

Wood-decay fungi and saproxylic beetles associated with living *Eucalyptus obliqua* trees: early results from studies at the Warra LTER Site, Tasmania

A.J.M. Hopkins^{1,2*}, K.S. Harrison^{1,2}, S.J. Grove³, T.J. Wardlaw³ and C.L. Mohammed^{1,2,4}

¹CRC for Forestry, Private Bag 12, Hobart 7001

²School of Agricultural Science, University of Tasmania, Private Bag 54, Hobart 7001

³Forestry Tasmania, GPO Box 207, Hobart 7001

⁴ensis, CSIRO, Private Bag 12, Hobart 7001

*e-mail: Anna.Hopkins@ffp.csiro.au (corresponding author)

Abstract

The succession and diversity of wood-decay fungi and saproxylic beetles in living trees in Australia are poorly known but are significant factors associated with the formation of habitat features such as decayed wood and tree hollows. This paper reports on work in progress investigating the communities of wood-decay fungi and saproxylic beetles associated with living Eucalyptus obliqua trees of different ages at Warra, Tasmania. Decay columns and their associated fungi and beetles were examined in six trees in each of three age classes: 69 years, 105 years and greater than 150 years. Preliminary results show that the amount of decay, and species richness of fungi and beetles, were all much greater in mature trees (> 150 years old) compared with trees in the younger age classes. The ecological importance for fungi and beetles of tree features such as hollows and large dead branches is discussed. The results of this study will provide information which can contribute to assessing the importance of mature living trees for biodiversity and ecosystem processes in Tasmanian wet E. obliqua forests.

Introduction

Old living trees, commonly referred to as veteran, oldgrowth, mature or commercially

over-mature trees, provide diverse structural and functional components of the forest landscape (Franklin *et al.* 2002). As trees age, they develop a multitude of features, including dead tops, hollows, decayed wood, crevices, sloughed bark and large diameter branches, each with important functional roles and habitat values. Many Northern Hemisphere studies document the finding that mature trees support a large proportion of total forest biodiversity. This ranges from arboreal, hollow-dwelling mammals and birds through to more cryptic fungi, lichens, bryophytes and invertebrates (e.g. Virkkala *et al.* 1994; Hanula *et al.* 2000; Ranius and Jansson 2000; Andersen and Ryvarden 2001; Nordén and Paltto 2001; Nilsson *et al.* 2002; Zack *et al.* 2002; Heilmann-Clausen 2003; Penttilä *et al.* 2004). Many Australia studies also highlight the importance of mature trees as habitat for arboreal mammals and birds (e.g. Mackowski 1987; Lindenmayer *et al.* 1993; Abbott 1998; Whitford and Williams 2001; Gibbons and Lindenmayer 2002; Gibbons *et al.* 2002), but little is known about their importance as habitat for more cryptic organisms such as wood-decay fungi and saproxylic (dead-wood dependent) invertebrates (Speight 1989). These organisms are of particular interest not only

in their own right, but also because they may be crucial to the creation of habitat for other organisms and for nutrient and carbon cycling (Swift 1977; Hanula 1996; Heilmann-Clausen 2003).

Few studies have examined the ecology of fungal colonisation and decay of eucalypts in Australia. Those that have done so have generally been in the context of improving commercial forest management. Tamblyn (1937) found that the most common decay in mature *Eucalyptus marginata* Donn ex Sm. was a brown rot caused by *Polyporus eucalyptorum* Fr. (now *Laetiporus portentosus* (Berk.) Rajchenb.). Refshuaga (1938) described eight different types of decay and their associated fungi in mature *E. regnans* F.Muell. Wilkes (1982) described the process and patterns of decay in *E. microcorys* F.Muell., relating most fungal entry points to branch stubs, while Parkin (1942) suggested a relationship between fungal colonisation and fire. Wardlaw (2003) examined regrowth eucalypts across Tasmania and found that few trees were free of decay and that most of the decay came from branch-related origins. Despite these studies, we still do not have a good understanding of how communities of wood-decay fungi develop with tree age (Wardlaw 2003), particularly from the perspective of habitat creation.

Studies of invertebrates associated with living eucalypts have concentrated primarily on canopy-dwelling fauna, particularly on leaf-feeders and their associates (Majer *et al.* 1997), with little focus on fauna dwelling in or feeding upon woody stems. Of the small numbers of saproxylic invertebrates that have been studied on living eucalypts, most have been studied because of their role as pests or potential pests (Elliott *et al.* 1998). These include species of termite (Isoptera) (Elliott and Bashford 1984; Perry *et al.* 1985), pinhole borer and longicorn beetle (Elliott *et al.* 1998).

Many invertebrates play an important ecological role in living trees by facilitating the entry of decay organisms into the

heartwood. For example, longicorn beetles and the larvae of cossid and xyloretid moths bore into the sapwood and often the heartwood of trees, creating entry tunnels for fungi and other saproxylic beetles and termites (Simpson and Eldridge 1986). Some species, such as ambrosia beetles (Coleoptera: Curculionidae: Platypodinae and Scolytinae) are even known to be directly associated with species of wood-decay fungi. The beetles carry fungal spores, often in specialised pouches (mycangia). The fungi develop and grow on the walls of the tunnels, making the wood more palatable for the beetles (Elliott *et al.* 1998).

In Australia, termites are a major contributor to the decomposition of wood in living trees, accounting for 92% of total timber loss in *Eucalyptus pilularis* Sm. in northern New South Wales (Greaves *et al.* 1967). Termite damage is often associated with tree wounds such as fire scars or logging damage. The presence of various pioneer decay organisms can also predispose a wound for termite colonisation (Simpson and Eldridge 1986).

Two recent studies on *Eucalyptus obliqua* L'Hérit. logs at Warra, in Tasmania's southern forests, found that they were very rich in saproxylic beetle species. Yee (2005) found more than 350 beetle species associated with logs in an intermediate decay stage, while Grove and Bashford (2003) found 148 beetle species emerging from logs in the first year after felling. It remains unclear what proportion of these species begin their life cycle in the living tree, or at least also depend on living trees for maintaining local populations.

This paper presents some early results of a study investigating the ecology of wood-decay fungi and saproxylic beetles associated with mature *Eucalyptus obliqua* trees of different age classes in the wet forests of southern Tasmania, through examining the relationship between species richness and tree age. It is part of a larger research programme at Warra, one of the

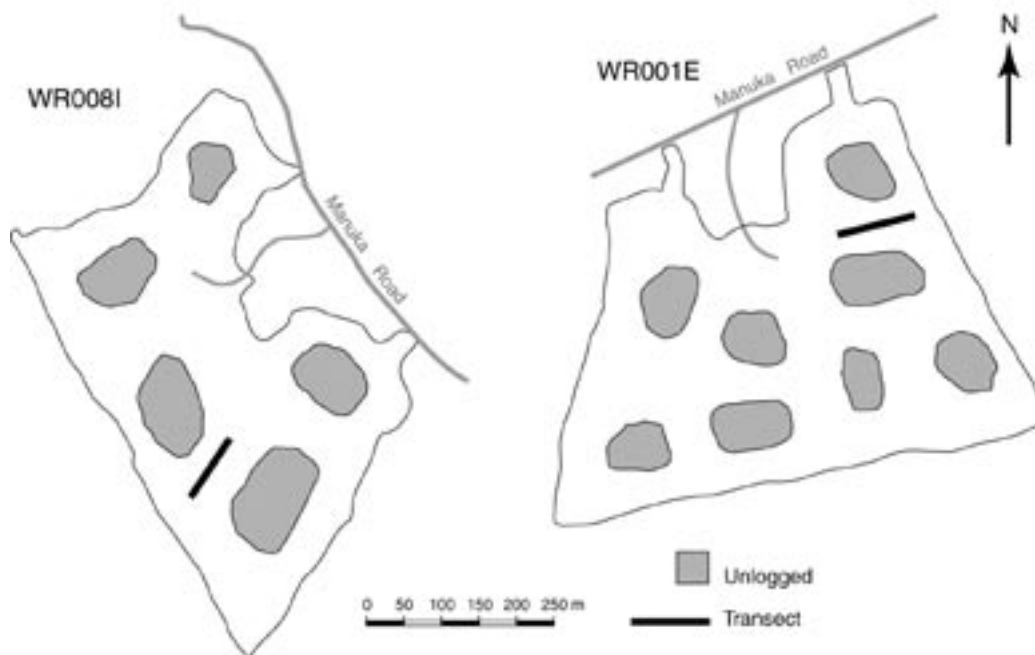


Figure 1. Location of 100 m by 10 m transects along which study trees were sampled in the aggregated retention coupes WR008I and WR001E.

aims of which is to address the paucity of data relating to the suitability and utilisation of mature living trees and coarse woody debris as habitat for these cryptic organisms. The invertebrate component of this study focussed on beetles, as they are relatively easy to identify to morphospecies, represent a range of life strategies and have been used in a number of comparable studies (Yee *et al.* 2001; Grove and Bashford 2003; Yee 2005).

Methods

Study site

This study took place at the Warra Long-Term Ecological Research Site in southern Tasmania, 60 km south-west of Hobart, in the 'aggregated retention' coupes WR008I and WR001E (Hickey *et al.* 2001). Three age classes of *Eucalyptus obliqua* trees are present at these sites. Two of these (69 years old and 105 years old) comprise trees that regenerated after the two most recent severe wildfire events in the area, in 1934 and 1898

respectively (Hickey *et al.* 1998; Alcorn *et al.* 2001). The third age class (mature trees, > 150 years old) comprises trees that were already well established at the time of the 1898 fire and survived both fire events, though their exact age is uncertain and could range from 150 to more than 350 years old (Alcorn *et al.* 2001). Trees were selected at the time of harvest (December 2002 to March 2003), along a 100 m by 10 m transect in each coupe (Figure 1). Grid references for the transects are 473785E, 5228171N (WR008I) and 474935E, 5228057N (WR001E).

Field sampling

Six *E. obliqua* trees in each age class (four trees from each age class in WR008I and two from each age class in WR001E) were selected and then examined immediately following felling by contractors. Each was assessed for structural characteristics and examined for the presence of fungi, beetles and decay. Key features of each tree were recorded, including diameter at breast height over bark (DBHOB), and the

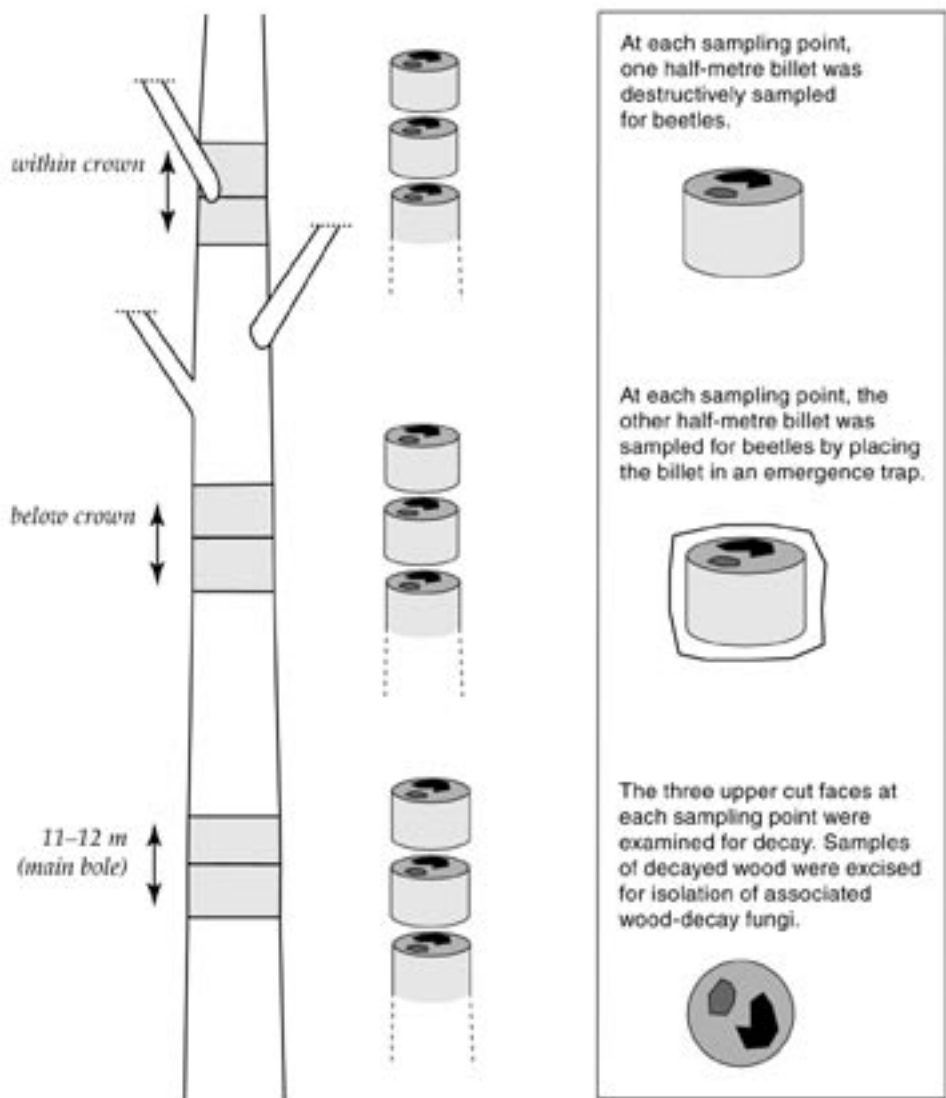


Figure 2. Method used to sample live trees. Two half-metre billets were cut from each of three standard sampling heights, producing six half-metre billets and nine upper cut faces from each tree.

presence of large dead branches, branch stubs, hollows and fire scars. This study focussed on branches greater than 5 cm diameter because of the increased potential of large dead branches as colonisation points for fungi (Wardlaw 2003). A range of other parameters was also recorded but the data are not presented here. Tree age class was confirmed by ring-counting all sample trees in the field (Leigh Edwards, pers. comm.).

The stem of each tree was then sampled at three standard points (Figure 2):

- along the main bole at 11–12 m height;
- immediately below the crown;
- within the live crown.

At each standard sampling point, two half-metre billets were cut from the stem, thus creating three upper cut faces.

Decay and fungi

The upper cut faces of each billet were photographed, and the number of patches of decay (i.e. decay columns) was counted. An indication of the amount of decay per tree was calculated by averaging the number of decay columns recorded on each of the nine upper cut faces per tree. A sample of decayed wood from each decay column was taken back to the laboratory, surface sterilised for two minutes in 2.5% bleach, and incubated on a specialised fungal medium (Appendix 1) to isolate associated wood-decay fungi. Control samples of clear heartwood and sapwood from each billet were also incubated on fungal media.

Fungal cultures were identified to morphospecies using traditional morphological taxonomy (Stalpers 1978; Nakasone 1990). For more information on the morphological techniques see Hopkins *et al.* (2005). Concurrent with this study, a reference collection of 130 identified fungal cultures was created by isolation from identified fungal sporocarps collected from woody substrates (e.g. logs, fallen branches, standing trees) in the vicinity of the study site (Gates *et al.* 2005).

Beetles

At each standard sampling point, one half-metre billet was destructively sampled for beetles by intensively searching and hand collecting the beetles within the billet, following techniques developed and adopted locally by Yee *et al.* (2001). The other billet was used to sample insects emerging over subsequent months. Bark was separated from the rest of the stem and each billet was placed in a separate emergence trap made of strong, fine (≤ 1 mm) mesh (Photo 1). Each trap was fitted with two collecting heads containing jars of diluted ethylene glycol (50–70%). One collecting head was positioned above the top of the billet to collect beetles attracted to light, and the other was placed

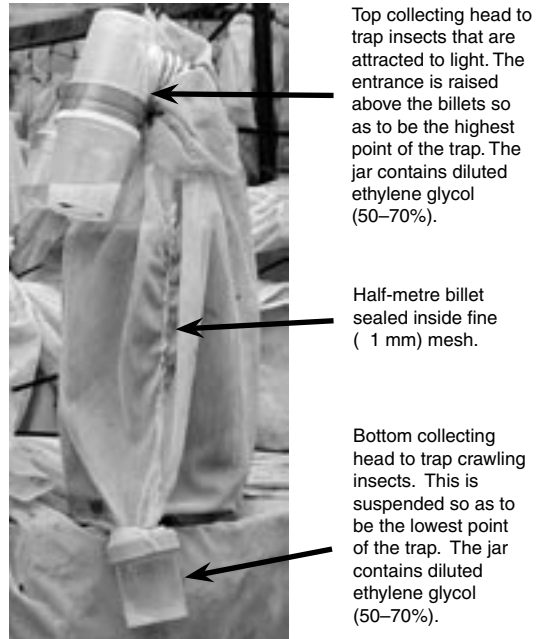


Photo 1. Half-metre wood billet in the emergence trap, showing top and bottom collecting heads.

at the bottom to catch crawling beetles (Bashford *et al.* 2001). Beetle emergence was monitored over a period of 18 months, with collecting jars changed monthly in summer and every third month in winter. All beetles were sorted, pinned and identified to morphospecies by comparison with the Tasmanian Forest Insect Collection (TFIC: Forestry Tasmania, Hobart). At the conclusion of the study, specimens will be lodged with the TFIC. Only data from the stem emergence traps are presented in this paper as processing of the hand collection samples has not yet been completed.

Statistical analysis

For the purposes of this study, one-way analyses of variance (ANOVA) were undertaken in SAS 9.1 (Anon. 2002), using age class as a random effect on either decay or fungal or beetle morphospecies richness. Species richness data were pooled from all three tree sections for each tree. A multiple comparison test (Ryan-Einot-Gabriel-Welsch Multiple Range Test: REGW test) was used to determine the nature of the differences.

Table 1. Selected architectural features of all trees measured in each age class (mean \pm standard error). Only decay column was analysed by ANOVA; letters a and b represent significantly different means from ANOVA ($P < 0.001$).

Tree code	Age class	DBHOB (cm)	Number of hollows	Fire scar area (m ²)	Number of large dead branches (> 5 cm diameter)	Mean number of decay columns per upper cut face ($n = 9$)
T41	69	24	0	0	0	0.9
T9		29	0	0	0	0.3
T25		29	0	0	0	0.8
T43		30	0	0	0	0.7
T24		31	0	0	0	2.2
T7		41	0	0	0	0.3
Mean			30.6 \pm 2.3	0	0	0
T10	105	43	0	0	4	0.4
T30		43	0	0	5	0.1
T2		64	0	0	0	0
T40		64	0	0	0	0.9
T42		64	0	0	0	1.2
T3		76	0	0	0	0
Mean			59.0 \pm 5.4	0	0	1.5 \pm 1.0
T6	> 150	73	0	0.40	5	5.6
T4		95	0	1.81	3	5.6
T44		96	0	0.47	2	7.2
T5		99	1	0.26	10	7.2
T45		99	2	1.16	6	5.3
T21		111	0	2.54	2	5.8
Mean			95.5 \pm 5.1	0.5 \pm 0.3	1.1 \pm 0.4	4.7 \pm 1.3

Results

Tree features

Tree diameter was related to tree age but with much variation (Table 1). Young trees (69 years old) ranged in diameter from 24–41 cm, 105-year-old trees ranged from 43–76 cm diameter, and trees greater than 150 years old ranged from 73–111 cm in diameter. Stem hollows were only found in two trees (T5 and T45), both of which were greater than 150 years old. Large areas of fire scars were found on the main bole of six trees, all of which were greater than 150 years old. Large diameter dead branches (> 5 cm in diameter) were found on all trees greater than 150 years old. Two 105-year-old trees (T10 and T30) also had large diameter dead branches, but none was present on the 69-year-old trees.

Decayed wood

Trees older than 150 years had significantly more decay columns than 69- and 105-year-old trees ($P < 0.001$, Table 1). The 69- and 105-year-old trees averaged less than one decay column per tree, with many having no decay columns at all (Table 1). In contrast, trees greater than 150 years old averaged 6.1 decay columns per tree, ranging from 5.5 to 7.2 decay columns per tree. All observed decay was confined to the heartwood.

Fungi

More than 600 samples of wood were collected, comprising over 300 samples of decayed wood and 324 samples of clear heartwood and sapwood. These samples together yielded more than 350 isolates of basidiomycete or ascomycete wood-decay

fungi. Isolates were considered to be wood-decay fungi if they responded positively to diagnostic enzyme tests (see Stalpers 1978) or if they displayed any characteristic basidiomycete or ascomycete features in culture. These cultural features included clamp connections, setae, chlamydospores and skeletal or binding hyphae, or the production of appropriate sporocarp structures (Stalpers 1978). From more than 350 isolates, 16 morphospecies were identified that occurred more than once, along with 170 morphospecies which occurred only in one sample. Details of these morphospecies can be found in Hopkins *et al.* (2005). No matches for any of these were found amongst the reference cultures isolated from identified basidiomycete sporocarps. Significantly more morphospecies of fungi were found in trees older than 150 years, compared with either of the younger age classes ($P < 0.001$, Figure 3) both in terms of mean number of morphospecies per tree (19) and total number of morphospecies (80) in the tree age classes. Numbers of morphospecies found in the 69- and 105-year-old age classes did not differ significantly.

Beetles

A total of 1477 beetles, attributable to 80 morphospecies (Appendix 2), was collected from the emergence traps. The number of beetles increased with increasing tree age, and significantly more morphospecies were found in trees older than 150 years compared with trees in either of the younger age classes ($P < 0.001$, Figure 3). Fifty-six beetle morphospecies were found in the older trees (> 150 years), while only 26 and 28 morphospecies of beetles were found in the 69- and 105-year-old trees respectively.

Discussion

This study is the first to examine systematically the wood-decay fungi and saproxylic beetles present in an age sequence of living *Eucalyptus obliqua* trees. While the data reported here are preliminary, in terms

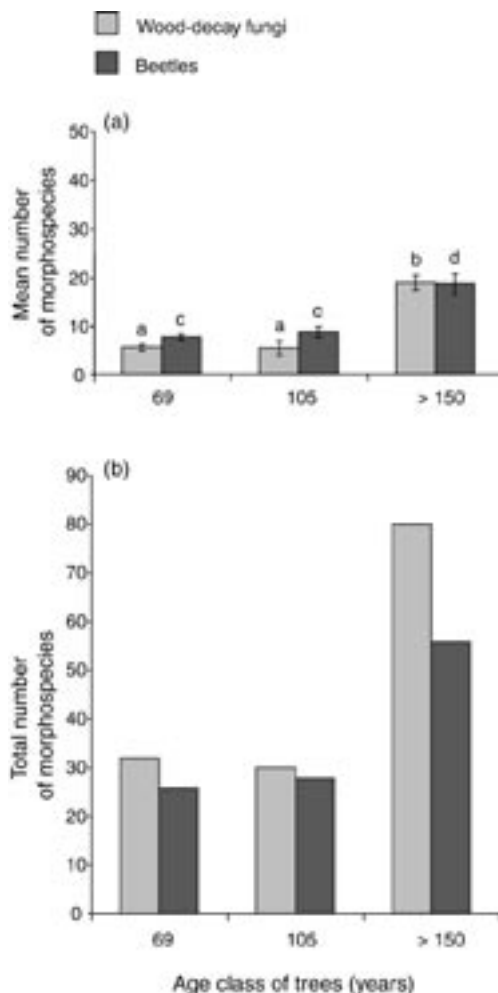


Figure 3. (a) Mean number of morphospecies of wood-decay fungi and beetles per tree in each tree age class. Error bars show standard error, with letters a, b, c and d representing significantly different means from ANOVA. (b) Total number of morphospecies of wood-decay fungi and beetles in each tree age class.

of sample size, taxonomic resolution and statistical analysis, some clear patterns are present. The number of decay columns per upper cut face and species richness of fungi and beetles were all much greater in the more mature trees compared with trees in either of the younger age classes. Given the intensive sampling methods used in this study, it is unrealistic to compare the species richness of beetles and wood-decay fungi found here with previous

studies on eucalypts in Australia. For instance, Tamblin (1937) identified only three species of wood-decay fungi from decay and sporocarps associated with 12 mature *E. marginata* trees, while Refshauge (1938) described eight different species of fungi causing decay in *E. regnans*. These differences give an indication of the advantages of intensive sampling (as in the present study) if the aim is to assess species richness in this habitat.

The comparatively high species richness of fungi and beetles in the mature trees (older than 150 years) may be related to a greater number of colonisation entry points in older trees. In this study, large dead branches and fire scars were predominantly found in the mature trees. It is probable that the presence of these features increased the opportunities for colonisation in the trees, creating more chances for fungal and beetle colonisation within the stem. Other tree features such as hollows and dead or broken tops (data not shown here) were also more common in the mature trees and may also have acted as colonisation pathways. Bar-Ness (2005) found similar patterns of features in *E. obliqua*, with stem hollows, fire scars and dead tops restricted to trees greater than 150 years old. Both large diameter branches and fire scars have been demonstrated as potential colonisation points for wood-decay fungi and invertebrates in eucalypts (Tamblin 1937; Parkin 1942; Perry *et al.* 1985; Marks *et al.* 1986; Simpson and Eldridge 1986; Wardlaw 1996; Wardlaw and Neilsen 1999) and other hardwoods (e.g. Basham 1958, 1991; Boddy 2001). For example, Wardlaw (2003) found that almost 85% of fungal decay in young regrowth eucalypts in Tasmania was associated with dead branches and poorly occluded branch stubs, a factor which increased when branches were larger than 2.8 cm in diameter. In addition, large diameter branch stubs can be associated with colonisation by wood-boring insects, providing a pathway to the central heartwood (Wardlaw 1996). Fire scars are also considered to be important for fungal colonisation (Parkin 1942), and may provide

good colonisation points for wood-boring beetles (Simpson and Eldridge 1986).

A second possibility for greater species richness in the mature trees in the present study is that the boles of the mature trees were generally of a larger diameter than the 69- and 105-year-old trees, and had therefore received a larger sampling effort. While this discrepancy in sampling effort will be the subject of further analysis, the greater surface area and volume of wood of the larger diameter trees also meant there was more wood available for fungal and beetle colonisation. This might reduce the chances of competition among colonisers, resulting in a greater number of successful colonisation events. In a study in north-eastern Queensland, Grove (2002) considered that local tree basal area (a parameter correlated with stem diameter of component trees) was a good correlate of saproxylic beetle species richness.

A third possibility is that older trees would have had a greater time period over which colonisation could occur, again increasing the chances of a successful colonisation event. Taken together, these factors may account for the greater number of fungi and beetles in mature trees.

One of the questions raised by this work is whether wood-decay fungi and saproxylic beetle species richness in living *E. obliqua* increases steadily and progressively with age or diameter increase, or whether there is a sudden onset of colonisation, perhaps in response to some extrinsic event (e.g. fire). There is not enough information on the age of trees in the present study to determine whether or not decay increases gradually with age. However, other studies have found a threshold age at which decay rapidly increases. Basham (1991) reviewed the decay/age relationships in a number of hardwoods in Ontario. In addition to a general increase in decay volume with age class, he noted that a rapid increase in decay often occurred once some threshold age was reached. Stem decay in basswood

(*Tilia americana* L.: Tiliaceae), for example, increased significantly from 2.8% at 101–120 years old to 15.6% at 121–140 years old. Similarly, black ash (*Fraxinus nigra* Marsh.: Oleaceae) jumped from 2.3% decay at 101–120 years old to 14.9% decay at 121–140 years old. In contrast, the more decay-prone species trembling aspen (*Populus tremuloides* Michx.: Salicaceae) showed a gradual increase in decay with age. In all three cases, the change in the amount of decay was not related to a particular disturbance event, but rather to an increase in the number of stem wounds and large diameter branches with tree age. These findings are reinforced by the work on grand fir (*Abies grandis* Dougl. ex D. Don: Pinaceae) by Aho (1977), who found a strong correlation between age and the amount of decay resulting from large branches, wounds and fire scars.

Within-site variation is also an important factor when considering amount of decay and fungal and beetle species richness. Wardlaw (2003) examined over a thousand 20–30-year-old regrowth eucalypts across Tasmania. Only 7% of the trees were free of decay, and 20% of them had decay in 5% or more of the stem. These proportions are similar to those found in the 69- and 105-year-old trees in the present study. Wardlaw (2003) considered that site-to-site variation accounted for only 17% of the total variation in amount of decay, while within-site (or tree-to-tree) variation accounted for most differences in amount of stem decay. Interestingly, the 69-year-old trees in the present study harboured a considerable amount of decay and number of wood-decay fungal species relative to the 105-year-old trees and to the trees studied by Wardlaw (2003). It is possible that, in the mixed-age forest sampled in the present study, the growth of these younger trees was suppressed by the surrounding older, dominant trees, making them more susceptible to decay. This idea is reinforced by relative tree height: all 69-year-old trees were much shorter than trees in the other two age classes (data not shown). In addition, their canopy was much less

developed, in that they had much lower numbers of branches (data not shown).

It is surprising that no matches were found between the 186 fungal morphospecies isolated from decayed wood and the 130 species in the reference cultures developed from identified basidiomycete sporocarps. This may be partly because many of the fungi isolated from decayed wood which have been identified to morphospecies have corticioid (sheet or paint-like) sporocarps. These are usually relatively cryptic and so may not have been collected and identified for the reference collection, which focussed primarily on polypores and mushroom-like sporocarps. The lack of matches may also simply be a result of the enormous diversity of fungi in the forest ecosystem. Although the reference collection contained 130 species, there are likely to be many more species of wood-decay fungi present in the southern forests of Tasmania (see Gates *et al.* 2005). In a study in other wet eucalypt forests in southern Tasmania, Packham *et al.* (2002) found 242 species of macrofungi, although not all of these were wood-decay fungi.

This study provides a link between the living tree and the log habitat examined in several other studies of invertebrates and wood-decay fungi in *Eucalyptus obliqua* trees in the Warra area. Bar-Ness (2005) also found mature trees (> 150 years old) and regrowth trees to be very species-rich in invertebrates. He compared the canopy arthropod fauna of mature and 100-year-old regrowth *E. obliqua* trees at Warra. Although the total number of arthropod morphospecies differed little between mature trees (233) and 100-year-old regrowth trees (226), the five most common taxa were more abundant in mature trees. One-third of all morphospecies collected were beetles. Yee (2005) found that large diameter logs contained specific decay types and beetle assemblages that were not present in small diameter logs. She surmised that the decay and saproxylic beetle assemblages in these large diameter

logs began to develop prior to tree fall. Small logs, on the other hand, contained no unique decay types and probably only developed decay subsequent to tree fall.

Future research directions

This preliminary study indicates the importance of mature trees as habitat for wood-decay fungi and saproxylic beetles, particularly in comparison with smaller diameter living trees. Future analyses will investigate successional relationships in wood-decay fungi and saproxylic beetle assemblages among all three age classes. Interactions among wood-decay fungi, beetle species and decayed wood will also be examined. Findings will also be compared to those of recently completed studies examining the fungal and beetle communities associated with decaying *Eucalyptus obliqua* logs (Yee *et al.* 2001; Grove and Bashford 2003; Yee 2005) and living trees (Bar-Ness 2005) at Warra. Together these studies will help to further understand the process of stem decay and habitat formation in Tasmania's wet eucalypt forests, particularly as it relates to the ecological importance of oldgrowth

features such as large logs and mature trees in the production forest landscape.

Acknowledgements

Genevieve Gates and David Ratkowsky (University of Tasmania) collected and identified the fungal sporocarps for the reference cultures. Jack Simpson (State Forests New South Wales) assisted in the identification of fungal cultures. Leigh Edwards (Forestry Tasmania) assisted with tree-ring counting, and Gerald Coombe (Forestry Tasmania) prepared Figure 1. K-Mac contractors arranged their logging schedule around the selection and felling of study trees. Malcolm Hall, Jill Butterworth, James Darmody and Danielle Wiseman helped with field sampling. The authors thank two anonymous reviewers for helpful comments on previous versions of this paper.

This study was supported by an Australian Postgraduate Award and grants from the CRC for Sustainable Production Forestry, Forestry Tasmania, and the Holsworth Wildlife Research Fund.

References

- Abbott, I. (1998). Conservation of the forest red-tailed black cockatoo, a hollow dependent species, in the eucalypt forests of Western Australia. *Forest Ecology and Management* 109: 175–185.
- Aho, P.E. (1977). Decay of grand fir in the Blue Mountains of Oregon and Washington. PNW-229. Pacific Northwest Forest and Range Experiment Station, USDA Forest Service.
- Alcorn, P.J., Dingle, J.K. and Hickey, J.E. (2001). Age and stand structure in a multi-aged wet eucalypt forest at the Warra silvicultural systems trial. *Tasforests* 13 (2): 245–259.
- Andersen, H. and Ryvarden, L. (2001). Wood inhabiting fungi on *Populus tremula*. *Windahlia* 24: 37–48.
- Anon. (2002). SAS (r) Proprietary Software Version 9.1. SAS Institute Inc., Cary, NC, USA.
- Bar-Ness, Y. (2005). Crown structure and the canopy arthropod biodiversity of 100 year old and old-growth Tasmanian *Eucalyptus obliqua*. Masters thesis, School of Geography and Environmental Studies, University of Tasmania, Hobart.
- Basham, J.T. (1958). Decay of trembling aspen. *Canadian Journal of Botany* 36: 491–505.
- Basham, J.T. (1991). Stem decay in living trees in Ontario's forests: a user's compendium and guide. Information Report O-X-408. Great Lakes Forestry Centre, Forestry Canada, Sault Ste. Marie, Ontario.
- Bashford, R., Taylor, R., Driessen, M., Doran, N. and Richardson, A. (2001). Research on invertebrate assemblages at the Warra LTER Site. *Tasforests* 13 (1): 109–118.
- Boddy, L. (2001). Fungal community ecology and wood decomposition processes in angiosperms: from standing tree to complete decay of coarse woody debris. *Ecological Bulletins* 49: 43–56.

- Elliott, H.J. and Bashford, R. (1984). Incidence and effects of the dampwood termite, *Porotermes adamsoni*, in two Tasmanian east coast eucalypt forests. *Australian Forestry* 47 (1): 11–15.
- Elliott, H.J., Ohmart, C.P. and Wylie, F.R. (1998). *Insect Pests of Australian Forests: Ecology and Management*. Inkata Press, Melbourne.
- Franklin, J.F., Spies, T.A., Van Pelt, R., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C., Bible, K. and Chen, J. (2002). Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. *Forest Ecology and Management* 155: 399–423.
- Gates, G.M., Ratkowsky, D.A. and Grove, S.J. (2005). A comparison of macrofungi in young silvicultural regeneration and mature forest at the Warra LTER Site in the southern forests of Tasmania. *Tasforests* 16: 127–152.
- Gibbons, P. and Lindenmayer, D. (2002). *Tree Hollows and Wildlife Conservation in Australia*. CSIRO Publishing, Collingwood, Victoria.
- Gibbons, P., Lindenmayer, D.B., Barry, S.C. and Tanton, M.T. (2002). Hollow selection by vertebrate fauna in forests of southeastern Australia and implications for forest management. *Biological Conservation* 103: 1–12.
- Greaves, T., Armstrong, G.J., McInnes, R.S. and Dowse, J.E. (1967). Timber losses caused by termites, decay and fire in two coastal forests in New South Wales. Technical Paper No. 7. CSIRO Division of Entomology, Canberra.
- Grove, S.J. (2002). Tree basal area and dead wood as surrogate indicators of saproxylic insect faunal integrity: a case study from the Australian lowland tropics. *Ecological Indicators* 1: 171–188.
- Grove, S.J. and Bashford, R. (2003). Beetle assemblages from the Warra log-decay project: insights from the first year of sampling. *Tasforests* 14: 117–129.
- Hanula, J.L. (1996). Relationship of wood-feeding insects and coarse woody debris. In: *Coarse Woody Debris in Southern Forests: Effects on Biodiversity* (eds J.W. McMinn and D.A. Crossley), pp. 55–81. USDA Forest Service, Athens, GA.
- Hanula, J.L., Franszreb, K.E. and Pepper, W.D. (2000). Longleaf pine characteristics associated with arthropods available for red-cockaded woodpeckers. *Journal of Wildlife Management* 64: 60–70.
- Heilmann-Clausen, J. (2003). Wood-inhabiting fungi in Danish deciduous forests - diversity, habitat preferences and conservation. Ph.D. thesis, Department of Economics and Natural Resources, The Royal Veterinary and Agricultural University, Frederiksberg, Denmark.
- 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 (2): 155–182.
- Hickey, J.E., Su, W., Rowe, P., Brown, M.J. and Edwards, L. (1998). Fire history of the tall wet eucalypt forests of the Warra ecological research site, Tasmania. *Australian Forestry* 62 (1): 66–71.
- Hopkins, A.J.M., Simpson, J.A., Grove, S.J., Wardlaw, T.J. and Mohammed, C.L. (2005). How to identify wood decay fungi in culture. I. Morphological descriptions of fungi from living *Eucalyptus obliqua*. Technical Report No. 161. CRC for Forestry, Hobart, Tasmania.
- Lindenmayer, D.B., Cunningham, R.B., Donnelly, C.F., Tanton, M.T. and Nix, H.A. (1993). The abundance and development of cavities in *Eucalyptus* trees: a case study in the montane forests of Victoria, southeastern Australia. *Forest Ecology and Management* 60: 77–104.
- Mackowski, C.M. (1987). Wildlife hollows and timber management in blackbutt forests. Masters of Natural Resource Management, The University of New England, Armidale, New South Wales.
- Majer, J.D., Recher, H.F., Wellington, A.B., Woinarski, J.C.Z. and Yen, A.L. (1997). Invertebrates of eucalypt formations. In: *Eucalypt Ecology: Individuals to Ecosystems* (eds J. Williams and J. Woinarski), pp. 278–302. Cambridge University Press, Cambridge.
- Marks, G.C., Incoll, W.D. and Long, I.R. (1986). Effects of crown development, branch shed and competition on wood defect in *Eucalyptus regnans* and *E. sieberi*. *Australian Forest Research* 16 (2): 117–129.
- Nakasone, K.K. (1990). Cultural studies and identification of wood-inhabiting Corticiaceae and selected Hymenomycetes from North America. *Mycologia Memoir* 15. J. Cramer, Berlin.
- Nilsson, S.G., Niklasson, M., Hedin, J., Aronsson, G., Gutowski, J.M., Linder, P., Ljungberg, H., Mikusinski, G. and Ranius, T. (2002). Densities of large living and dead trees in old-growth temperate and boreal forests. *Forest Ecology and Management* 161: 189–204.
- Nordén, B. and Paltto, H. (2001). Wood-decay fungi in hazel wood: species richness correlated to stand age and dead wood features. *Biological Conservation* 101: 1–8.

- 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.
- Parkin, G. (1942). Fungi associated with typical truewood decays observed in Victorian forest trees. *Australian Forestry* 6: 82–86.
- Penttilä, R., Siitonen, J. and Kuusinen, M. (2004). Polypore diversity in managed and old-growth boreal *Picea abies* forests in southern Finland. *Biological Conservation* 117: 271–283.
- Perry, D.H., Lenz, M. and Watson, J.A.L. (1985). Relationships between fire, fungal rots and termite damage in Australian forest trees. *Australian Forestry* 48 (1): 46–53.
- Ranius, T. and Jansson, N. (2000). The influence of forest regrowth, original canopy cover and tree size on saproxylic beetles associated with old oaks. *Biological Conservation* 95: 85–94.
- Refshauge, L.D. (1938). Types of decay occurring in mature and young *Eucalyptus regnans* (Mountain Ash) as observed during a preliminary observation. *Victorian Forester* 2 (3): 24–28.
- Simpson, J.A. and Eldridge, R.H. (1986). Agents of change: fungal decay and insect degradation of wood in living trees. *Forest and Timber* 22: 19–22.
- Speight, M.C.D. (1989). *Saproxylic Invertebrates and their Conservation*. Council of Europe, Strasbourg, France.
- Stalpers, J.A. (1978). *Identification of Wood-Inhabiting Aphyllophorales in Pure Culture*. Studies in Mycology 16. Institute of the Royal Netherlands Academy of Arts and Sciences, Amsterdam.
- Swift, M.J. (1977). The ecology of wood decomposition. *Scientific Progress, Oxford* 64: 175–199.
- Tamblyn, N. (1937). Decay in timber with special reference to jarrah (*Eucalyptus marginata* Sm.). *Australian Forestry* 2 (1): 6–13.
- Virkkala, R., Rajasarkka, A., Vaisanen, R.A., Vickholm, M. and Virolainen, E. (1994). Conservation value of nature reserves: do hole-nesting birds prefer protected forests in southern Finland? *Annales Zoologici Fennici* 31: 173–186.
- Wardlaw, T.J. (1996). The origin and extent of discolouration and decay in stems of young regrowth eucalypts in southern Tasmania. *Canadian Journal of Forest Research* 26: 1–8.
- Wardlaw, T.J. (2003). The extent, impact and management of stem decay in young regrowth eucalypt forests scheduled for thinning in Tasmania. Ph.D. thesis, School of Agricultural Science, University of Tasmania, Hobart.
- Wardlaw, T.J. and Neilsen, W.A. (1999). Decay and other defects associated with pruned branches of *Eucalyptus nitens*. *Tasforests* 11: 49–57.
- Whitford, K.R. and Williams, M.R. (2001). Survival of jarrah (*Eucalyptus marginata* Sm.) and marri (*Corymbia calophylla* Lindl.) habitat trees retained after logging. *Forest Ecology and Management* 146: 181–197.
- Wilkes, J. (1982). Pattern and process of heartrot in *Eucalyptus microcorys*. *Australian Forestry* 45 (1): 51–56.
- Yee, M. (2005). The ecology and habitat requirements of saproxylic beetles native to Tasmanian wet eucalypt forests: potential impacts of commercial forestry practices. Ph.D. thesis, School of Agricultural Science, University of Tasmania, Hobart.
- Yee, M., Yuan, Z.-Q. and Mohammed, C. (2001). Not just waste wood: decaying logs as key habitats in Tasmania's wet sclerophyll *Eucalyptus obliqua* production forests: the ecology of large and small logs compared. *Tasforests* 13 (1): 119–128.
- Zack, S., George, T.L. and Laudenslayer, W.F.J. (2002). Are there snags in the system? Comparing cavity use among nesting birds in 'Snag-rich' and 'Snag-poor' eastside pine forests. USDA Forest Service General Technical Report, Albany, C.A.

1% Malt agar with thiabendazole; to make 1 L

Ingredients: 10 g malt extract
15 g powdered agar
50 mg penicillin
50 mg streptomycin sulphate
25 mg polymixin
1 mL thiabendazole solution

The thiabendazole solution is made by dissolving 23 g in 100 mL of lactic acid.

Methods: Add malt extract and agar to 960 mL distilled water. Autoclave at 121°C for 15 minutes. Dissolve remaining ingredients in 40 mL sterilised distilled water. Add to malt agar while it is cooling (at about 60°C). Dispense into plates as required.

Appendix 2. Provisional taxonomic listing of beetle morphospecies collected from stem emergence trapping at Warra, showing presence (x) or absence in each tree age class.

Species	Tree age class		
	69	105	> 150
Carabidae			
<i>Trechimorphus diemenensis</i> (Bates, 1878)	x	x	x
<i>Mecyclothorax ambiguus</i> Erichson, 1842		x	x
Ptiliidae			
Ptiliidae TFIC sp 01	x	x	x
Ptiliidae TFIC sp 04		x	x
Leiodidae			
<i>Nargomorphus</i> TFIC sp 02		x	
<i>Nargomorphus</i> TFIC sp 03	x	x	x
Scydmaenidae			
Scydmaenidae TFIC sp 04			x
Scydmaenidae TFIC sp 06			x
Staphylinidae			
<i>Aleocharinae</i> TFIC sp 02	x		
<i>Aleocharinae</i> TFIC sp 07	x	x	x
<i>Aleocharinae</i> TFIC sp 10	x		x
<i>Aleocharinae</i> TFIC sp 13	x	x	x
<i>Aleocharinae</i> TFIC sp 14	x	x	
<i>Aleocharinae</i> TFIC sp 31	x		
<i>Baeocera</i> TFIC sp 01			x
<i>Falagria</i> TFIC sp 01	x	x	x
<i>Falagria</i> TFIC sp 04			x
<i>Macrodicax</i> TFIC sp 01			x
<i>Quedius sidneensis</i> Fauvel			x
<i>Sepedophilus</i> TFIC sp 01		x	x
Staphylinidae KH sp 01			x
Staphylinidae KH sp 06	x		
Staphylinidae KH sp 10			x
Staphylinidae KH sp 14		x	
Staphylinidae KH sp 15	x		
Staphylininae TFIC sp 03			x
Staphylininae TFIC sp 05	x		
Staphylininae TFIC sp 08			x
Scarabaeidae			
<i>Heteronyx pilosellus</i> Blanchard, 1850			x
Clambidae			
<i>Clambus bornemisszai</i> Endrody-Younga, 1990	x	x	x
<i>Sphaerotherax tasmani</i> (Blackburn, 1902)		x	x
Scirtidae			
<i>Prionocyphon?</i> TFIC sp 01		x	x
<i>Pseudomicrocara</i> TFIC sp 02		x	
Throscidae			
<i>Aulonothroscus elongatus</i> (Bonvouloir, 1859)			x
Elateridae			
<i>Augenotus quadriguttatus</i> (Erichson, 1842)			x
Elateridae TFIC sp 05			x
Cantharidae			
<i>Heteromastix nigripes</i> Lea, 1909			x
Cleridae			
<i>Lemidia subaenea</i> Gorham, 1877			x

Species	Tree age class		
	69	105	> 150
Nitidulidae			
<i>Brachypeplus planus</i> Erichson, 1842	x	x	x
<i>Epuraea victoriensis</i> (Blackburn, 1891)	x	x	x
Phloeostichidae			
<i>Hymaea succinifera</i> Pascoe	x	x	x
<i>Myrabolia grouvelliana</i> Reitter			x
Silvanidae			
<i>Cryptamorpha</i> TFIC sp 01	x		x
<i>Uleiota australis</i> Erichson, 1842	x		
Phalacridae			
Phalacridae TFIC sp 01			x
Cryptophagidae			
Cryptophagidae KH sp 01	x	x	x
<i>Cryptophagus gibbipennis</i> Blackburn, 1892	x		x
<i>Cryptophagus tasmanicus</i> Blackburn, 1907			x
Cerylonidae			
<i>Philothermus tasmanicus</i> Slipinski, 1988	x	x	x
Corylophidae			
<i>Holopsis</i> TFIC sp 04		x	
<i>Sericoderus</i> TFIC sp 05	x	x	x
<i>Sericoderus</i> TFIC sp 06		x	
Latridiidae			
<i>Aridius costatus</i> (Erichson, 1842)		x	x
<i>Aridius nodifer</i> (Westwood, 1838)	x	x	x
<i>Bicava verrucifera</i> Rucker	x		
<i>Corticicara</i> TFIC sp 02		x	x
Zopheridae			
<i>Enhypon tuberculatus</i>			x
<i>Pycnomerus</i> TFIC sp 02			x
Prostomidae			
<i>Prostomis atkinsoni</i> Waterhouse, 1877			x
Oedemeridae			
<i>Asclera sublineata</i> Waterhouse			x
<i>Dohrnia miranda</i> Newman			x
Oedemeridae KH sp 01			x
Aderidae			
Aderidae KH sp 01			x
Scraptiidae			
<i>Scraptia laticollis</i> Champion		x	
Chrysomelidae			
<i>Altica pagana</i> Blackburn, 1896			x
Curculionidae			
<i>Cossonus</i> KH sp 01	x		
Curculionidae KH sp 02			x
<i>Exithius capucinus</i> Pascoe			x
<i>Platypus subgranosus</i> (Schedl)			x
<i>Prostomus murinus</i> (Lea)			x
<i>Tyrtaeosus ustulatus</i> Pascoe			x

