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Fumigation of regrowth karri stumps with metham-sodium to control *Armillaria luteobubalina*

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Summary

The use of metham-sodium as a possible control agent for armillaria root disease was studied on 13-year-old karri (*Eucalyptus diversicolor*) regrowth stumps. As a consequence its effect on colonisation by wood decay organisms was also examined. *Armillaria luteobubalina*-infected stumps, with volumes of about 2000 cm^3 (11-12 cm diam.) and 8000 cm^3 (21.5-23.5 cm diam), were treated with 500 ml of metham-sodium and examined after 3½ years. Control stumps with volumes of about 4000 cm^3 (16-17 cm diam.) were not treated. Compared to untreated stumps, the volume of uncolonised wood and advanced decay was significantly greater in metham-sodium treated stumps. The volume of stump colonised by *A. luteobubalina* was lower in metham-sodium treated stumps than in untreated stumps. In stumps with a volume of 2000 cm^3, treatment with metham-sodium eliminated *A. luteobubalina* from 40% of the stumps and enhanced colonisation by white rot organisms, including an unknown species which colonised 45%-60% of the volume of the stumps in which it occurred. The use of fumigants to control armillaria root disease in regrowth forests is, however, very labour intensive and costly, and it creates health and safety issues for the operator. It is considered not to be a practical option.

Keywords: plant disease control, plant pathogens, fungi, stumps, fumigation, metham-sodium, *Armillaria*, *Eucalyptus diversicolor*

Introduction

Armillaria luteobubalina Watling & Kile is an endemic pathogen of native forests in the south-west of Western Australia. It causes armillaria root disease (ARD) and is associated with deaths of karri (*Eucalyptus diversicolor* F. Muell.), wandoo (*E. wandoo* Blakely), jarrah (*E. marginata* Donn ex. Sm.), non-native eucalypts planted on mine-sites and in plantations, and plant communities in the coastal dune system (Pearce *et al.* 1986; Shearer and Tippett 1988; Shearer 1995; Shearer *et al.* 1997a,b). *A. luteobubalina* spreads below ground from host to host by mycelial spread at root contact points (Podger *et al.* 1978; Pearce *et al.* 1986; Shearer 1995). In the south-west karri forests, ARD is widespread in both mature and regrowth forests (Robinson and Rayner 1998), where it causes basal lesions which may eventually girdle and kill trees of all ages. Alternatively, sufficient roots may be killed to reduce growth rate and increase the probability of wind throw (Pearce 1989). The spread of ARD in newly established regrowth forests has been associated with infected stumps left following logging (Pearce *et al.* 1986; Kellas *et al.* 1987). *A. luteobubalina* can rapidly invade the root systems of fresh stumps and persist saprophytically on *E. obliqua* L'Hérit. stumps, 60-110 cm diameter, for 25 years or more (Kile 1981).

The most effective way of reducing the expansion of *Armillaria* from existing foci is by reducing or eliminating the colonisation of stumps of recently felled trees (Hagle and Shaw 1991). Operationally, this may be achieved by stump removal or whole-tree harvesting. Alternatively, infected stumps can be treated with a chemical or a fumigant. The application of 40% ammonium sulphamate, a chemical herbicide, to the surface of freshly cut hardwood stumps controls coppice development and can favour colonisation by some species of wood decay fungi which have the ability to compete with *A. mellea sensu lato* (Rishbeth 1976). Greig (1990) reported that metham-sodium is a relatively safe and effective treatment to prevent colonisation of conifer stumps by several species of *Armillaria*. Metham-sodium is an aqueous soil fumigant used as a biocide against weeds, weed seeds, fungi, nematodes and soil insects (Windholz 1983). In dry aerated soils it rapidly decomposes to form methyl isothiocyanate which is fungitoxic (Turner and Corden 1963). In southern Australian eucalypt forests, maximum efficacy is likely to be achieved when metham-sodium is applied in the late summer.

A trial was conducted in 13-year-old karri regrowth forest to test the efficacy of metham-sodium as a potential control measure for ARD.

Methods

Study site and tree selection

The trial was established in 1979 regrowth karri forest at Lawson Road, in Warren Forest Block, about 11 km south-west of Pemberton (lat. 34°310'26"S, long. 115°57'06"E). The stand consisted of karri, which was planted following harvesting in 1978, and a small number of naturally regenerated marri (*Corymbia calophylla* (Lindl.) K.D. Hill and L.A.S. Johnson). Infected karri trees were identified by the presence of symptoms such as inverted V-shaped lesions and/or mycelial fans under the bark or *A. luteobubalina* fruitbodies at the base of trees. Sixty infected trees were selected for study in June 1992. To ensure access for extraction machinery, all trees were between 10 and 50 m from the edge of the road, and extended over a distance of 400 m along the road.

Trees were allocated to treatments based on the proportion of root collar colonised by *A. luteobubalina*, and stump diameter under bark (Table 1). The treatments were deliberately unbalanced with respect to stump diameter so that chemical treatments would be applied to trees which were significantly larger (P <0.05) and smaller (P <0.05) than control treatments. The rationale for this was to establish whether applying the same volume of chemical to stumps of different size would indicate an appropriate rate of application.

Table 1. Stump diameter under bark, above ground stump volume and fraction of root collar colonised by *Armillaria luteobubalina* for each treatment

Treatment	No. of stumps	Stump diameter (cm) (mean ± s.e.)	Stump volume (cm^3) (mean ± s.e.)	Fraction of root collar colonised(%) (mean ± s.e.)
Control	40	16.5 ± 0.8	4653 ± 451	42.9 ± 4.7
Metham-sodium A[1]	10	11.2 ± 0.5	2016 ± 197	47.0 ± 8.2
Metham-sodium B[2]	10	22.7 ± 1.1	8274 ± 777	48.5 ± 7.6
F[3]		17.2	15.1	0.16
P-value[3]		<0.001	<0.001	>0.05

[1] 500 ml metham-sodium / 2 000 cm^3 stump volume
[2] 500 ml metham-sodium / 8 000 cm^3 stump volume
[3] Results from ANOVA

Table 1 shows a total of 40 stumps in the control treatment compared with 10 stumps in each of the metham-sodium treatments. Initially this study was designed to compare biocontrol treatments with that of a chemical treatment for *A. luteobubalina* in karri stumps (Davison *et al.* 1995). However, techniques used to introduce isolates of competitive fungi into 30 stumps proved to be unsuccessful and at the completion of the trial none of the competitive fungi were isolated from the 'inoculated' stumps. The 'inoculation' technique used was non-destructive (see Discussion for further comments) and the stumps allocated to biocontrol treatments were colonised only by naturally occurring wood decay species. They were thus included in the control treatment.

Treatment of stumps

Trees were felled in November 1992; the stumps were cut horizontally 20 cm above the ground and labelled with a metal tag. Diameter under bark was measured, and the cut surface of all stumps was treated with ammonium sulphamate immediately after felling and again on the following day. Ammonium sulphamate was applied as a 40% aqueous solution with a brush so that the entire stump surface was saturated with the chemical.

Metham-sodium (tradename METHAM Soil Fumigant, 42% w/v sodium monomethyldithiocarbamate) was applied in March 1993. Two chemical treatments were applied. Both treatments used 500 ml of metham-sodium, but the stump volume in treatment A was significantly smaller (P <0.05) than that in treatment B (Table1). This effectively gave two application rates of metham-sodium, 0.269 ± 0.078 ml cm^{-3} for treatment A and 0.066 ± 0.021 ml cm^{-3} for treatment B. Stump volume was calculated on the dimensions of the above-ground portion. A hole, 3 cm diameter and 20 cm deep, was drilled vertically into the centre of each stump and 100 ml of metham-sodium was poured into the hole which was then sealed with a rubber bung. An additional 100 ml of chemical was poured into each of four holes in the soil (about 8 cm diam. x 10 cm deep) spaced equally around and positioned as close as possible to the stump. The treated stump was then covered with a large polythene bag and sealed by burying the edge of the bag in the soil. The bags were removed after 8 weeks. Control stumps were not treated following ammonium sulphamate application.

Assessment of fruiting

Stumps were examined every two weeks during the *Armillaria* fruiting season, which was May to July for each year 1993-1995 and 1997. All stumps on which *A. luteobubalina* fruited were recorded.

Stump excavation and examination

Using a backhoe, all stumps were excavated in September 1997 and transported to the laboratory. Each stump was then wrapped in plastic and stored in a refrigerated room at 4°C. When examined, each stump was cross cut with a chainsaw into 10 cm discs from the stump surface through to the base of the taproot (Fig. 1a,c). The first disc (containing the surface face of the stump) was discarded. The remaining discs were examined for colonisation by wood decay fungi. Decay boundaries on the upper face of each disc were mapped (Fig. 1b,d). Uncolonised

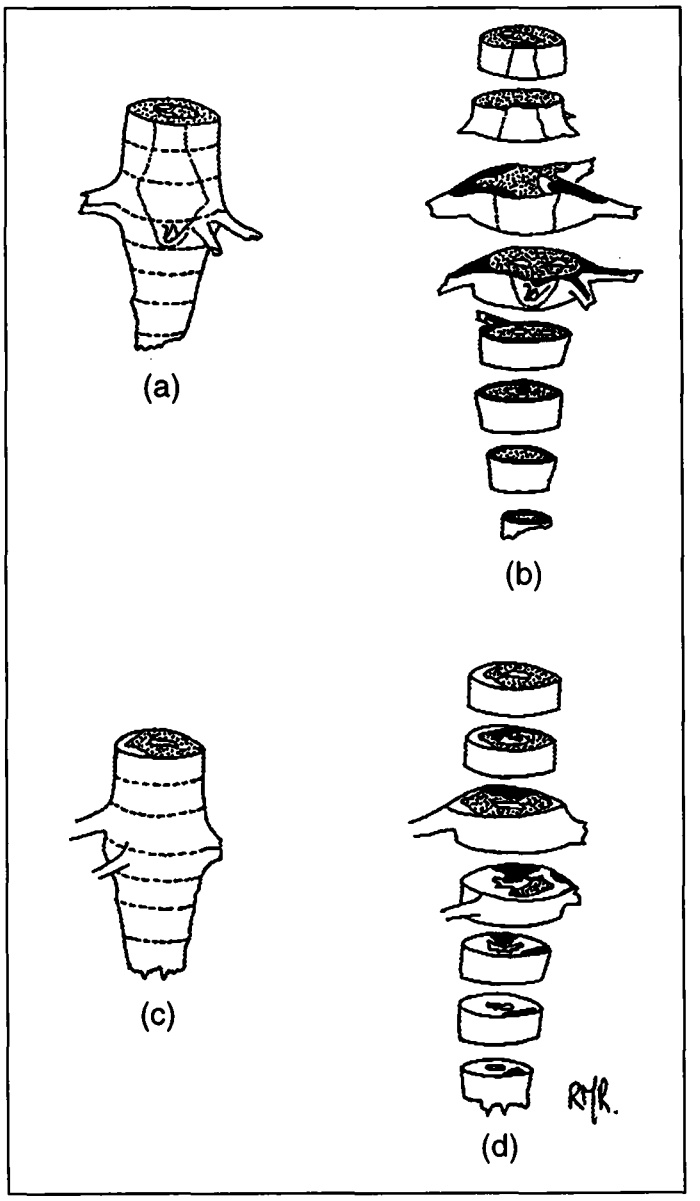

Figure 1. Diagram of debarked stumps showing method of dissection and mapping of decay boundaries: (a) Control Stump 2, whole stump; (b) Control Stump 2, dissected; (c) Metham-sodium Treatment A Stump 1, whole stump; (d) Metham-sodium Treatment A Stump 1, dissected; ■ wood colonised by *A. luteobubalina*; □ wood colonised by white rot (Species E); ▦ wood colonised by white pocket rot; clear (uncolonised) wood is restricted to central core

(pale-coloured) wood was classified as 'clear', discoloured wood as 'brown-stained' and colonised wood was classified according to the type of rot present, i.e. white rot, white pocket rot or brown rot. In some stumps decay was so advanced that the type of rot was not easily recognised and was classified simply as 'advanced decay'. The volume of wood affected by termites was also assessed. The upper surface area of the disc and the area within each decay boundary were measured using a circular template divided into 20 cm^2 sections. Areas were then converted into volumes, using the surface areas and thickness of the disc. The total volume of each stump was calculated by summing the volumes of individual discs.

The organisms associated with decay were isolated from wood chips onto 2.5% malt extract agar (MEA) amended with 6 ppm of benomyl. Pure isolates were then transferred to 2.5% MEA. Isolates were grouped on the basis of their culture morphology and the type of rot produced in the wood. For each stump, a decay organism was linked to each decay column. The volume and fraction of the wood occupied by each distinct isolate was then calculated for each colonised stump.

Statistical analyses

x^2 analysis was used to detect any difference between treatments for *A. luteobubalina* fruiting on stumps at the end of the experiment (1997). An analysis to examine differences in incidence and fraction of the volume colonised by decay organisms in each treatment was performed in two stages. Firstly, x^2 analyses were used to detect any difference in the number of stumps colonised by each decay type or organism in each treatment. Then any difference in stump volume colonised by different decay types or organisms in each treatment was determined using ANOVA (Wardlaw 1996). Volumes were calculated using only those stumps colonised by each decay type or organism. The volume data were converted from a percent to an angle using an arcsine transformation before applying the ANOVA.

Because colonization of stumps by wood decay fungi is opportunistic, the total percent volume occupied by each decay type or organism in each treatment was determined using only the volumes of those stumps colonised by that particular organism. However, as all stumps were colonised by *A. luteobubalina* prior to treatment; the total volume of all stumps in each treatment was used to determine final percent volumes of *A. luteobubalina* in each treatment.

Results

A. luteobubalina fruited less frequently on stumps treated with metham-sodium and more frequently on control stumps (Table 2). Thirteen morphologically different cultures, presumed to be decay-causing fungi, were isolated from decayed and discoloured wood in the stumps (Table 3). Of these fungi, three were identified; *Armillaria luteobubalina, Hypholoma australe* O.K. Miller and *Stereum hirsutum* (Wild ex Fr.) S.F. Gray. These three species all cause white rot (WR). Species E was regularly isolated from wood with white rot. Species C and D were also isolated from wood with white rot. Species C, F and G were isolated from wood with white pocket rot (WPR) and brown stain. Identification of the remaining cultures is continuing, being aided by the collection and isolation of cultures from fungi fruiting on karri stumps that can be identified by their fruitbodies.

Table 2. The number of stumps in each treatment on which *Armillaria luteobubalina* fruited between 1993 and 1997[1]

Treatment	1993	1994	1995	1997
Control	9	9	17	16
Metham-sodium A[2]	0	0	0	2
Metham-sodium B[3]	0	1	1	2

[1]No assessment done in 1996

[2]500 ml metham-sodium / 2 000 ml stump volume

[3]500 ml metham-sodium / 8 000 ml stump volume

Table 3. The number of isolates of putative wood decay fungi cultured from columns of the listed decay type

Species	White rot	White pocket rot	Brown stain	Brown rot	Advanced decay	Total No. of isolates
H. australe	5	2			1	8
A. luteobubalina	64		1			65
S. hirsutum	13		1			14
C	3	22	9			34
D	1	3				4
E	43			1		44
F	2	7	3			12
G		8	4			12
H		1	2			3
I				1	1	2
J	2					2
K		2				2
L	2					2
O	2		1	1	3	7
Q	2					2
R	2					2
S	1	1	1			3

In all treatments, fungi causing WR and WPR colonised a high proportion of the stump volume in those stumps which they colonised (Table 4, Fig. 2). Species E was responsible for the greatest amount of WR not caused by *A. luteobubalina*. In five out of six metham-sodium treated stumps in which it occurred, Species E occupied 45%-62% of the stump volume.

Chemical treatment of the stumps with metham-sodium resulted in a significantly higher percentage of clear (i.e. uncolonised) wood and a lower volume colonised by *A. luteobubalina* (Table 4, Fig. 2), with Treatment A having a marginally greater effect. *Armillaria luteobubalina* was eliminated from four stumps in Treatment A (Table 5). Treatments with metham-sodium had little effect on the incidence of stumps colonised by fungi causing WR (Table 5) but increased the volume colonised in those stumps in which they occurred (Table 4, Fig. 2). Stumps treated with metham-sodium were significantly less colonised by fungi causing WPR, both in terms of incidence and volume colonised (Tables 4 and 5, Fig. 2). The volume of wood with advanced decay was significantly greater in Treatment B (Table 4, Fig. 2). Advanced decay was generally the result of white rot, but isolating wood decay organisms from this material was difficult.

Table 4. The fraction (%) of wood volume affected by decay and discolouration in the stumps from each treatment (calculated using only the total volume of those stumps affected by each decay type in each treatment)

Treatment[1]	Clear wood	Al[2]	White rot[3]					White pocket rot	Brown stain	Brown rot	Advanced decay	Termites
			Ha	Sh	Sp E	Other	Total					
Control	11.5	18.1	11.8	15.3	30.8	13.4	21.4	38.6	15.1	6.6	14.2	5.1
M-S A	17.8	10.6	0	25.0	51.7	15.4	35.1	31.6	7.0	19.5	14.7	52.4 *
M-S B	20.6	13.5	11.9	0	44.1	19.6	39.1	20.0	7.9	9.8	30.8	3.6
F[4]	3.56	2.24			1.25		2.56	1.83	0.61	1.88	3.22	6.06
P-value[4]	0.03	0.12			0.32		0.09	0.17	0.55	0.20	0.05	0.02

[1]Control = No Treatment, M-S A = 500 ml metham-sodium / 2000 cm3 stump volume, M-S B = 500 ml metham-sodium / 8000 cm3 stump volume

[2]Al = Armillaria luteobubalina

[3]Ha = Hypholoma australe, Sh = Stereum hirsutum, Sp E = Unidentified species designated 'Species E'

[4]Results from ANOVA performed on arcsine-transformed data.

*Significantly different based on Student-Newman-Keul's multiple range test (at α=0.05).

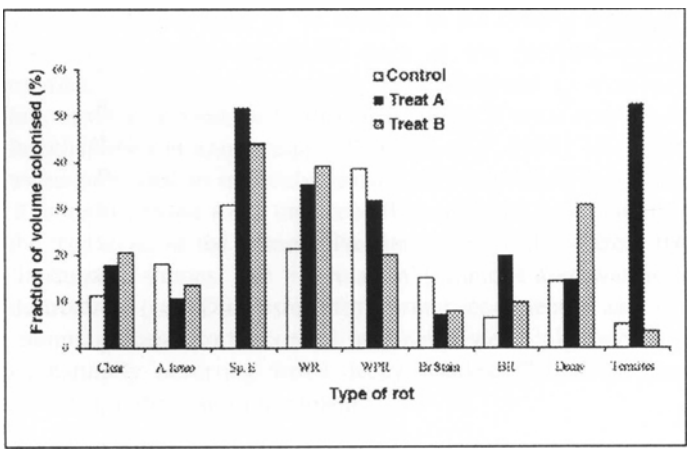

Figure 2. The fraction of stump volume which was uncolonised (Clear), discoloured (Br Stain), or colonised by *A. luteobubalina* (*A. luteo*), Species E (Sp. E), other white rots (WR), white pocket rot (WPR), brown rot (BR), unidentified advanced decay (Decay) and destroyed by termites (Termites). Treatment A = 500 ml metham-sodium / 2000 cm^3 stump volume, Treatment B = 500 cm^3 metham-sodium / 8000 ml stump volume

Treatment with metham-sodium had no effect on the incidence of termites in karri stumps. However, the volume of stump affected by termites was significantly higher in Treatment A (Table 4). Two stumps in Treatment A were almost totally destroyed by termites, eliminating all traces of *A. luteobubalina* from the wood.

Discussion

This study was originally designed to compare chemical control and biocontrol of *A. luteobubalina* (Davison *et al.* 1995). In addition to treating 20 stumps with metham-sodium, an attempt was made to introduce 10 stumps each with one of three species of cord-forming fungi. These fungi were *Hypholoma australe*, *Phanaerochaete filamentosa* (Berk. & M.A. Curtis) Burds. and *Ceraceomyces* sp., *Hypholoma australe* and *P. filamantosa* have been shown to significantly reduce colonisation by *A. luteobubalina* in 11-year-old karri stumps (Pearce *et al.* 1995). However the 'inoculation' technique, which involved burying twelve 2 cm^3 blocks of wood inoculated with the biocontrol fungus in the soil immediately surrounding the stump (to allow natural colonisation of the stump to take place without directly innoculating the stump) was not successful. Using a similar technique in Canada, Chapman and Xiao (2000) demonstrated that *Hypholoma fasiculare* (Huds. ex Fr.) Kummer can successfully colonise conifer stumps. However, their inoculum consisted of 1.3 kg of sawdust inoculated with *H. fasiculare* being buried in contact with a main lateral root. Chapman and Xiao (2000) emphasised the need for a high inoculum potential for *H. fasiculare* to successfully invade fresh stumps. The inoculum potential of the 2 cm^3 blocks used in this study was obviously too small. No isolates of the test fungi were recovered from any of the target stumps.

Armillaria fruiting on stumps was not a reliable indicator with which to assess the effects of the treatments. While fruitbodies obviously indicate presence, lack of fruitbodies cannot be assumed to indicate absence. *A. luteobubalina* failed to fruit on two control stumps in which it had occupied 19% and 31% of the volume at the time of excavation, and fruiting was not consistent on the same stump each year. In both treatments, fruitbodies did not develop on several stumps despite *A. luteobubalina* colonising 22%-38% of stump volume. Stump excavation and examination was essential to measure the effects of treatments.

Methyl bromide has been shown to successfully eliminate *Armillaria* spp. from conifer stumps in forest soil (Filip and Roth 1977; Greig 1990) and from almond root segments buried in orchard soil (Adaskaveg *et al.* 1999). It has also been recommended to reduce levels of *A. luteobubalina* in infected soil prior to planting fruit orchards and vineyards in Australia (Heaton and Dullahide 1989). However, it is highly toxic and ozone-depleting (EPA 2001) and is unlikely to be acceptable for forestry application. Metham-sodium has been trialed as a safer alternative (Filip and Roth 1977; Grieg 1990; Adaskaveg *et al.* 1999) with mixed results. In conifer stumps it has been reported as almost eliminating *A. mellea sensu lato* from ponderosa pine (*Pinus ponderosa* Laws.) stumps one year after application (Filip and Roth 1977), and either eliminating or significantly reducing *Armillaria* spp. from Scots pine (*Pinus sylvestris* L.) stumps and roots 3½ years after application (Greig 1990). However, 11 months after treatment with metham-sodium, the

Table 5. The number of stumps in each treatment affected by decay and discolouration

Treatment[1] and number of stumps	Clear wood	Al[2]	White rot[3]					White pocket rot	Brown stain	Brown rot	Advanced decay	Termites
			Ha	Sh	Sp E	Other	Total					
Control (40)	39	38	8	6	11	9	30	36 *	21	7	23	7
M-S A (10)	8	6 *	0	1	2	2	5	6	6	3	4	4
M-S B (10)	10	10	1	0	4	3	8	5	6	3	4	4
P-value	0.55	0.002			0.49		0.30	0.007	0.86	0.68	0.44	0.17
x^2	6.3	13.2			1.45		2.45	12.89	0.30	0.78	1.67	3.57

[1]Control = No Treatment, M-S A = 500 ml metham-sodium / 2000 cm³ stump volume, M-S B = 500 ml metham-sodium / 8000 cm³ stump volume

[2]Al = *Armillaria luteobubalina*

[3]Ha = *Hypholoma australe*, Sh = *Stereum hirsutum*, Sp E = Unidentified species designated 'Species E'

*Significantly different ($P<0.05$) based on pair-wise x^2 tests

recovery of *A. mellea* (Vahl:Fr) P. Kumm. was not significantly reduced from either the stumps or primary roots of *Armillaria*-killed almond-peach rootstock trees (Adaskaveg *et al.* 1999).

Treatment of karri stumps with ammonium sulphamate prevents coppice formation and ensures rapid killing (Pearce *et al.* 1995). Rapid killing of stumps (and roots) is almost certainly a prerequisite for effective control of *Armillaria* spp. (Leach 1939; Rishbeth 1976). In Britain, it has also been shown that treating hardwood stumps with 40% ammonium sulphamate may favour colonisation by fungal species such as *Coriolus versicolor* (L. ex Fr.) Quél., *Bjerkandra adusta* (Wild. ex Fr.) Karst. and *Phlebia merismoides* Fr., which cause white rot and rapid decay (Rishbeth 1976; Rayner 1977). In this trial, treatment with ammonium sulphamate followed by treatment with metham-sodium initially suppressed fruiting of *A. luteobubalina* on stumps. After 3½ years, however, the effect of metham-sodium appeared to be abating (Table 2). The results of stump excavation and dissection show that metham-sodium treatment was associated with a reduction in the volume of stump colonised by *A. luteobubalina* (Table 4, Fig. 2). Although these results do not appear to be as dramatic as those of Fillip and Roth (1977) and Greig (1990), their results were expressed as fraction of positive isolations and not as stump volume occupied by the pathogen. In treatment A, *A. luteobubalina* was eliminated from 40% of the stumps, and an overall reduction (although non-significant) in the volume of stump colonised was observed (Tables 4 and 5). After 3½ years, the volume colonised by *A. luteobubalina* ranged from 4.6%-32% in treatment A, and 1.5%-37.8% in treatment B. Colonisation by *A. luteobubalina* in the control stumps ranged from 5.8%-54.5% and in 2 stumps (5%) *A. luteobubalina* had failed to spread and was not isolated from the original lesion.

Although WPR organisms were aggressive and common colonisers of non-metham-sodium treated karri stumps, they were predominantly isolated from the heartwood and therefore found internal to the cambium and sapwood colonised by *A. luteobubalina*. Heartwood in eucalypts may be resistant to decay by species of *Armillaria* (Redfern and Filip 1991). However, *Armillaria* sp. has been reported as causing heart or butt rot in eucalypts in the wet sclerophyll forests of Tasmania (Wardlaw 1996). In this study, *A. luteobubalina* was isolated only from the sapwood of infected karri stumps and WPRs occupying the internal portion of the stump would have little influence on colonisation of sapwood by *A. luteobubalina*. The suppression of colonisation by WPR organisms in metham-sodium treated stumps (Table 4 and 5) is likely to have been the result of direct exposure to the chemical, which was applied through holes drilled in the centre of the stump surface.

The organisms causing white rot (WR) were isolated from the sapwood (or outer) region of the stumps. Sapwood-colonising decay fungi have the ability to occupy the same niche as *A. luteobubalina*, and thus reduce the substrate available for colonisation by *A. luteobubalina*. Natural colonisation of karri stumps by *H. australe* can result in partial or complete exclusion of inoculated *A. luteobubalina* (Pearce and Malajczuk 1990) and *H. fasiculare* can be induced to invade fresh conifer stumps if the inoculum potential is large enough (Chapman and Xiao 1999). In this study, treatment with metham-sodium did not affect the incidence of natural colonisation by WR organisms, but the fraction of volume occupied by WR organisms was greater in those metham-sodium treated stumps which were colonised. Species E was the most commonly isolated WR organism (Table 3 and 4) in both treated and control stumps. When it colonised control stumps it occupied about the same volume as *A. luteobubalina*. However, treatment with metham-sodium increased the volume colonised by Species E relative to *A. luteobubalina*. In both Treatments A and B the volume occupied by species E was about three times that of *A. luteobubalina* (Table 4). Identification of wood decay fungi from cultures is difficult. Although there are taxonomic keys for a wide range of Northern Hemisphere species (Nobels 1948; Stalpers 1978; Nakasone 1990) none are available for Australasian species. Identification thus relies on experience and access to a culture collection from known and identified fruitbodies. However, further investigation into the identification of Species E, and its potential as a biocontrol agent for armillaria root disease in karri regrowth forests in the south-west of Australia, is needed. The interaction between wood decay fungi and fumigants is an area that warrants further investigation in Australia.

Termites may be an effective agent for biocontrol of *A. luteobubalina* in small karri stumps. Termites colonise decayed wood in the fire scars of living jarrah and karri trees in the south-west of Western Australia (Perry *et al.* 1985). They also cause substantial damage to living alpine ash (*E. delegatensis* R.T. Baker), mountain gum (*E. dalrympleana* Maiden) and blackbutt (*E. pilularis* Smith) trees in NSW (Greaves *et al.* 1965; Greaves and Florence 1966). Termites

established in colonies in old-growth trees and stumps can infest regrowth trees (Greaves and Florence 1966). Evidence suggests, however, that eucalypts grown within their recognised geographic range on high quality sites will remain free from attack by termites if they are protected from fire (Carne and Taylor 1984). The use of termites as a potential biocontrol agent for root diseases such as ARD needs further investigation.

Metham-sodium can reduce the volume colonised by *A. luteobubalina* in 13-year-old karri regrowth stumps. It may even eliminate *A. luteobubalina* from small stumps of subdominant trees and enhance colonisation by competitive white rot fungi. These results, however, were not statistically significant. Application of fumigants in regrowth forestry is labour intensive and very costly, and following thinning in a 25-year-old karri regrowth forest, there may be more than 1000 stumps ha^{-1} (CALM 1992; Florence 1996) with a range of diameters from 10 to 30 cm. This would require a range of application rates to treat the stumps. Despite reports that metham-sodium is relatively safe (Greig 1990), methyl isothiocyanate (the fungitoxic gas it yields) is extremely irritating to respiratory mucous membranes and eyes and requires the operator to wear full protective equipment including a respiration apparatus. Wearing this equipment in the Australian summer, in the physically demanding regrowth forest environment, is also very stressing on the operator. Fumigants may be useful in treating isolated stumps in a horticultural situation, but their large-scale use to control root diseases in regrowth forest management is impractical. Alternative silvicultural techniques such as tree pulling (Morrison and Mallett 1996) may offer more promise for successful thinning of *Armillaria*-infested juvenile regrowth stands.

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