abundant in the soils of mature forests. Studies such as these assist in a growing understanding of the nature of the early successional mycota in the southern forests of Tasmania.

Introduction

One of the premises under which clearfell, burn and sow (CBS) silviculture operates in Tasmanian lowland wet eucalypt forest is that this form of harvesting emulates the massive disturbances caused by periodic wildfires (Attiwill 1994), to the extent that many native forest species are expected to respond in similar ways to CBS as to wildfire. Notwithstanding some profound differences between these two disturbance types (Turner *et al*. 2009), similarities in response have indeed been demonstrated, to varying degrees, through studies on a range of taxa, including vascular plants (Hickey 1994), bryophytes (Turner and Pharo 2005), birds (Hingston 2000) and litter-dwelling beetles (Baker *et al.* 2004). Most such studies are confined to particular points in time post-disturbance, and thus represent a snapshot at a particular stage of ecological succession. Studies documenting changes over time are rare, and this is particularly so for the first few years following disturbance, when arguably the most rapid changes in soil chemistry and in ecosystem function and reassembly are taking place (Cunningham 1960; Pennington *et al.* 2001).

The Warra silvicultural systems trial was established as a means of assessing a range of alternatives to clearfell, burn and sow (CBS) in Tasmania's lowland wet eucalypt forest (Hickey *et al*. 2001). Research at Warra demonstrates that all viable alternatives retain the use of a post-harvest regeneration burn, because of the high level of dependence of eucalypt seedlings on a burnt seedbed (Neyland *et al*. 2009). Following ecological assessments at Warra (Kantvilas and Jarman 2004; Baker *et al*. 2009; Lefort and Grove 2009) and elsewhere, there is growing concensus that aggregated retention (ARN) is a suitable alternative to clearfelling in old-growth forest. Implementing regeneration burning in ARN coupes is a logistical challenge (Chuter

2007), but is nevertheless considered fundamental to the success of natural regeneration.

This reliance of both natural systems and silvicultural systems on burning emphasises the relevance of the present study, which sought to take advantage of the opportune and close juxtaposition in space and time of a series of independent disturbance events. These events have enabled us to examine the succession of macrofungal assemblages over the first 38 months following fire in lowland wet eucalypt forest. Macrofungi were an appropriate choice of study for two reasons. First, fungi are 'arguably among the most important of forest organisms' (Robinson and Bougher 2003), as many species are mycorrhizal, influencing plant community structure and succession over decades and centuries (Pascoe and Shipton 1996), while others are saprophytic, playing an important role in releasing and recycling nutrients from dead organic matter (Bougher and Syme 1998). Second, macrofungi have been the focus of previous studies in the Warra silvicultural systems trial area (Gates *et al*. 2005), meaning that the local mycota of recently clearfelled and burnt forest was already reasonably well-characterised.

Methods

Sites and survey methods

This study incorporates data-sets from two previous studies of the macrofungi in regenerating harvested coupes. One (Gates *et al*. 2005) provided a data-set on macrofungi following a clearfell burn and sow (CBS) operation (Warra coupe WR008J), while the other (Gates *et al*. 2009) provided data from the harvested area (HAR) of an aggregated retention operation (Warra coupe WR001E). A third data-set (hereafter referred to as WLF) was collected specifically for this study, following a wildfire (originating from an escaped regeneration burn) in mature forest 13 km east of Warra, at the junction of Bennetts Road and Arve Road. The dominant eucalypt in each of these study sites was *E. obliqua.*

The surveys for each of these data-sets occupied different, but overlapping, time-lines after the fire (Figure 1). The WLF surveys started shortly after 'time-zero' (i.e. the wildfire), and continued fortnightly for 14 months; the HAR surveys started ten months after the end of site-preparation (including a regeneration burn), and continued fortnightly for 16 months (i.e. up to a point 26 months after 'time-zero'); and

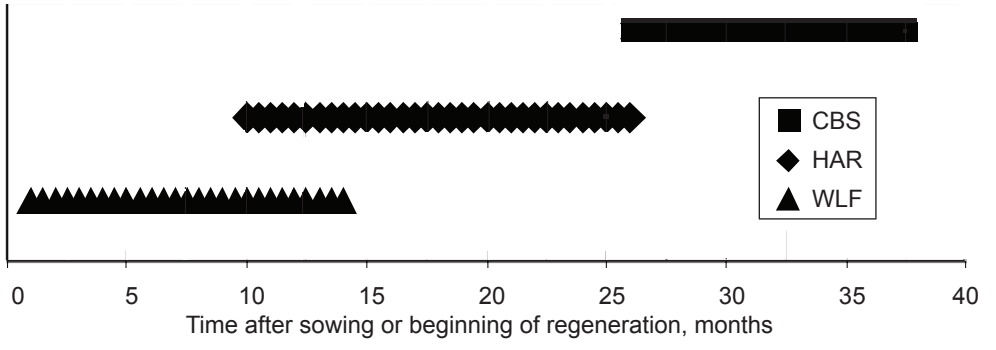

Figure 1. Periods of data collection at the three regenerating sites compared in this study, covering the early stages of regeneration.

the CBS surveys started 26 months after aerial sowing (which immediately post-dated the regeneration burn), and continued fortnightly for 12 months (i.e. up to a point 38 months after 'time-zero'). Thus the three studies taken together gave an unbroken period of 38 months for monitoring the succession of macromycota after fire in the lowland wet eucalypt forests of southern Tasmania.

The CBS coupe was sown with eucalypt seed on 16 April 2001 after a high intensity burn was applied on 7 April 2001. The fungal survey in that coupe followed cut transect lines totalling about 1.3 km; the survey was carried out 27 times between 12 June 2003 and 29 June 2004 – see Gates *et al*. (2005). The HAR portion of the aggregated retention coupe was burnt on 20 April 2004, with no subsequent sowing of seed. In the survey of HAR, carried out over a period of 16 months between February 2005 and June 2006 (Gates *et al*. 2009), the length of the transect was about 400 m. The wildfire at WLF occurred on 1 April 2005. The burnt area that was surveyed was located in a corner at the junction of Arve and Bennetts Roads, and approximated a rectangle 30 x 50 m. The length of the traverse in WLF was shorter than for the two silvicultural treatments, but was not measured exactly. The fungal survey at WLF commenced on 13 April 2005, on which date no fungi were observed, but 29 additional visits to that site were made over a period of 14 months at approximately fortnightly intervals, on the same days that visits were made to HAR.

Life mode

In this study, we ascribed each basiomycetous species to one of two life-mode categories, "decomposers" (to encompass both saprotrophic and parasitic species) and "ectomycorrhizal" (the latter being predominantly found on soil). Because most ascomycetous taxa remain unidentified to species level and are of uncertain life mode (e.g. Tedersoo *et al.* 2006), we retained them in a third category, Ascomycota.

Statistical methods

Because the three regenerating areas that were compared in the present study were not part of a single, designed experiment, it would be inappropriate to apply some of the statistical procedures employed in, for example, our two previous studies (Gates *et al.* 2005, 2009). Thus, although the observed number of species in the regenerating unit from each survey could be used as a measure of species richness and displayed in a Venn diagram, the inequality of the sampling effort and the fact that the surveys were not all conducted in the same year might not represent fairly the differences between the regenerating units.

Similarly, although differences in species assemblage composition could be examined with a constrained ordination such as the canonical analysis of principal coordinates (Anderson and Willis 2003), using the three regenerating units as predefined groups to obtain an exact significance test, this use may not be appropriate as the sampling effort was not equal. Instead, we can at most use an unconstrained ordination procedure to display visually the multivariate patterns among the samples in the regenerating units, which might suggest future hypotheses to be tested. We chose to use nonmetric multidimensional scaling (MDS) for this purpose, with similarity being based upon the presence or absence of the species in the species lists recorded at each visit, defined using the Bray-Curtis measure without standardisation or data transformation. MDS was run in the program PC-ORD (McCune and Mefford 1999), to reveal a potential correlation between the positions of the points on the ordination diagram and the time since disturbance, bearing in mind that every point encompasses a value in days between the initiation of the disturbance and the date of the visit.

Table 1. Number of macrofungal species observed, classified by sampling unit and phylum/life mode combination. Percentages are based upon the total number of basidiomycetous species in each sampling unit. Spp., species.

Sampling unit	Phylum/Life mode			
	Ascomycota spp.	Basidiomycetous decomposer spp.	Basidiomycetous ecto-mycorrhizal spp.	Total spp.
WLF	12	60 (93.8%)	4 (6.2%)	76
HAR	11	105 (92.1%)	9 (7.9%)	125
CBS	13	105 (91.3%)	10 (8.7%)	128

Table 2. Number of macrofungal species observed, classified by sampling unit and substrate (the minor substrates dung and bryophytes are omitted). Percentages are based upon the total number of species in each sampling unit.

Sampling unit	Substrate			
	Litter	Soil	Wood	Total
WLF	11 (14.5%)	40 (52.6%)	24 (31.6%)	76
HAR	21 (16.8%)	39 (31.2%)	57 (45.6%)	125
CBS	6 (4.7%)	55 (42.6%)	59 (45.7%)	128

Results

Fungal surveys were carried out during the same times in the same year in HAR and WLF, but not in CBS. Differences in lists of species may therefore incorporate differences both in the emergence of mycota from year to year as well as in transect length.

Species richness

A total of 225 macrofungal species was recorded in the combined regenerating units, with 128 species in CBS, 125 species in HAR, and 76 species in WLF. The species lists for CBS and HAR were given in Gates *et al.* (2005, 2009), respectively. The species list for WLF is given in Appendix 1, which also provides information on the phylum/life mode of each species and the preferred season or seasons in which each was found. The numbers of species unique to CBS, HAR and WLF are 58, 46 and 38, respectively. The total of unique species, 142, is 63% of the species total of 225, indicating that the species lists in the three sampling units are substantially different.

Table 1 presents species numbers as a function of phylum/life mode. The proportion of the Basidiomycota species in each regenerating unit that is ectomycorrhizal is small, ranging from 6.2 to 8.7%, with only a small change in ectomycorrhizal species numbers and proportions with increasing time since regeneration. Table 2 presents numbers and proportions for the three main substrate categories, litter, soil and wood. A contingency table analysis indicated a highly significant difference across substrates and sampling units ($\chi^2 = 16.9$ with 4 d.f., $P = 0.002$), mainly reflecting the small proportion of species on litter in CBS and disparities in the distribution of fungal species on wood in HAR and WLF.

Assemblage composition

Figure 2 presents a 2-dimensional MDS based upon the fungal species lists in the three regenerating areas, with the points representing individual visits. As the stress is only 0.09, the representation is highly acceptable, clearly separating WLF and CBS in this unconstrained ordination and strongly suggesting different species

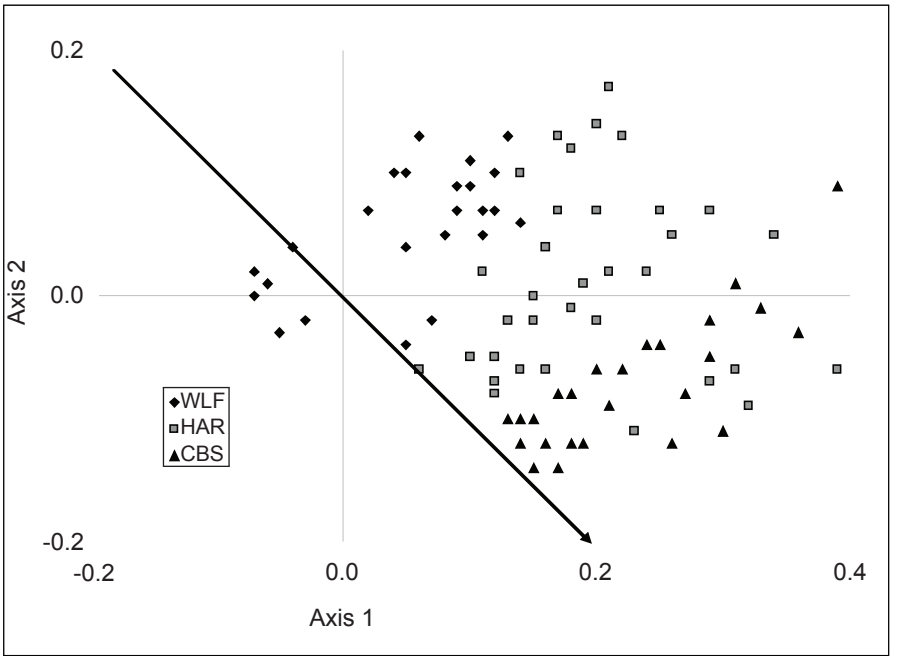

Figure 2. Two-dimensional MDS ordination for macrofungal data from three regenerating sites. A composite axis, used for subsequent graphing against time after disturbance, is shown with an arrowhead. Code for symbols: CBS = clearfelled, burnt and sown coupe; HAR = harvested areas of an aggregated retention coupe; WLF = area burned by wildfire at junction of Bennetts and Arve Roads. The first visit to WLF found no fungi and was omitted from the ordination, while visits 2-6 found few fungi and were included in the ordination but not shown on this graph, having very large negative Axis 1 scores. Stress = 0.09.

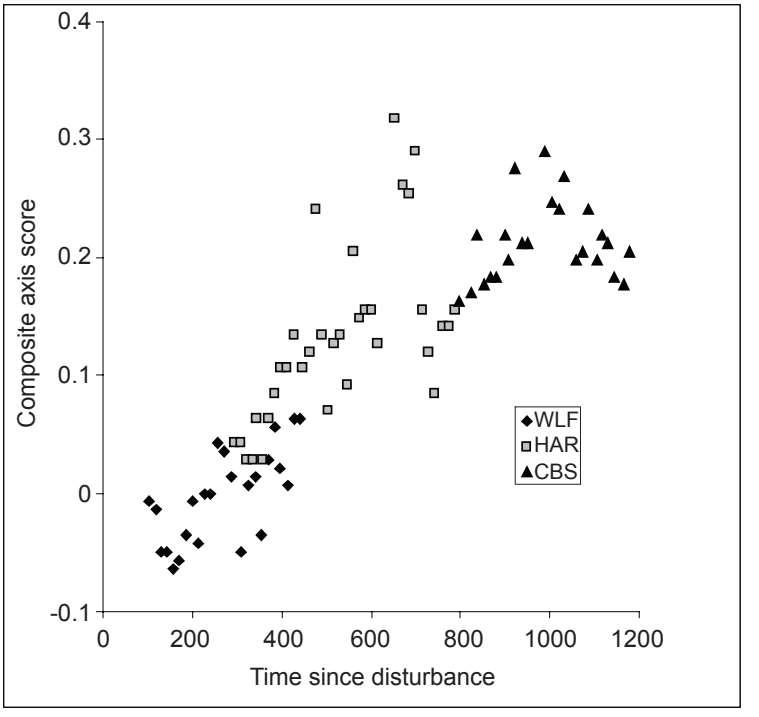

Figure 3. Composite scores, obtained by the projection of points onto a composite one-dimensional axis (with arrowhead, Figure 2), plotted against time after disturbance (in days). Code for symbols: CBS = clearfelled, burnt and sown coupe; HAR = harvested areas of an aggregated retention coupe; WLF = area burned by wildfire at junction of Bennetts and Arve Roads. First six visits to WLF are omitted; see caption to Figure 2.

assemblage compositions in these sampling units. The points for HAR overlap with those from both of the other two areas. Figure 2 shows all but the first six visits to WLF. The first visit to that area found no fungi and was not included in the analysis. The next five visits found between one and five species, data for which was included in the analysis but the points (with very large negative values on Axis 1) are not shown on Figure 2.

Figure 3 shows the composite one-dimensional axis score from the MDS plotted against the time of visit after disturbance. A composite score was used as the regenerating units are separated better on an axis located approximately at a 45° angle from the horizontal (Figure 2) than on either of the two axes of the two-dimensional ordination. The composite score is the projection of the points representing the visits on the composite axis. A single relationship between these scores and the time after disturbance is strongly supported, suggesting species assemblage compositions change with increasing time from initial site disturbance.

Discussion

Species richness and assemblage composition

There is no justification for making comparisons of total species richness among the three regenerating areas, because of the unequal sampling efforts and the different real times in which the surveys were carried out. Year-to-year differences in fungal species emergence may be considerable. Thus, although the 76 species found in WLF appear to be a lot fewer than the 125 species found in HAR and the 128 species found in CBS, caution should be employed in any comparison about the relative richness of the three areas. However, there appear to be clear differences among their species assemblage compositions (Figures 2 and 3), and also among the distributions of the species on the various substrates (Table 2).

The early-appearing fungi in WLF, *Anthracobia muelleri, Ascobolus archeri, Hypocrea rufa, Laccocephalum tumulosum, Neolentinus dactyloides, Peziza echinospora, P. tenacella, Plicaria recurva, Pulvinula archeri* and *Pyronema omphalodes*, were all recorded within the first 200 days after the wildfire, and are well-known early colonisers after fire, with all but one (*Hypocrea rufa*) appearing on soil. Many of these species have been reported as occurring after fire in Australia (May and Fuhrer 1989; Warcup 1990; McMullan-Fisher *et al.* 2002; Robinson *et al.* 2008), and closely related species also occur in the Northern Hemisphere, where they are known to be among the early anthracophilic representatives (El-Abyad and Webster 1968; Petersen 1970; Bleken *et al.* 1997). *Tephrocybe anthracophila*, another cosmopolitan "fireplace fungus" occurring on soil, appeared after 200 days.

The next stage in the post-fire time sequence was HAR. Since the regenerating area was only partially or incompletely burnt, one might expect opportunistic saprotrophs to be present amongst the anthracophilic species. Thus, whereas *Laccocephalum sclerotinium* responds to fire through its sclerotium, a storage organ that enables the species to fruit abundantly after severe fire, the wood-inhabiting *Fistulina hepatica, Laetiporus portentosus* and *Schizophyllum commune* are decomposers that probably do not require fire to account for their presence. The soil-borne species *Coprinellus disseminatus* and *Nothojafnea thaxteri*, as well as *Scutellinia scutellata*, the latter being found on rotten wood or on soil near wood, also probably do not require fire. The various unnamed *Mycena* and *Psathyrella* species that are abundant amongst the litter are saprotrophs likely to be taking advantage of an open, competition-free environment.

The CBS plot was further along the scale of fungal succession than the other two regenerating areas. The unconstrained ordination given by MDS (Figure 2) shows that the fungal species compositions in

WLF and CBS are widely different. The species composition at HAR, however, is intermediate between those two, overlapping with both. Its intermediate nature may reflect a combination of the intermediate time since burning and the lower intensity of the burn. The non-exclusive fungal species in HAR were found more often in CBS than in WLF, and were largely saprotrophic. None of the species shared by HAR and CBS, but not found in WLF, can be considered to be fireplace fungi. In contrast, among the species shared by HAR and WLF were *Coprinellus angulatus* and *Pholiota highlandensis*, which are known to be anthracophilic species in the Northern Hemisphere (Bleken *et al*. 1997).

McMullan-Fisher *et al.* (2002) concluded that there were three phases in the recolonisation after fire in *Eucalyptus regnans*-dominated forests in the Eastern Central Highlands of Victoria, Australia. The first was the immediate post-fire phase, lasting 12 months. Among the species observed exclusively in that phase were *Laccocephalum tumulosum, Neolentinus dactyloides*, and *Peziza echinospora*, well-known cosmopolitan anthracophilic species that were also observed exclusively in WLF. Of interest here is the fact that the immediate post-fire phase of the McMullan-Fisher *et al*. (2002) study was in a forest that was regeneration-burnt after logging, in contrast to wildfire as in WLF. This suggests that the fire itself may be more important in determining the immediate post-fire mycota than whether the fire regime was planned or not. The second phase in post-fire recolonisation in the study of McMullan-Fisher *et al.* (2002) was an intermediate phase 2-4 years after the fire, which includes the whole of the survey period of CBS of the present study as well as the later visits to HAR. Few species characterised that age group, the most frequently observed in their study being *Pycnoporus coccineus*, which was also found abundantly in our HAR and CBS areas but never in the mature forest control plots. The third phase in recolonisation after fire of the McMullan-Fisher *et al.* (2002) study involved a more mature phase of 7-year-old and older plots. This phase had a large group of macrofungi that did not appear in the younger phases. This included species such as *Amauroderma rude, Artomyces piperatus* (as *Clavicorona pyxidata), Campanella olivaceonigra, Hydnum repandum, Marasmiellus affixus, Melanophyllum haematospermum, Mycena austrofilopes, M. austrororida, M. cystidiosa* (as *M. hispida), M. interrupta,* and *Xylaria apiculata*. We have also observed all of these species in the course of our various surveys in mature Tasmanian forests (e.g. the control plots of Gates *et al.* 2005, 2009), but, in addition, we found *Hydnum repandum* in WLF, *Mycena austrofilopes* in WLF, *M. cystidiosa* in WLF and CBS, and *Melanophyllum haematospermum* in CBS. Therefore, those species are not all exclusive to older forests in Tasmania.

A further comparison of species in CBS, HAR and WLF can be made against the macrofungal species found in mature and regrowth wet eucalypt forest in Southern Tasmania by Packham *et al*. (2002). The youngest of the eight sites that they studied was estimated to be 25-30 years old, and was therefore not in an early stage of regeneration. There were only 13 species found in common between WLF and in the study of Packham *et al.* (2002) - a relatively small list. They were *Armillaria hinnulea, A. novaezelandiae, Ascocoryne sarcoides, Gymnopilus eucalyptorum, Hydnum repandum, Laccaria* spp., *Mycena austrofilopes, M. cystidiosa, M. epipterygia, M. sanguinolenta, Omphalina chromacea, Postia pelliculosa* and *Psathyrella echinata,* and 7 of the 13 were recorded in WLF only once.

Substrate

The significant differences in proportions of species found on the various substrates (Table 2) indicate that wood is less important, and soil more important, as a substrate in WLF than in the other two regenerating areas. This may be because most of the earliest-appearing fungi after

a fire are soil-borne, and the fact that the hot fire in WLF consumed all of the litter and small pieces of wood, leaving only severely charred fallen logs and standing trees. In CBS, litter played a very small role as a host, with only about 5% of the fungi that favour that substrate appearing during the survey. This may reflect the fact that litter was sparse in CBS compared with HAR and WLF, since the high-intensity regeneration burn applied to CBS would have removed virtually all the smaller litter that remained after clearfelling. The lack of nearby standing trees meant that there was no source of abundant new litter. This was not the case for HAR, which had incomplete burning and, therefore, more surviving small wood than WLF, which could account for its higher percentage of macrofungi on wood compared to WLF. Although the wildfire in WLF was a high-intensity fire similar to that applied to CBS, the standing trees remained a good and constant source of leaf litter throughout the period of the survey.

Main life mode

The WLF site, being affected by a wildfire, still retained the host trees. This is one of the differences between a wildfire and a fire after clearfelling (Lindenmayer *et al.* 1990). Although the litter, understorey species and leaf canopy of the trees in WLF were completely burnt, the trees were coppicing 6 months after the fire. Many early-stage successional fungi were found there in accordance with other studies on succession of fungi after wildfire. Thus, *Laccocephalum tumulosum*, *Peziza echinospora*, *Peziza tenacella* and *Pyronema omphalodes* appeared along with two late successional basidiomycetous ectomycorrhizal species, an unnamed *Cortinarius* sp. and *Russula neerimea*. The emergence of these last two species may have been possible because the host trees were not completely destroyed by the wildfire. In general, the proportion of basidiomycetous species that were ectomycorrhizal was low in each of the regenerating areas. Therefore, all of the areas can be considered to be in an early stage of succession in this respect. McMullan-Fisher *et al.* (2002) suggested that it may take a minimum of seven years before ectomycorrhizal species reappear in large numbers after harvesting and regeneration burning in forests in Victoria, Australia. The process of re-establishment of ectomycorrhizal communities in a wildfire plot such as WLF is likely to be quicker. To examine this premise, we revisited WLF on 7 June 2008, 38 months after the wildfire, and found seven basidiomycetous ectomycorrhizal species, namely three unnamed *Cortinarius* spp., *Descolea recedens*, an unnamed *Laccaria* sp., an unnamed *Russula* sp., and *Xerocomus* aff. *subtomentosus*. As there were only three (or four) basidiomycetous ectomycorrhizal species found in the previous visits to WLF, this suggests that the gradual recovery of ectomycorrhizality after a wildfire continues over at least the first three years.

Conclusions

With respect to species composition, the macrofungal species lists obtained from the three study sites investigated here indicate a clear succession related to time since fire, a majority of the species obtained in each site being different from those in the other sites. The evidence suggests that the nature of the fire, i.e. whether it is a wildfire or a regeneration burn, is of less consequence than the time after fire for determining whether or not a fungal species will emerge. The rates at which the number of basidiomycetous ectomycorrhizal species increase in the various regenerating areas are still to be determined. Of particular interest is the contrast between the recolonising rates in an area affected by a wildfire, where standing trees still remain, and an area subjected to a regeneration burn after clearfell harvesting. The recovery of affected areas after fire is part of the process by which the biodiversity of the forest and the health of their trees is maintained, and the native forest ecosystem restored.

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References

Attiwill, P.M. (1994). Ecological disturbance and the conservative management of eucalypt forests in Australia. *Forest Ecology and Management* 63: 301–346.

Anderson, M.J. and Willis, T.J. (2003). Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology. *Ecology* 84: 511-525.

Baker, S.C., Richardson, A.M.M., Seeman, O.D. and Barmuta, L.A. (2004). Does clearfell, burn and sow silviculture mimic the effect of wildfire? A field study and review using litter beetles. *Forest Ecology and Management* 199: 433-448.

Baker, S., Grove, S.J., Forster, L., Bonham, K.J. and Bashford, D. (2009). Short-term responses of ground-active beetles to alternative silvicultural systems in the Warra Silvicultural Systems Trial, Tasmania, Australia. *Forest Ecology and Management* 258: 444-459.

Bleken, E., Mysterud, I. and Mysterud, I. (1997). *Forest Fire and Environmental Management: a technical report on forest fire as an ecological factor.* Contracted report. Directorate for Fire & Explosion Prevention and Department of Biology, University of Oslo, Norway. 266 pp.

Bougher, N.L. and Syme, K. (1998). *Fungi of Southern Australia*. University of Western Australia Press, Perth.

Chuter, R. (2007). Feasibility of burning debris from wet eucalypt forests harvested to an aggregated retention prescription. *Division of Forest Research and Development Technical Report* No. 10/2007. Forestry Tasmania.

Cunningham, T.M. (1960). Seed and seedling survival of *Eucalyptus regnans* and the natural regeneration of second-growth stands. *Appita* 13: 124–131.

El-Abyad, M.S.H. and Webster, J. (1968). Studies on pyrophilous Discomycetes. I. Comparative physiological studies. *Transactions of the British Mycological Society* 51: 353-67.

Gates, G.M., Ratkowsky, D.A. and Grove, S.J. (2005). A comparison of the macrofungi in young silvicultural regeneration and mature forest at the Warra LTER Site in the southern forests of Tasmania. *Tasforests* 16: 127-152.

Gates, G.M., Ratkowsky, D.A. and Grove, S.J. (2009). Aggregated retention and macrofungi: a case study from the Warra LTER site, Tasmania. *Tasforests* 18: 35-56.

Hickey, J.E., Neyland, M.G. and Bassett, O.D. (2001). Rationale and design for the Warra silvicultural systems trial in wet *Eucalyptus obliqua* forests in Tasmania. *Tasforests* 13: 155-182.

Hickey, J. (1994). A floristic comparison of vascular species in Tasmanian oldgrowth mixed forest with regeneration resulting from logging and wildfire. *Australian Journal of Botany* 42: 383–404.

Hingston, A.B. (2000). Impacts of logging on autumn bird populations in the southern forests of Tasmania. Pap. Proc. Roy. Soc. Tasman. 134: 19-28.

Kantvilas, G. and Jarman, S.J. (2004). Lichens and bryophytes on *Eucalyptus obliqua* in Tasmania: management implications in production forests. *Biological Conservation* 117: 359-373.

Lefort, P. and Grove, S.J. (2009). Early responses of birds to clearfelling and its alternatives in lowland wet eucalypt forest in Tasmania, Australia. *Forest Ecology and Management* 258: 460-471.

Lindenmayer, D.B., Norton, T.W. and Tanton, M.T. (1990). Differences between wildfire and clearfelling on the structure of montane ash forests of Victoria and their implications for fauna dependent on tree hollows. *Australian Forestry* 53: 61-68.

May, T. and Fuhrer, B. (1989). Notes on fungi occurring after fire in Australia. 1. Introduction and description of *Gerronema postii. Victorian Naturalist* 106: 133-137.

McCune, B. and Mefford, M.J. (1999). PC-ORD for Windows. Multivariate Analysis of Ecological Data, Version 4.17. MjM Software, Gleneden Beach, Oregon, USA.

McMullan-Fisher, S.J.M., May, T.W. and Keane, P.J. (2002). The macrofungal community and fire in a Mountain Ash forest in southern Australia. In: *Fungal Succession* (eds K.D. Hyde and E.B.G. Jones), pp. 57-76, Fungal Diversity Press, Hong Kong.

Neyland, M., Hickey, J., Beadle, C., Bauhus, J., Davidson, N. and Edwards, L. (2009). An examination of stocking and early growth in the Warra silvicultural systems trial confirms the importance of a burnt seedbed for vigorous regeneration in *Eucalyptus obliqua* forest. *Forest Ecology and Management* 258: 481-494.

Packham, J.M., May, T.W., Brown, M.J., Wardlaw, T.J. and Mills, A.K. (2002). Macrofungal diversity and community ecology in mature and regrowth wet eucalypt forest in Tasmania: A multivariate study. *Austral Ecology* 27: 149-161.

Pascoe, I. and Shipton, W. (1996). Biology of fungi. In: *Fungi of Australia, Volume 1A, Introduction - Classification* (eds. C. Grgurinovic and K. Mallett), pp. 207–262. Australian Biological Resources Study, Canberra.

Pennington P., Laffan, M., Lewis, R. and Otahal, P. (2001). Assessing the long-term impacts of forest harvesting and high intensity broadcast burning on soil properties at the Warra LTER Site. *Tasforests* 13: 291-301.

Petersen, P.M. (1970). Danish fireplace fungi: an ecological investigation on fungi on burns. *Dansk Botanisk Arkiv* 27: 1-97.

Robinson, R.M. and Bougher, N.L. (2003). The response of fungi to fire in jarrah (*Eucalyptus marginata*) and karri (*Eucalyptus diversicolor*) forests of south-west Western Australia. In I. Abbott and N. Burrows (eds). *Fire in ecosystems of south-west Western Australia: impacts and management.* pp. 269-289. Backhuys, Leiden.

Robinson, R.M., Mellican, A.E. and Smith, R.H. (2008). Epigeous macrofungal succession in the first five years following a wildfire in karri (*Eucalyptus diversicolor*) regrowth forest in Western Australia. *Austral Ecology* 33: 807-820.

Tedersoo, L., Hansen, K., Perry, B.A. and Kjøller, R. (2006). Molecular and morphological diversity of pezizalean ectomycorrhiza. *New Phytologist* 170: 581-596.

Turner, P.A.M. and Pharo, E.J. (2005). Influence of substrate type and forest age on bryophyte species distribution in Tasmanian mixed forest. *The Bryologist* 108: 67–85.

Turner, P.A.M., Balmer, J. and Kirkpatrick, J.B. (2009). Stand-replacing wildfires? The incidence of multi-cohort and single-cohort *Eucalyptus regnans* and *E. obliqua* forests in southern Tasmania. *Forest Ecology and Management* 258: 366-375.

Warcup, J.H. (1990). Occurrence of ectomycorrhizal and saprophytic discomycetes after a wild fire in a eucalypt forest. *Mycological Research* 94: 1065-1069.

Appendix 1. Species at Bennetts Road (WLF) (listed in alphabetical order).
Phylum/Life mode: A=Ascomycota; BD = Basidiomycota/Decomposer (incl. saprophytes and parasites); BM = Basidiomycota/Ectomycorrhizal
Seasons: Sp = spring; Su = summer; A = autumn; W = winter

Species binomial	Number of records	Substrate	Phylum/ Life mode	Preferred season(s)
Agaricus 'marzipan'	1	Soil	BD	A
Agaricus sp.	2	Soil	BD	A,W
Anthracobia aff. *muelleri* (Berk.) M.A. Rifai	6	Soil	A	W
Armillaria hinnulea Kile & Watling	1	Wood	BD	A
Armillaria novaezelandiae (G. Stev.) Herink	3	Wood	BD	Su,A
Ascobolus archeri Berk.	1	Soil	A	Sp
Ascocoryne sarcoides (Jacq.) J.W. Groves & D.E. Wilson	2	Wood	A	A,W
Ascomycete 'stalked yellow-brown disc on rotting eucalypt leaves'	1	Litter	A	Sp
Bovista brunnea Berk.	5	Soil	BD	Su,A
Byssomerulius corium (Pers. : Fr.) Parmasto	2	Wood	BD	W
Cantharellus 'orange'	3	Soil	BD	A,W
Coprinellus angulatus (Peck) Redhead, Vilgalys & Moncalvo	14	Soil	BD	Sp,Su,A
Coprinus 'white'	1	Soil	BD	A
Cortinarius 'brown, striate, white stipe'	1	Soil	BM	A
Flammulina velutipes (Curtis : Fr.) Singer	2	Wood	BD	A,W
Galerina nana (Petri) Kühner	9	Soil	BD	All year
Gymnopilus allantopus (Berk.) Pegler	1	Wood	BD	W
Gymnopilus eucalyptorum (Cleland) Singer	1	Wood	BD	W
Gymnopilus ferruginosus B.J. Rees	1	Wood	BD	W
Gymnopilus tyallus Grgur.	1	Wood	BD	A
Gymnopus 'brown frilly'	2	Soil	BD	A,W
Gymnopus 'hygrophanous reddish brown'	4	Soil	BD	W,Sp,Su
Hohenbuehelia 'large brown, tomentose, no odour'	1	Soil	BD	Su
Hydnum repandum L. : Fr.	1	Soil	BD	W
Hypholoma sublateritium (Fr.) Quél.	1	Wood	BD	W
Hypocrea rufa (Pers.:Fr.) Fries	11	Wood	A	W,Sp
Laccaria spp.	21	Soil	BM	All year
Laccocephalum tumulosum (Cooke) Núñez & Ryvarden	2	Soil	BD	Sp
Lentinellus tasmanicus R.H. Petersen	7	Soil	BD	Sp,Su
Loreleia marchantiae (Singer & Clémençon) Redhead, Moncalvo, Vilgalys & Lutzoni	13	Bryophytes	BD	All year
Marasmius elegans (Cleland) Grgur.	1	Soil	BD	Su
Melanoleuca sp.	3	Soil	BM?	W,Sp
Melanotus hepatochrous (Berk.) Singer	8	Wood	BD	All year
Mycena 'brown striate, becoming sulcate'	4	Litter	BD	A,W
Mycena 'grey-brown cap, white decurrent gills, glutinous stipe'	1	Litter	BD	A
Mycena 'grey-brown with bleach odour'	2	Litter	BD	A
Mycena 'M152, brown, dry, pellucid, drying reddish brown'	2	Litter	BD	A

Appendix 1. Continued.

Species binomial	Number of records	Substrate	Phylum/ Life mode	Preferred season(s)
Mycena 'M156, black & grey'	1	Litter	BD	Su
Mycena albidocapillaris Grgur. & T.W. May	1	Litter	BD	W
Mycena austrofilopes Grgur. & A.A. Holland	1	Litter	BD	W
Mycena cystidiosa (G. Stev.) E. Horak	2	Litter	BD	A,W
Mycena epipterygia (Scop. : Fr.) Gray	1	Litter	BD	A
Mycena mulawaestris Grgur.	1	Wood	BD	W
Mycena sanguinolenta (Alb. & Schwein. : Fr.) P. Kumm.	10	Soil, Litter	BD	All year
Mycena subgalericulata Cleland	1	Wood	BD	W
Neolentinus dactyloides (Cleland) Redhead & Ginns	4	Soil	BD	A,W
Omphalina chromacea (Cleland) T.W. May & A.E. Wood	10	Soil	BD	Sp,Su,A
Oudemansiella 'burnt'	5	Soil	BD	Su,A,W
Oudemansiella radicata (Relhan : Fr.) Singer	3	Soil	BD	Sp,A
Peziza echinospora P. Karst.	3	Soil	A	W,Sp
Peziza repanda M.A. Rifai	4	Soil	A	A,W
Peziza tenacella W. Phillips ex Cooke	6	Soil	A	W,Sp
Phanerochaete filamentosa (Berk. & M.A. Curtis) Burds.	1	Wood	BD	A
Pholiota highlandensis (Peck) Smith & Hesler	12	Soil	BD	All year
Plicaria recurva (Berk.) Rifai	5	Soil	A	W,Sp
Polyporus melanopus (Sw. : Fr.) Fr.	7	Wood	BD	Sp,Su
Postia dissecta (Lév.) Rajchenb.	2	Wood	BD	A,W
Postia pelliculosa (Berk.) Rajchenb.	1	Wood	BD	W
Psathyrella 'conical, squamulose, spores long & narrow'	1	Soil	BD	A
Psathyrella 'ochre'	5	Soil	BD	All year
Psathyrella 'reddish brown'	15	Soil	BD	All year
Psathyrella candolleana (Fr. : Fr.) Maire	2	Soil	BD	Sp,A
Psathyrella echinata (Cleland) Grgur.	1	Wood	BD	W
Psilocybe 'bruni-islander'	1	Wood	BD	W
Psilocybe 'in moss'	2	Litter	BD	A
Psilocybe 'with awlshaped cheilocystidia'	1	Wood	BD	W
Pulvinula 'brown'	2	Soil	A	W
Pulvinula archeri (Berk.) Rifai	4	Soil	A	Sp
Pyronema omphalodes (Bull.) Fuckel	2	Soil	A	A
Ramaria 'orange'	1	Soil	BD	W
Russula neerimea Grgur.	2	Soil	BM	A
Ryvardenia campyla (Berk.) Rajchenb.	2	Wood	BD	Su,A
Stereum ochraceoflavum (Schwein.) Sacc.	2	Wood	BD	A,W
Tephrocybe 'grey-brown'	2	Soil	BD	A,W
Tephrocybe anthracophila (Lasch) P.D. Orton	4	Soil	BD	A,W
Tremella mesenterica Retz. : Fr.	1	Wood	BD	W