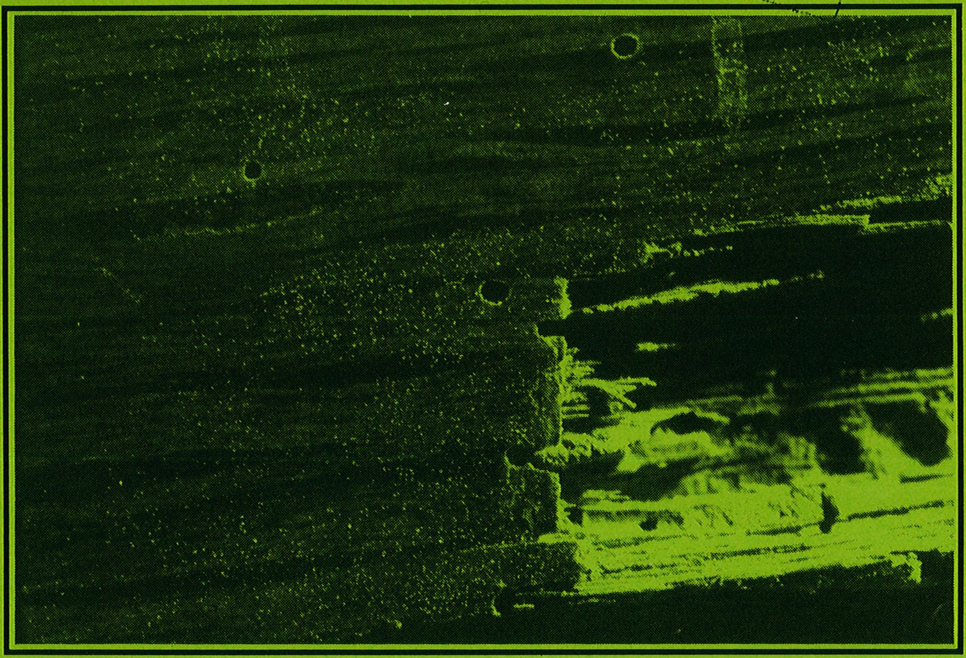
Powder Post Borer (*Lyctus* spp.) Attack on Dry Timber - A Review

G.K. Brennan



Report No. 19

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Wood Utilisation Research Centre
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SUMMARY

The relationship between timber properties and condition, and the susceptibility of timber to *Lyctus* spp attack is discussed. The factors involved include; sapwood starch content, timber pore diameter in relation to insect ovipositor and egg size, and sapwood moisture content. Major studies concerning *Lyctus* spp attack, particularly by *L. brunneus* (Steph.) on timber were conducted in the 1930s, and some in the 1950s. Literature on the life cycle and biology of *L. brunneus* and fluctuations in sapwood starch levels is reviewed. Research relating to *Lyctus* in Western Australia is discussed as well as methods of preventing attack.

INTRODUCTION

The powder post borer, particularly *Lyctus brunneus* (Stephens), Lyctidae (Coleoptera), is a major pest which attacks dry timber in Australia, reducing wood to a fine white powder. Sapwood of pored timbers (hardwoods) only is attacked, and non-pored timbers (softwood or coniferous timbers) such as pines (*Pinus* spp.), cedars (*Cedrus* spp.) and firs (*Abies* spp.) are non-susceptible (Boas 1947). Starch and allied chemicals are extractives in the sapwood and used by the larva as food material, thus timbers not containing food reserves palatable to *Lyctus* are immune to attack. Pore (vessel) size also influences susceptibility. Where the largest pores are small enough to prevent the insect inserting its ovipositor to lay eggs, the timber is immune.

Lyctus is essentially a pest of sawmills, timber yards and manufacturers' premises, where converted susceptible hardwoods are stored. Apart from losses sustained when damage is detected and eliminated before or during manufacture, the greatest problem arises from the inadvertent use of actively infested parts in newly manufactured wood-work, furniture and flooring, leading to complaints from consumers when attack is ultimately revealed. Moreover, the reputation of the manufacturer may suffer (Anon 1959).

RECOGNISING *LYCTUS* ATTACK

The best characteristic in recognising attack is the abundant frass (faeces or 'dust'), which is tightly packed into the borer tunnels, and often forms little heaps beneath or around the flight holes. Frass is smooth and floury (not gritty) and a yellow-white colour, and flight holes are round (1 to 2 mm in diameter) with no staining around their margins. The fact that only the sapwood of susceptible hardwood timbers is attacked is another useful diagnostic feature (Beesley 1956).

LIFE CYCLE OF *LYCTUS*

Lyctus occurs throughout the world. About twenty different species are known, but all of those studied have similar life histories and methods of attacking timber. The most common species in Australia is *L. brunneus* (Anon 1935).

In its development, the *Lyctus* borer passes through four distinct stages - egg, larva, pupa and adult beetle. Iwata and Nishimoto (1981 and 1982) described the external morphology and the surface structure of *L. brunneus* for larvae and pupae, and adult and eggs in greater detail.

Throughout the year in tropical climates and during spring and summer in temperate regions the female adult beetle searches actively, by crawling and flying (usually after dusk), for starch-containing sapwood in which to lay her eggs. When suitable sapwood is found (i.e. the ovipositor can be inserted and adequate starch is present), the beetle lays her eggs into the pores of the wood. Eggs hatch into small creamy coloured larvae which feed upon the starch in the sapwood. The feeding period is the time when most damage occurs in timber, ranging from two to three months in warm climates and heated buildings, to 12 or 18 months under adverse conditions.

When the larvae are fully fed, they pupate and after about a month emerge as mature beetles. If their flight path is obstructed, beetles can bore through plaster sheeting, hardboard and in exceptional cases asbestos sheeting and lead flashing (Beesley 1956).

Egg

Female beetles insert their eggs into sapwood pores using a long thin tube attached to the abdomen, called the ovipositor. *Lyctus* eggs are minute, white, cyclindrical bodies and cannot be easily seen without magnification. The relationship between the egg and pore size is discussed later.

Larva (grub stage)

Young grubs first subsist on the residual yolk in the egg, and then eat their way out into wood where they initially tunnel in the direction of the pores, then frequently work at right angles to them. When fully matured, the grub bores its way near to the timber surface to build a pupal chamber, where it rests before changing into a beetle. Grubs can tunnel through truewood or non-pored woods adjacent to the pored sapwood in order to get near the surface.

Pupa

The pupa is not protected and externally appears like the mature beetle. Metamorphosis from pupa to beetle takes about one month.

Beetle

After developing, the beetle begins to cut its way to the wood surface, pushing fine dust in front of it, which results in small piles of dust forming on the surface. Upon emergence a flight hole of 1 to 2 mm diameter is evident.

Lyctus beetles are flattened, elongated insects, brown to black in colour. Their lengths vary from about 3 to 6 mm and they are capable of flight.

Beetle emergence usually takes place in spring or summer, with early summer being the most favoured period under normal conditions. The beetles mate soon after they emerge and the female proceeds to infest new timber or re-infest previously attacked material. Flight holes often expose further pores into which eggs can be laid (Anon 1935).

BIOLOGY OF *L. brunneus*

Oviposition

The pre-oviposition period appears to be relatively short, occupying the few days the adult beetle spends within the pupal chamber while its cuticle is hardening and darkening (Gay 1953). Newly emerged beetles are able to mate and lay fertile eggs within 24 hours of emergence. Eggs are deposited within the vessels of the wood, generally two or three eggs being placed one behind the other in the vessel lumen. Gay (1953) found that the depth of egg deposition for seven susceptible Australian species ranged from 1 mm to 6.5 mm and in all timbers some eggs were laid to depths in excess of 5 mm.

The effect of the exposed surface to attack was examined for three *Lyctus*-susceptible species (*Schizomeria ovata.* D. Don, *Sterculia acerifolia* F. Muell and *Alstonia scholaris* (L.) R. Br.) (Gay 1953). It was seen that in each species, oviposition can occur on any of the three exposed faces (transverse, radial or tangential). Oviposition is heaviest on the transverse face, but appreciable egg laying is possible on both radial and tangential faces. Such oviposition may take place in the ends of vessels exposed owing to sloping grain, but eggs are also laid in the lumen of vessels exposed by the mandibular action of the adult beetles. These tasting marks, which have been referred to by Parkin (1936), appear to have the dual function of enabling the female beetle to select suitable starch-containing wood, and of exposing the ends of vessels in which eggs can be laid.

Ito and Hirose (1978) found a positive relationship between the number of tasting marks and number of eggs laid. Although the female adults laid most of their eggs through natural pores of wood vessels, they laid a few eggs through the tasting marks opened by themselves.

Ito (1983) observed that males, regardless of mating, made tasting marks selectively on starchy veneers, but tasting by the mated females on starchy veneer was more frequent.

Number of eggs

Gay (1953) obtained complete oviposition histories of 25 females. Total oviposition ranged from 0 to 221 eggs, with an average of 76 eggs per female. The maximum period over which egg laying extended was 22 days, but in most instances it lasted 7 to 14 days, with the majority of the eggs being laid within the first 7 to 8 days of the female's life. Most females live for several days after oviposition has ceased. Subsequent dissection showed that 40 per cent of these females still had unlaid eggs present in the reproductive system. All females that laid eggs began oviposition within the first 24 hours after emergence and in a majority of instances the highest single daily egg deposition occurred in this first 24-hour period. The greatest number of eggs deposited by one female in a day was 37.

Dissection of newly emerged females showed from 20 to 80 eggs present in the reproductive system (the average for 14 females was 48 eggs). These eggs are laid during the first few days of the oviposition period, after which the primordia visible in the ovarioles develop into additional eggs.

Developmental period

The length of the developmental period from egg to adult is influenced by the temperature and to a lesser extent by the relative humidity. Gay (1953) presented a summary of tests in which *L. brunneus* was reared at various combinations of temperature and relative humidity.

Development was very slow at 15°C, requiring a minimum of about sixteen months for the completion of the life cycle. An increase in temperature to 20°C reduced this period to five to six months, while a further increase to 26°C reduced the time to approximately four months, which appeared to be close to the optimum temperature for the species. This is supported by the fact that at each relative humidity level, many more beetles emerged at 26°C than at the other temperatures studied.

At 30°C very few insects were able to complete their development and those that did took about six months. Larval development appeared quite successful and pupation appeared to take place quite normally, however, heavy mortality occurred in the pupal stage and relatively few adults emerged.

Development was possible over the relative humidity range of 40 to 80 per cent, and there was no definite correlation with the length of the developmental period. Extremely low and high humidities were deleterious, the former probably because of desiccation effects and the latter because of increased fungal activity.

Gay's data indicated that the length of the developmental period is over-estimated in the literature. The most frequently quoted period is one year from egg to adult, whereas under favourable conditions it may be only four months. If conditions are optimal rather than favourable, the minimum developmental period may be reduced to as little as two months. This acceleration in development appears to depend on nutritional rather than physical factors.

Sex ratio

The sex ratio of *L. brunneus* determined from almost 45 000 beetles reared during three years was practically 1:1 (Gay 1953).

Length of adult life

An adult's life-span varies considerably and is influenced by the temperature. Adult longevity at 15°, 26° and 30°C is summarised in Table 1, which shows that while some adults died soon after emergence, others lived for considerable periods, the longest being 84 days. As the average temperature rises, the life-span reduced. At all the temperatures studied, female beetles lived longer than males.

Table 1

Longevity of adult *L. brunneus* at various temperatures (Gay 1953)

		Males		Females	
Temperature and relative humidity (°C)	(RH %)	Mean (days)	Range (days)	Mean (days)	Range (days)
15	60	35.7	3-58	49.1	20-84
26	75	20.2	6-33	22.4	13-34
30	60	16.8	1-27	19.9	12-26

Temperature tolerance of eggs and young larvae

The investigation by Gay (1953) obtained information on the temperatures and exposure time necessary to ensure effective heat sterilization (i.e. kiln treatment).

Two tests of both egg and larval blocks exposed to various temperatures and times are summarized in Table 2. Untreated blocks were used as a control. The time of exposure necessary to give a complete kill of eggs and young larvae decreased with increasing temperature. At 50°C and half hour exposure a complete kill of both stages was obtained. Larvae were somewhat more resistant to heat treatment than the eggs.

Fisher (1929) reviewed the biology of *L. brunneus, L. linearis*, *L. parallelopipedus* and *L. planicollis* and described the minute differences in eggs laid by the four species.

Table 2
Two tests of the temperature tolerance of eggs and larvae of *L. brunneus* (Gay 1953)

A = eggs
B = larvae
L = some eggs or larvae alive
D = all eggs or larvae dead

Exposure	37.5°C		40.0°C		42.5°C		45.0°C		47.5°C		50.0°C	
(h)	A	B	A	B	A	B	A	B	A	B	A	B
0.5									D	D	D	D
1	L	L	L	L	L	L	L	L	D	D	D	D
1.5											D	D
2	L	L	L	L	L	L	L	L	D	D	D	D
3									D	D	D	D
4	L	L	L	L	L	L	D	D	D	D		
6							D	D				
8	L	L	L	L	D	D	D	D				
24	L	L	L	D	D	D						
0.5									L	L	D	D
1	L	L	L	L	L	L	L	L	D	D	D	D
1.5											D	D
2	L	L	L	L	L	L	L	L	D	D	D	D
3									D	D	D	D
4	L	L	L	L	L	L	D	D	D	D		
6							D	D				
8	L	L	L	L	L	L	D	D				
24	L	L	L	L	D	D						

RELATIONSHIP OF OVIPOSITOR AND EGG SIZE TO PORE DIAMETER

Timber is immune where the largest pores are smaller in diameter than the smallest *Lyctus* egg. As the percentage of pores of greater diameter increases, the probability of attack becomes greater. The pore size of many commercial Australian hardwoods are sufficiently large to permit deposition of the eggs (Cummins and Wilson 1934).

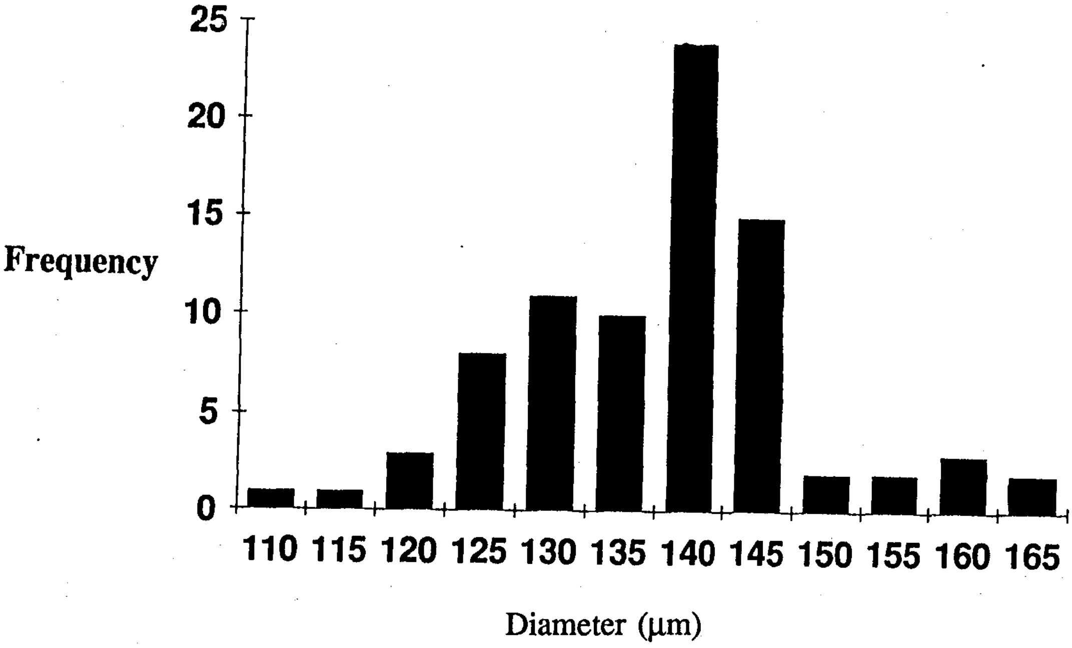
Clarke (1933) reported that the maximum diameter of the smallest egg measured was 137 µm and the average was 150 µm. He regarded 137 µm as the smallest maximum diameter possible. Where the largest pores of a given wood are less than 137 µm, it would be highly improbable that the timber could be attacked. Clarke (1933) also regarded the smallest maximum diameter of a *Lyctus* egg as the critical figure, but that the mean figure should be used when predicting immunity.

Cummins and Wilson (1934) believed that Clarke's conclusions required certain modifications, because he gave only 20 measurements of *Lyctus* eggs, and maximum diameter for 19 of these ranged from 137 µm to 159 µm, with the remaining egg measuring 183 µm. Ignoring the last value, the standard deviation reduced considerably and all of the measurements would be expected to fall within the range 126 µm to 168 µm. It appeared safer, on the data presented, to place a limiting pore size (assuming other factors are favourable), at a maximum of about 126 µm.

Cummins and Wilson (1934) referred to research by Chowdhurry (1933), who measured the maximum diameter of 10 eggs of *L. africanus,* and found these to be almost constant at 130 µm. He measured the radial and tangential pore diameters of 52 species of Indian timbers, and concluded that oviposition can only occur in those pores, with tangential and radial diameters both larger than the diameter of the egg. The method of egg laying is very important, when considering susceptibility. Parkin (1933) found that the egg elongated considerably in its passage down the ovipositor, and as it issues from the ovipositor, it generally shortens in length and expands in diameter to give a so-called normal diameter. If the pore is smaller than the normal diameter, this expansion is not possible and elongated eggs will result. Figure 1 shows the distribution of maximum diameter of 75 *L. brunneus* eggs, indicating that susceptibility to *L. brunneus* attack is based on the relationship between pore diameter and the ovipositor diameter. Measurements of the average ovipositor diameter of 34 *L. brunneus* individuals gave an average of 78 µm with a minimum of 56 µm.

Cummins and Wilson (1934) examined the pore size of 94 different species of *Lyctus*-infested timber. In 47 of these specimens, sections were prepared from heartwood adjoining the infested sapwood, and measurements were made of the radial diameters of cross sections of the 10 largest pores. It is reasonable to assume that the measurements of pores in heartwood are similar to those in the adjacent sapwood. Even allowing a small difference, all the species measured contained some pores greater than 180 µm. In the remaining 48 specimens, sections were prepared from infested sapwood.

Figure 1. Frequency of maximum diameters of 75 *L. brunneus* eggs (from Parkin 1933)



Most of the species measured had radial pore diameters greater than tangential, but their pore sizes are so large that, even allowing a ratio of radial to tangential diameter of 1.5 to 1, the minimum size would be above 120 μm. From the data available to Cummins and Wilson (1934), it does not appear possible for infestation to occur under Australian conditions in wood containing pores with a minimum diameter less than about 90 μm. However, Parkin (1933) considered that it was possible for eggs to be laid in timber containing pores sufficiently large enough for the introduction of the ovipositor, that is pores with a minimum average diameter of about 56 μm.

Samples of regrowth karri (*Eucalyptus diversicolor* F. Muell.) and W.A. sheoak (*Allocasuarina fraseriana* (Miq.) L. Johnson) had mean pore sizes of 259 ± 10 μm and 158 ± 18 μm respectively, which according to Cummins and Wilson's estimates are large enough for oviposition. Pore diameter for old-growth karri ranged from 150 μm to 250 μm (Brennan unpublished data).

STARCH

Food requirements of Lyctus larvae

Parkin (1936) conducted a series of experiments to assess the possible use of control methods based on the insect's food requirements. He used four methods to determine the substances utilised for food by *Lyctus* larvae. They were:

(i) chemical analysis of food and excrement

(ii) removal of certain substances from the wood by extraction with solvents

(iii) testing for the presence of certain enzymes

(iv) feeding on artificial diets.

The results confirmed that starch is a necessary constituent of the food, and indicated that a soluble sugar, such as sucrose or glucose, and probably a small amount of protein, are also required by *Lyctus* larvae. None of these substances is a complete food by itself. Experiments proved conclusively that *Lyctus* larvae can satisfy their food requirements with the cell contents of suitable timber, and do not need any additional nutrients which may be available in the cell wall. In addition, other substances in wood which are possibly required by *Lyctus* are steroids, linoleic acid and sterols as well as mineral nutrients. A bacterium-like symbiont in the *Lyctus* gut has been assumed to supply the host with vitamins.

Most of these nutritional substances required are contained in the parenchyma cell contents of the sapwood (Iwata and Nishimoto 1981). Their experimental evidence suggests that a substance found in the *Lyctus* larvae contains approximately 90 per cent of available carbohydrate which can be converted into sugars by enzymic hydrolysis. Polysaccharides can be converted into sugar by the gut enzymes of *Lyctus* larvae and used for growth and development (Campbell 1935).

It is evident that beetles can not only differentiate between samples suitable or unsuitable for larval development, but also sense differences in the starch content of suitable samples and therefore lay most of their eggs in samples which contain most starch (Parkin 1936). Reference to the 'tasting marks' on the samples again shows that the number of these incisions is roughly correlated both with the food value of the wood and the number of eggs found, but gives no indication of the ability of the beetles to detect differences in the starch content of suitable samples.

Campbell (1935) found that, in oak, the yield of starch from *Lyctus* frass and from sapwood were 0.28 per cent and 0.9 per cent respectively, indicating that starch is used effectively by the insect for growth and development.

Starch depletion

Starch is essential for the growth of *Lyctus* larvae. Any methods that produce starch-free wood by inducing the cells of green timber to re-absorb their food reserves would prevent attack. Some methods include:

(i) girdling standing trees
(ii) log storage (dry or ponded)
(iii) low temperature kiln treatment.

In considering the production of starch-free timber two factors must be taken into account:

(i) fluctuations of the starch content of the living tree to ensure a minimum level at the start
(ii) the continuance of vital activities in the timber to remove the remainder of the stored food (Phillips 1938).

Respiration is the process of paramount importance in all methods of depletion, and this is only possible if the cells of the wood remain alive. The enzymes concerned in respiration will continue to catalyse isolated reactions after the death of the cells. However, for maintaining a continuous supply of enzymes, normal functioning of the living protoplasm is essential. Death of living tissue caused by drying needs to be prevented if this method is to be successful.

The general pattern of starch depletion across the sapwood is fairly consistent, usually being greatest towards the bark and least near the heartwood. This has been found by other workers and results from greater ease of gaseous exchange during respiration along the medullary rays near the surface than at greater depth (Harris 1961).

Fluctuations of starch levels in living trees

Starch grains occur either singly or in aggregates in the cells of the medullary rays and xylem parenchyma. In many hardwoods the starch-bearing tissues form 20 to 30 per cent of the total volume of sapwood. The amount of starch does not usually exceed 3 per cent, but up to 5.9 per cent has been recorded for elm (*Ulmus* spp.). Various authors have shown the starch content of different woods varies from 0 to 5.9 per cent and the sugar content (calculated as glucose) from 0 to 6.2 per cent. The carbohydrates present as cell contents probably average 3 to 6 per cent (Parkin 1936).

Wilson (1935) concluded that starch reserves vary from species to species, as does the kind of material stored; and in quantity from tree to tree, within the tree, from year to year and most important, from season to season in all trees and particularly in deciduous species.

Brimblecombe (1945) found a relationship between mean monthly starch content and season for lemon scented gum (*Eucalyptus citriodora* Hook.) and spotted gum

(*E. maculata* Hook.). In contrast to the one general rise and fall in starch of deciduous trees of the northern hemisphere, there are two general rises and falls in starch content of these two species (and presumably other eucalypt species) each year. Cockerham, in Wilson (1935) studied the variation in starch content in twigs, stems and roots of sycamore trees during a year. The seasonal variation of starch in 20-year-old sycamore trunks (*Acer pseudoplatanus* L.) is shown in Figure 2. Starch content was recorded in four grades using an iodine-potassium iodide solution test (Lugol's solution). The winter reduction in starch is owing to the conversion of some starch to sugar in cold weather and the sudden reduction from a spring maximum is due to heavy withdrawals as the foliage forms (Fig. 2). The heavy drain on the reserves in spring does not, as a rule, completely empty the storage tissue, because a sufficient amount to produce a second crop of leaves is retained should the first be destroyed. It is rare, however, for the sapwood of the trunk of a tree to be completely denuded of reserves (Wilson 1935).

In spring the temperature rises and, apparently irrespective of rainfall, there is a burst of foliage growth. However, the existing foliage cannot provide sufficient materials for its development, so the food reserves are drawn upon. In midsummer a stage is reached where photosynthesis provides sufficient carbohydrates to maintain the new growth and withdrawal of food reserves ceases. Starch is gradually replaced so that during summer a peak in starch content is obtained.

Figure 2. Seasonal variation of starch levels in 20-year-old sycamore trees(stem region) grown in the Northern Hemisphere. (After Cockerham in Wilson 1935).

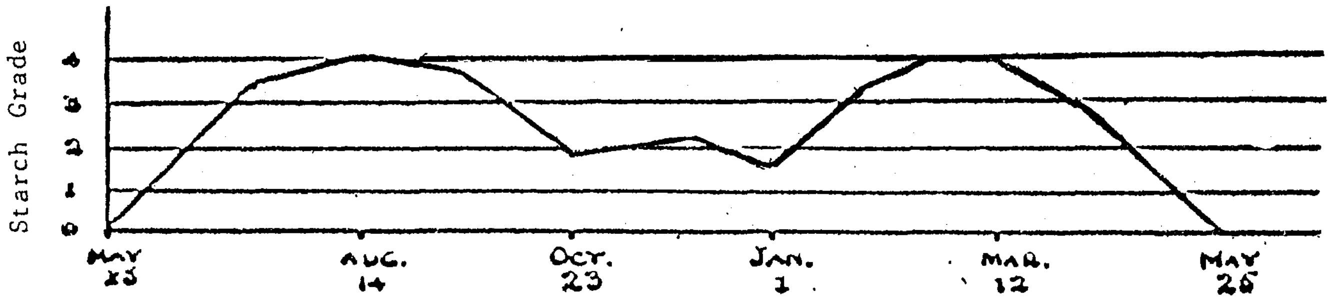
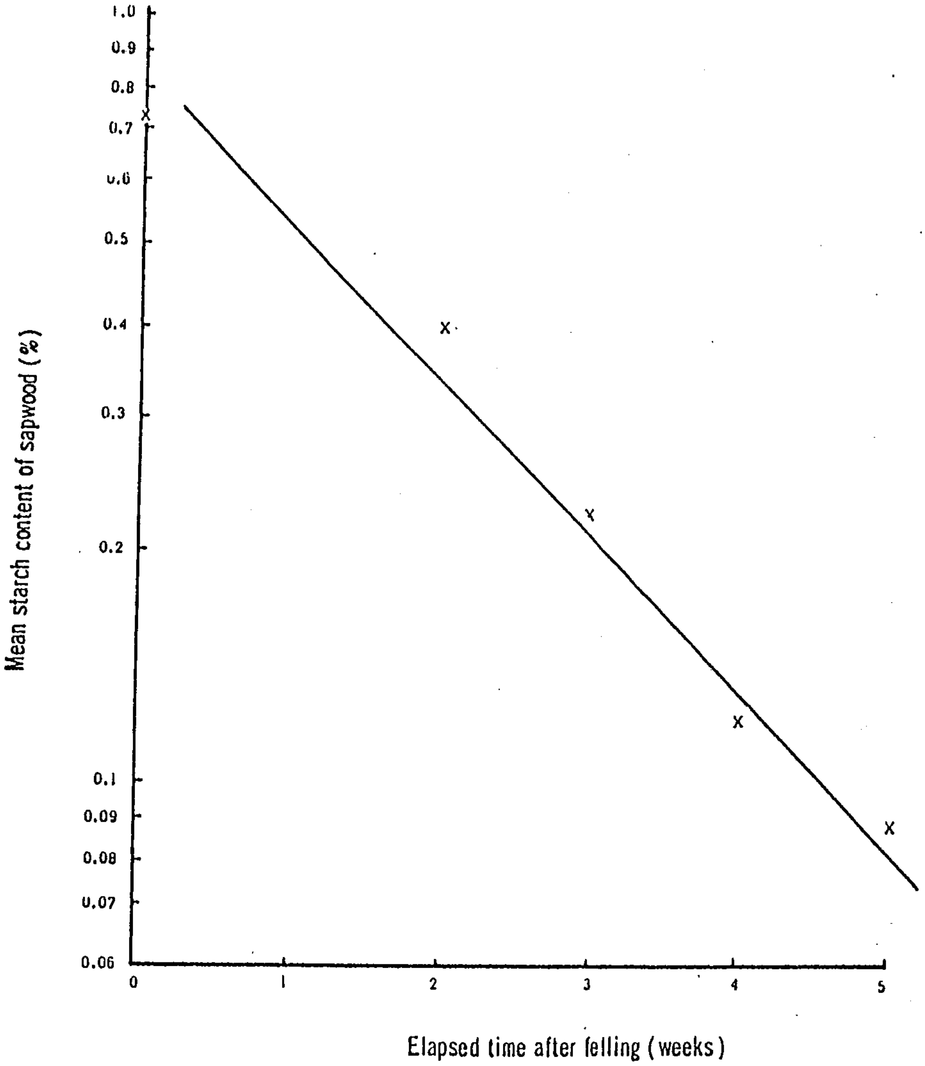


Figure 3. Starch content of the sapwood of *Eucalyptus grandis* logs after felling (After Humphreys and Humphreys 1966).



In autumn, probably simulated by rain, there is another growth period. Again the need for carbohydrates exceeds that produced by the foliage and there is a withdrawal of starch reserves.

Brimblecombe (1961) did further studies on starch variation in Australian tree species. Using 11 eucalypts and two *Tristania* (now *Lophostemon*) species from Queensland, he found most species showed a noticeable fluctuation in starch content from month to month and from season to season. A primary peak occurred fairly consistently in summer, and a secondary peak in late winter.

Bamber and Humphreys (1965) studied the effect of starch content on artificially defoliated (pruned) trees, trees defoliated by fire, trees defoliated by Phasmatids, and trees defoliated by Psyllids. For the artificially defoliated trees, the mean values of the starch levels in the control trees showed seasonal variations, declining during periods of flush growth and increasing during periods when the crown was comparatively dormant. Pruned trees rapidly lost their starch while they were re-establishing their crowns, returned to the initial level by the end of the 12-month period, and continued in the same pattern as the control trees thereafter. Continually defoliated trees lost their starch rapidly at first and then more slowly, until finally there was zero starch content.

Trees defoliated by fire had significantly less sapwood starch content than the control trees after both 117 and 166 days, indicating that rapid growth of new leaves is associated with a depletion of sapwood starch. After 12 months, mean starch levels were close to the initial measurements (Bamber and Humphreys 1965).

Trees defoliated by Phasmatids showed sapwood starch levels which were significantly lower than in the unattacked trees. All the dead trees examined, including a tree which had died just prior to sampling, had no starch in the sapwood. As these trees died after repeated heavy Phasmatid attacks, it seems reasonable to assume that death could be caused bythe exhaustion of the starch reserves arising from successive defoliations and subsequent regeneration.

Similar results occurred following Psyllid attack, because the mean starch levels of trees in the heavily attacked area were significantly lower than those of trees in either the recently attacked area or the unattacked area.

Starch levels in flooded gum (*E. grandis* W. Hill ex Maiden) sapwood were assessed by Humphreys and Humphreys (1966). They found that starch levels follow a similar seasonal variation pattern to other coastal species previously investigated, reaching a peak in spring and early summer and their lowest point in late autumn. Differences in starch levels were found between dominant, co-dominant and suppressed trees. Dominant trees were found to have the smallest fluctuatuions and the co-dominant trees had siginficantly higher starch contents than the dominant and suppressed trees. A rapid decline in sapwood starch content occurred whether the crown was intact or removed. Humphreys and Humphreys (1966) stated that 'if we assume about 0.8 per cent starch is required to support *L. brunneus* then no tree is susceptible three weeks after felling'. Logs left intact for one month after felling appeared to have very little chance of being *Lyctus*-susceptible. Figure 3 shows the decline in starch content of the sapwood of *E. grandis* logs after felling.

Starch depletion rates in regrowth karri

A study was conducted by Simpson (1988) for the Department of Conservation and Land Management's Wood Utilisation Research Centre, to determine the rate of starch depletion for 21-year-old regrowth karri (*E. diversicolor* F. Muell) logs, stored under intermittent water spray using a schedule of one hour on: four hours off, and compared with dry storage (Tables 3 and 4). In addition, starch levels were measured in 50-year-old standing karri at various times of the year, in trees that were ringbarked and left standing, and in trees felled with their crowns intact (Table 5).

Table 3

Mean starch levels (% w/w) of regrowth karri logs stored under an intermittent water spray schedule of 1 h on:4 h off

	Time (weeks)								
Log No	**1**	**4**	**7**	**10**	**13**	**16**	**19**	**22**	**25**
1	0.93	0.62	0.47	0.42	0.30	0.40	0.25	0.18	0.26
2	0.35	0.48	0.29	0.31	0.20	0.30	0.16	0.15	0.13
3	0.58	0.57	0.56	0.45	0.37	0.30	0.14	0.14	0.14
4	0.41	0.45	0.35	0.39	0.29	0.28	0.12	0.14	0.14
5	0.64	0.69	0.54	0.61	0.48	0.61	0.16	0.25	0.19
6	0.46	0.42	0.41	0.44	0.24	0.45	0.15	0.21	0.14
7	0.19	0.17	0.20	0.23	0.14	0.17	0.15	0.16	0.12
8	2.32	1.43	1.60	1.47	0.95	1.59	0.60	0.56	0.57
9	0.83	0.72	0.57	0.84	0.63	0.64	0.38	0.57	0.47
10	1.13	1.49	1.29	1.25	0.76	1.05	0.71	0.70	0.81
11	0.54	0.74	0.48	0.74	0.43	0.50	0.35	0.41	0.40
12	0.43	0.48	0.38	0.55	0.33	0.31	0.30	0.30	0.27
Mean	0.73	0.69	0.60	0.64	0.43	0.55	0.29	0.31	0.30

Table 4

Mean starch levels (% w/w) of regrowth karri logs stored in a dry stockpile for 19 weeks

	Time (weeks)						
Log No	**1**	**4**	**7**	**10**	**13**	**16**	**19**
1	0.78	0.87	0.42	0.34	0.17	N/A*	0.25
2	0.34	0.46	0.22	0.20	0.15	0.24	0.15
3	0.60	0.41	0.24	0.17	0.11	0.23	0.16
4	1.55	0.81	0.51	0.26	0.22	0.36	0.28
5	0.77	0.61	0.38	0.39	0.25	0.39	0.21
Mean	0.81	0.63	0.35	0.27	0.18	0.30	0.21

* N/A = Not assessed.

Table 5
Mean starch levels of 50-year-old regrowth karri sapwood from Big Brook Block, Pemberton District

	Mean starch (% w/w)			
Treatment Method	**May '87**	**Aug/Sept '87**	**Feb '88**	**May'88**
No treatment (controls)	0.70	0.59	0.35	0.27
Ringbarking (March '87)	N/A	0.63	0.17	0.19
Felled (Sept '86 with crown intact)	0.39	0.23	0.21	0.19

N/A = Not assessed

Starch levels declined more rapidly in the dry storage logs compared with the logs stored under intermittent water spray (Tables 3, 4). Ringbarked trees had a greater rate of starch depletion than trees felled with their crowns intact (Table 5). However, trees were treated at different times of the year, and the initial starch levels were unknown, so caution should be exercised when interpreting these results. Standing, untreated regrowth karri showed starch levels varied according to season and, more importantly, rainfall. When low starch levels were recorded, the monthly rainfall was correspondingly high.

Trees which have well-marked seed years at long intervals (e.g. beech) have a corresponding variation in reserve materials (Wilson 1935). A combination of high rainfall and the occurrence of a seed year could have resulted in a decline in starch levels. Starch levels were found to vary more widely between trees than within trees (Simpson 1988).

For starch levels to decline in wood, it is necessary for starch to be degraded and used either by the tree or by invading organisms. Both processes entail respiration which involves exchange or transport of oxygen and carbon dioxide. Factors affecting transport such as solubility and diffusion rate may be the reason for spray or wet storage logs having relatively slow starch depletion rates (Simpson 1988).

Immunity starch level

A simple, rapid and convenient means of determining the starch content of small wood samples would be useful, particularly in relation to work on the immunity starch level for *Lyctus* i.e. the amount of starch in wood which is just insufficient for the needs of *Lyctus* larvae (Parkin 1936). The determination of the immunity level, however, is complicated by the fact that the life cycle of *Lyctus* can be extended to two years, instead of the normal one, in wood containing a relatively small quantity of starch. It may be possible to extend the period of development even beyond this time.

Girdling methods

Girdling involves removing a band of tissue down to and including the cambium, thus interrupting the downward passage of sugars manufactured in the crown. The effect of girdling during the period of active growth would have a more drastic effect on the tree than if the operation were prior to the commencement of growth. A large quantity of starch is removed from the sapwood during fruiting and seed production (Phillips 1938), and girdling should occur during these periods.

Brimblecombe (1945) showed that starch depletion is practicable in lemon scented gum and spotted gum by means of high ringbarking at just below crown break, rendering the wood immune to *Lyctus* attack for a maximum period of 6 months in lemon scented gum and 8 months in spotted gum. During the course of the investigation 80 per cent of the trees survived the treatment, with only 4 trees dying within 6 months and another 20 within 12 months. No trees died before there was complete resorption of starch from the sapwood, but most died soon afterwards.

Parkin and Phillips (1939) carried out three experiments, investigating the variation in starch content following girdling of English oak (*Quercus robur* L.). They concluded that where felling can be planned 1 to 2 years ahead, girdling at the top of the bole offers a means of rendering about 85 per cent of the trees relatively low in starch content and 40 per cent immune against *Lyctus* attack. Owing to the great starch variability which may be encountered, it is not possible to guarantee success of the treatment.

In the Northern Hemisphere, girdling should be carried out in June, then felling in the following January. There seem to be no advantages in leaving trees standing any longer. The type of girdle is unimportant in relation to starch depletion, as long as the bark is cleanly removed from a ring 15 to 25 cm wide. Shallow notching is recommended as the safest type; deep notching is to be avoided because of the greater potential for fungal attack.

Starch is reduced in large quantities only in that part of the trunk below the girdle. Treatment should be carried out as high up the tree as possible. Better results will be achieved if epicormic shoots are removed when they emerge, and girdling done during the summer following a good seed production year. A combination of girdling with subsequent log storage for a few months will further reduce the starch content.

Parkin and Phillips (1939) concluded that, unless further depletion is achieved by subsequent log storage, starch depletion by girdling cannot be considered sufficiently reliable for general commercial use, because there may be a small percentage of trees still containing starch. However, trees with narrow sapwood, high recent growth rate, a vigorous but compact crown and long clean bole free from epicormic shoots appear to rapidly deplete their starch reserves.

Storing of logs in the round with bark intact
In this method the ends of the logs may be coated with an antiseptic moisture-proofing substance to reduce drying rates.

Parkin (1938), using short lengths of oak (*Q. robur*), ash (*Fraxinus excelsior* L.) and walnut (*Juglans regia* L.) branchwood, observed that depletion of starch from the sapwood proceeds while the cells remain alive. During the depletion process, the risk of fungal stain or decay depends upon the species, and the conditions under which logs are kept. Ash logs usually possess a wide sapwood band and cannot normally be rendered starch-free after one year's storage under English weather conditions. The relatively narrow sapwood band on oak logs would be generally starch-free after storing for 12 months in the open or under cover, irrespective of whether or not the bark was intact.

Using young ash logs, Wilson (1933) found that starch had completely disappeared when the logs had been stored under cover for 12 months. Examination at intervals during the year showed that the starch depletion took place gradually from the bark inwards, and more rapidly in the first four or five months.

Storing of logs and timber in water
This method overcomes certain disadvantages of the above method, because it minimises the danger of attack by wood-destroying or staining organisms, prevents moisture loss and allows greater control of the temperature. Increasing the carbon-dioxide concentration may accelerate the respiration process, but low concentrations of oxygen (particularly in stagnant water) may require artificial aeration to maintain normal aerobic respiration. Leaching of soluble food reserves will tend to hasten depletion (Phillips 1938). Log immersion after the death of the sapwood cells will result in no further starch depletion.

Kiln treatment of sawn timber
This method involves using a relatively high temperature (around 40°C) to accelerate respiration, and also a high humidity to minimise moisture loss (Phillips 1938). Temperatures above the optimum required for respiration, and inadequate humidity control will result in death of sapwood cells and starch fixation. Conditions favouring growth of mould and sap-stain fungi should also be avoided.

Harris (1961) investigated the effect on starch depletion, and consequent susceptibility to *Lyctus* attack, by kiln and air drying oak (*Q. robur*). Under the conditions of the experiment neither method of drying resulted in sufficient starch depletion to render all material immune from *Lyctus*. Much greater starch depletion, and consequently less *Lyctus* attack, was produced by kiln drying than by air drying. Practically all air-dried boards were attacked, compared with approximately half of the kiln-dried boards. The greater starch depletion in kiln-dried oak sapwood must be attributed to the initial stages of the schedule when a relatively moderate temperature (40.5°C) and a high relative humidity were operating.

The effect of different temperatures on the rate of starch depletion in green oak discs showed that respiration and starch depletion is near the optimum at 40°C and is prevented at 45°C (Harris 1961). At 43.5°C results were somewhat inconclusive, slight depletion occurring during the first few days but not increasing subsequently. The most favourable conditions for depleting starch in the air-dried timber would be warm, humid weather, and the most unfavourable, warm dry weather.

Where kiln schedules commence at 45°C or above, rapid death of the cells and fixation of starch occurs. Drying*Lyctus*-susceptible timber at temperatures of about 45°C or above would probably result in less starch depletion and greater susceptibility to *Lyctus* than occurs following air-drying.

Lyctus Susceptibility Trial - CSIRO

Joint trials between the Department of Conservation and Land Management (CALM), and CSIRO Division of Forestry and Forest Products are investigating the susceptibility of regrowth karri and W.A. sheoak to attack by *L. brunneus*. Both high temperature dried and air-dried samples were subjected to *Lyctus* attack. Two different provenances and ages of regrowth karri have been examined (Creffield *et al.*, 1987b; 1988) and one provenance of W.A. sheoak (Creffield *et al.* 1987a).

Currently, mature and regrowth jarrah (*E. marginata* Donn ex Sm.) from three areas of the jarrah forest (western, eastern, and southern), mature karri from three sites (northern, central and southern), and regrowth karri (45-50 years old) stored under intermittent water spray (15 min on: 105 min off) for 0, 1.5, 3, 6, and 12 months are being inoculated with *Lyctus*. Results from this series of trials will be reported jointly by CSIRO and CALM, and a recommendation on *Lyctus*-susceptibility of these species and on a method for reducing *Lyctus* attack will be made.

METHODS OF PREVENTING ATTACK

In Australia, *Lyctus* attack is common in most areas except Tasmania and eastern Victoria. In Queensland and New South Wales, where rainforest species often have a very wide sapwood band and in some cases are virtually all sapwood, it was necessary to introduce legislation to control the sale and use in those States of wood products containing sapwood susceptible to *Lyctid* borers (Bootle 1983). The current Acts are the Timber Marketing Act 1977 in New South Wales, and Timber Utilization and Marketing Act 1987 and Timber Utilization and Marketing Regulations 1987 in Queensland.

These Acts and Regulations require that timber from which a long life might reasonably be expected by the purchaser, shall not contain sapwood which is susceptible to attack by lyctid borers, unless it has been impregnated by a preservative approved by the relevant forestry authority. The State Government organisation specifies the required concentration of the approved preservative and registers the treatment plant. In those two States, importation of susceptible timber from elsewhere in Australia and from overseas also come within the ambit of the Acts.

The New South Wales Act is more lenient because it permits framing timber, which is out of sight in the finished building, to have up to 25 per cent of its perimeter in susceptible sapwood. This avoids wasting those pieces of scantling with corners of sapwood.

Modification of moisture content

The female beetle lays her eggs in the pores of exposed sapwood when the timber moisture content is within the range of approximately 8 to 25 per cent (Bootle 1983). Howick (1968) quoted a sapwood moisture content range of 10 to 20 per cent. Timber surfaces dried for two or three weeks have been known to be attacked. Fisher (1939) found that *Lyctus* could attack in one week. Fisher's experiments did not determine how moisture content affected the rate of larval development, but showed that eggs can be laid and larvae will feed in comparatively moist oak timber.

Fisher commented that oven-dried oak sapwood, allowed to absorb moisture from the air before exposure to beetles, was attacked just as readily as oak which had not been oven-dried. If a chemical change takes place when drying timber, this apparently does not determine whether or not it will be attacked by *Lyctus.*

Introduction of predators and parasites

Lyctus species are subject to attack by predators and parasitoids, but the control achieved is unreliable and not a satisfactory alternative to artificial methods (Anon 1959). Two predaceous beetles of the family Cleridae, *Tarsostenus univitartus* (Rossi), and *Paratillus carus* (Newm.), are commonly found in and on *Lyctus*-infested wood. Both are approximately the same shape and size as *Lyctus*. Three small black wasps, *Hecabolus sulcatus* (Curtis), *Eubadizon pallidipes* (Nee) and *Scleroderma* spp. have been recorded as parasitoids, and a mite, *Pediculoides ventricosus* (N.), occasionally causes heavy mortality of *Lyctus.*

Removal of sapwood

As only sapwood is attacked by *Lyctus*, its careful removal offers the first method for prevention of attack or spread of borers. This method is practical for scantling, but is uneconomical for some furniture woods, and it is advisable to treat the timber. If starch is absent from the sapwood, then no control measures are necessary.

General hygiene

When sapwood is included in furniture timbers, care should be taken that waste sapwood pieces are not left lying in timber storage sheds. Such pieces become breeding places for *Lyctus* and act as sources of infestation.

Timber containing sapwood should be isolated and separated from sound wood. In this way, regular inspections are required and preventative action taken at the first sign of damage. Frequent inspection of timber, particularly in spring and early summer, is required to indicate attack. Stickers or strips containing susceptible sapwood are a serious source of infestation and should not be used.

Heat sterilization

This is the most effective method of killing *Lyctus* in all stages of its life cycle. However, timber which has been sterilized by suitable heat treatment or kiln drying is not immune from further re-infestation (Anon 1935). Reconditioning treatment for removal of collapse effectively sterilizes susceptible timbers.

When round logs are infested with *Lyctus,* sterilization can be carried out by placing the log in a steaming chamber and heating with steam for about 3 to 6 h.

Chemical treatment

Immunisation treatments against *Lyctid* borers involve the penetration of susceptible sapwood by diffusion using an aqueous solution containing boron and/or fluoride. Such preservatives are leachable when subject to frequent wetting. However, if the treated wood is used either indoors or painted, the wood will remain resistant to these borers so long as adequate amounts of preservative remain in the wood (Barnacle 1985).

Where remedial treatments are required for *Lyctus,* usually an approved insecticide in a light organic solvent e.g. kerosene or mineral turpentine, is used either by injecting into flight holes or by brush application.

Under the Queensland Timber Utilisation and Marketing Act (T.U.M.A) of 1987, the following preservatives are approved:

boron - 0.035 per cent (w/w) boron or 0.2 per cent (w/w) boric acid, applied by using the dip diffusion method

CCA - applied by using the vacuum pressure treatment method

dieldrin and sodium fluoride - applied in solution.

Dieldrin is approved by T.U.M.A., but is not used commercially in Queensland, and sodium fluoride is used only in small amounts. The Australian Standards had recommended these chemicals.

If only small quantities of preservatives are needed, it is usually more economical to purchase a proprietary brand of prepared preservative (Barnacle 1985).

Williams and Mauldin (1985) recommended the following for commercial trial treatments of freshly sawn banak (*Virola* spp.) and similar woods in the Brazilian Amazon:

(i) Treatment solution - In situations where most boards are 38 mm thick, a 25 to 30 per cent boric acid equivalent solution of sodium borate should be used and 4 to 5 kg of sodium pentachlorophenate (Na PCP) added for mould prevention in each 1000 L of solution.

(ii) Because heated solutions yielded better results and steam heat is often readily available, the treatment solution should be maintained at 50° to 60°C.

(iii) Dip time - A minimum time of 1 min is suggested.

(iv) Diffusion storage - Boards should be placed on piling sticks immediately after dipping and stored under a roof or other cover for 1 week.

(v) Other factors - Low wood moisture caused by delay between sawing and treating, or procedures used for piling treated lumber, may affect the penetration of boron into wood.

Williams and Amburgey (1987) found that borate dip-diffusion treatments will protect banak lumber and mouldings from *L. brunneus* at a boric acid equivalent (BAE) level below 0.2 per cent. However, at this concentration, boron treatment did not protect banak lumber from mould or soft-rot decay fungi. The borate treatment is most suitable for wood exposed in nonleaching conditions above ground, where it is protected by a roof or finish such as paint or water repellent.

Application of insecticide

For products such as flooring boards, joints, rafters and posts, the liquid can be applied with a brush, spray or dipping. With polished, painted or stained surfaces the best method is to insert the liquids through the flight holes with a hypodermic syringe (Anon 1935).

This is an in-service treatment, but it is preferable to prevent attack before the finished product is put in-service.

The best time for treatment is during spring and summer. Spring would be preferred as the grubs work closer to the surface to build their pupal chamber, and are more readily reached by the insecticide (Anon 1935).

Fumigation with certain poisonous gases may be employed in special circumstances, but owing to the danger inherent in the use of such substances, this means of control can only be carried out by experts (Anon 1959). In any case it gives no immunity to later attack.

Ito *et al.* (1976) investigated the use of three insecticides; permethrin, fenitrothion and chlordane, against *Lyctus* larvae infesting wood of lauan and meranti (*Shorea* spp) timber groups or on an artificially prepared diet. They found that of the three insecticides, permethrin showed the most rapid action and highest efficacy against the larvae in the wood. Permethrin is slightly less hazardous than fenitrothion but contact and stomach toxicities of chlordane were the lowest among the three insecticides. Permethrin showed the highest preventive efficacy against attacks of the *Lyctus* beetle among the three insecticides, and treatment at 0.01 per cent could protect sapwood of the woods for the experimental period of three months.

Peters (1986) sprayed spotted gum (*Eucalyptus maculata* Hook.) logs with different chemicals to give protection from *Lyctid* and *Bostrychid* beetles. Complete protection for at least six months occurred when logs were sprayed with permethrin (0.1 per cent), deltamethrin (0.01 per cent), dieldrin (0.5 per cent) and PP321 (0.01 per cent).

Paton and Creffield (1987) investigated the tolerance of some timber insect pests to atmospheres of pure carbon dioxide in air. They found that *L. brunneus* survived exposure to 100 per cent carbon dioxide for seven days. However, a lack of information on insect numbers and stages present prior to exposures, and the limited number of infested blocks available, prevented them from qualifying the effect of carbon dioxide on *L. brunneus.*

It would appear that insects possess the potential to adopt and occupy niches where, for relatively long periods, levels of carbon dioxide are high and oxygen is low or absent. This adaptation can be made relatively quickly as has been demonstrated in *Misitophilus granarius* (L.) where a threefold tolerance to carbon dioxide was demonstrated in seven generations.

Filling the wood pores

If the wood pores, including both side and end grain, are effectively filled, then deposition of the eggs is prevented. A filler like linseed oil and barytes, varnish, gloss oil or wax could be applied on all surfaces. This will add slightly to the cost of the furniture, but it will protect such furniture free from attack provided eggs have not been laid before applying the pore filler.

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