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1. Wood Structure and its Relation to the Penetration of Preservatives. By E. H. B. Boulton, M.A. (Technical Director, Timber Development Association, Ltd.).
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3. The Control of the *Lyctus* Beetle. By Dr. S. E. Wilson, M.Sc., Ph.D., D.I.C. (Chief Executive Officer and Secretary, National Home Grown Timber Council).

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1937

WOOD STRUCTURE AND ITS RELATION TO THE PENETRATION OF PRESERVATIVES

By E. H. B. Boulton, M.A.
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To understand the absorption and penetration of preservatives it is necessary to have a working knowledge of the structure of wood. There is a very marked distinction between the wood of the conifers (commercially called softwoods) and that of the angiosperms (called the broad-leaved trees or hardwoods).

The structure of the conifers is by far the simpler of the two, as the vertical cells are practically all of one kind, except for the scattered " resin canals." These cells are called " tracheids " and have numerous openings in their walls, especially on the radial walls, called " bordered pits." Horizontal resin canals are found in the genera Pinus, Picea, Pseudotsuga and Larix, and are an aid to the penetration of preservatives.

The simple pits found in the ray parenchyma are also an aid, and preservatives travel along these ray cells for some considerable distance.

The wood of hardwoods, however, is much more complex, as the vertical cells are exceedingly variable both in size and character. The vertical cells consist of wood fibres, vessels and some wood parenchyma cells.

Tracheids occur in all woods in some form. They are, however, often so infrequent in the hardwoods as to be of little consequence. They always have the peculiar bordered pits in the walls.

The vertical tubes known as vessels or pores form more or less continuous tubes throughout the length of the tree, and, unless clogged with ingrowths, known as " tyloses," or gums or other vessel deposits, allow a free passage of fluids vertically. These deposits are found in the Heartwood and are largely responsible for the resistance to penetration.

There are many factors that influence the resistance of wood to penetration of fluids. Trees of the same species grown in different localities may differ greatly in their properties. Timber which has just been felled, and which is, therefore, in the green condition, is, as a rule, very much more resistant to treatment than that which has had the moisture removed. The method of seasoning may also have a bearing on the resulting penetration and absorption of preservatives. The moisture content of the wood is a very important factor.

The ease or difficulty of securing a satisfactory penetration does not appear to depend upon the density. Woods having high specific gravities are sometimes treated with greater ease than species of much lower specific gravity, and *vice versa*.

In general, longitudinal penetration is much greater than radial or tangential penetrations.

A much greater variation in penetration is found in the diffuse-porous than in the ring-porous species. Diffuse-porous hardwoods are those woods with a structure consisting of vessels gradually diminishing in size from Spring to Summerwood, whereas a ring-porous wood is one in which large vessels are arranged in the Springwood and immediately diminishing in size in the Summerwood. In diffuse-porous woods the tyloses are not so uniformly distributed, which causes irregular penetrations. Diffuse-porous woods also show considerable variation, due to gums, infiltrating substances, and cross-grained structure.

When the pores or vessels are closed penetration must pass through the cell walls or through the pitting in the cell walls. Wood fibres in the Sapwood take treatment far more readily than the Heartwood. Penetration and absorption of the preservative is much less uniform in woods of the diffuse-porous group than in the ring-porous, probably because the tyloses in the vessels, and the gums and infiltrating substances, are less uniformly distributed in diffuse-porous woods. In many species of hardwoods little or no penetration of preservative occurs in the ray parenchyma cells.

With very few exceptions, all of the conifers contain either resin cells or resin canals, and some species contain both.

The distribution of resin cells varies in different species ; in some they are scattered throughout the wood, while in others they are arranged in zones.

The size of the cavity of resin canals varies in different species, the five-needle pines often having large cavities, whereas those canals found in three-needled and four-needled pines are much smaller. Larch and Douglas Fir have very small resin canals and have frequent constrictions which tend to close the canal. An exception is the Long Leaf Pitch Pine, where the resin canals are abundant, large and almost entirely without constrictions, except in the case of resin canals in the rays ; the rays as a rule are not penetrated. In some species, however, ray tracheids are penetrated and sometimes the whole ray, especially in Long Leaf Pine.

Open Springwood is difficult to creosote and penetration is always greater in the Summerwood, with one or two exceptions. Since the Springwood is difficult to treat, woods with wide Spring growth should be avoided, especially when the ultimate use of the wood is for paving blocks.

Much discussion has taken place as to whether the cell walls under pressure treatment are permeable to creosote or whether the oil passes through the pits, canals, and other cell openings. The first supposition is not likely to be correct owing to the erratic and very rapid penetration

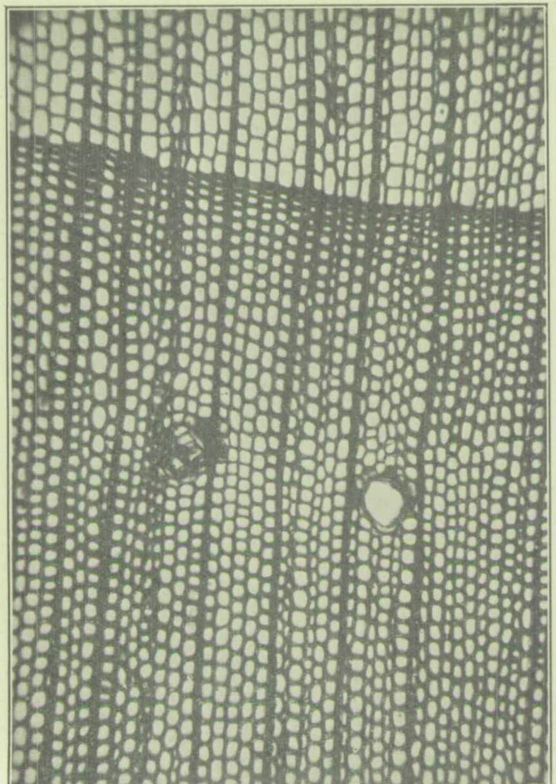

PLATE I

Vertical resin canals, open and closed by tyloses *Pinus sylvestris*
(Transverse section)

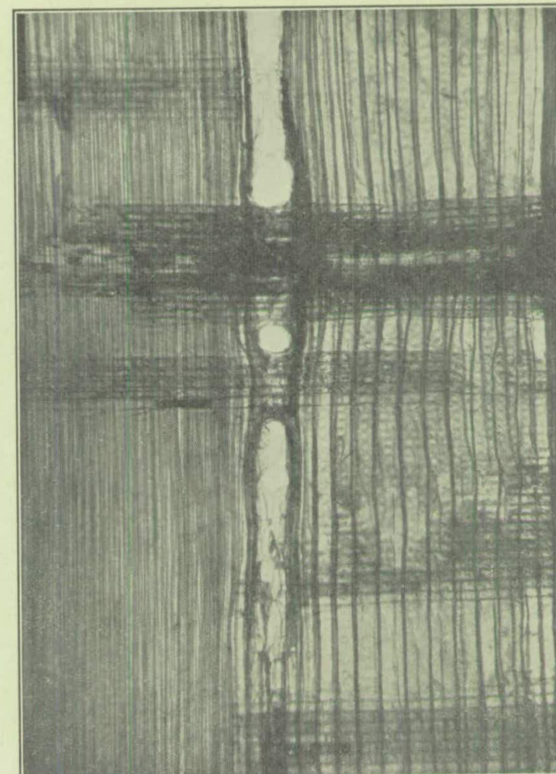

PLATE II

Vertical resin canal in longitudinal section *Larix decidua*
(Radial section)

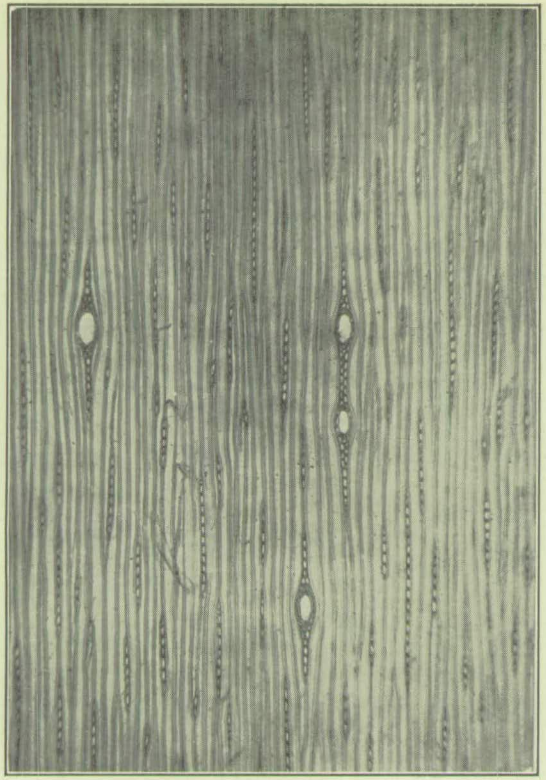

PLATE III

Horizontal resin canal in rays *Picea excelsa*
(Tangential section)

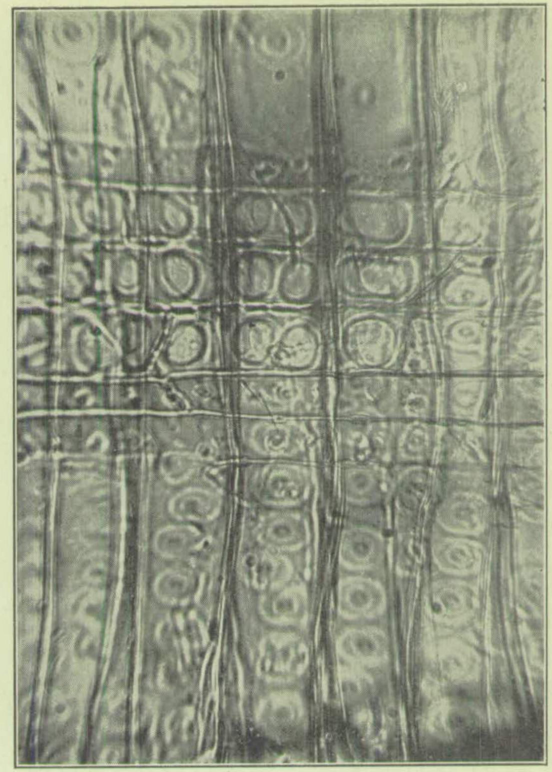

PLATE IV

Ray showing simple pits and tracheids-bordered pits *Pinus strobus*
(Radial section)

of certain species, especially those with thicker-walled Summerwood tracheids, whilst the thin-walled Springwood tracheids resist the penetration. It has been suggested that minute seasoning slits appear and allow a more easy method of penetration.

No satisfactory theory or explanation of the variation of absorption or penetration of wood by creosote has yet been put forward.

The following points are important and further study is necessary to solve the difficulties.

The dense Summerwood in the conifers is usually easier to penetrate than the Springwood. In most pines the penetration of the Springwood is usually very erratic; often some portions of the wood may be easily penetrated whilst other parts almost entirely resist the creosote.

In all pines, spruces, larches, and Douglas fir the Sapwood is more penetrable than the Heartwood. In the silver firs and hemlock both Heartwood and Sapwood are about equally penetrable. The results of penetration cannot be applied to even the same species, however similar in structure they may appear.

TESTING WOOD PRESERVATIVES IN THE LABORATORY

By W. P. K. Findlay, M.Sc., D.I.C.
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Introduction

Field tests and service trials of wood preservatives cannot yield definite results for a number of years, and it is therefore important to have some rapid means for determining whether a substance has any preservative value before submitting it to lengthy and expensive full-scale tests. While the final test of any wood preservative will always have to be made on the actual materials which it is designed to protect, we can by laboratory tests eliminate worthless and unsuitable substances. In fact the laboratory test must be regarded as "a sorting out" test, so that full-scale or commercial trials shall be made only on substances which have proved promising in the preliminary laboratory tests. What then are the characteristics which a good wood preservative should possess and by which we may judge it in the laboratory?

First. *Toxicity* or killing power towards the decay-producing organisms.

Second. *Permanence*; for example, a substance which is highly volatile may be useful as a fungicide or insecticide, *i.e.* it will kill infection already present, but will be useless as a preservative.

Third. *Penetrating Power*, *i.e.* ability to penetrate into wood during impregnation processes.

Fourth. "*Inoffensiveness*," under which may be grouped absence of corrosive action, unpleasant smell, poisonousness, etc.

In this paper only tests for toxicity will be considered in detail, and a brief reference made to tests for permanence. As regards the last heading, special tests are required according to the purpose to which the preservative is to be put. For instance, if a preservative is to be used for the preservation of sleepers it must not corrode the iron chairs, and tests of its effect on metals will be necessary—again, if it is to be used on the insulating timber of a cold store, it must not have an odour which will taint food. A point to be emphasized here is that a preservative must be considered in relation to the particular purpose for which it is required. This is now being recognized and many special preservatives are being prepared. The extraordinary success of creosote as a wood preservative for so many purposes perhaps has made us lazy in looking for substances suitable for those special cases in which creosote cannot be used. There is no one best preservative for all purposes, and this should be borne in mind when making our laboratory tests.

Toxicity Tests

A number of different methods have been designed to test the toxicity of wood preservatives. Some of these have been made using artificial media, while others have employed wood in various forms as the substratum. A very complete survey of these methods has been made by van den Berge (5), in a thesis which has been translated into English. We need not refer here to much of the earlier work, except to note that owing to the lack of a standard method it is impossible to compare the results obtained in one laboratory with those obtained elsewhere.

In 1915, Humphrey and Fleming (2) published a description of a method for testing wood preservatives in an agar medium, and this method, with slight adaptations, having since been very extensively used in the United States, in 1930 a meeting was held at St. Louis to attempt to standardize closely the conditions under which the test should be made. A paper by Schmitz (4) describes the standard test which was agreed to at this meeting. Shortly after this Dr. von Schrenk visited Europe and called together at Berlin a conference of the European workers in this field. At this conference it soon became apparent that there was a great cleavage of opinion between the workers on this side of the Atlantic and on the other. Particularly in Germany, the so-called " wood-block test " had been developed, and was regarded as very much more reliable than the agar test. As a result of this conference a committee was set up to go into the details of the wood-block tests and to determine how far reliable results can be obtained in different laboratories using this test. The results of this committee's work have recently been published (3), and were briefly reviewed in Vol. V of the Journal of this Association. The general conclusion was that the agar test must be regarded solely as a preliminary test, and that the wood-block test, if carried out under standardized conditions, can give quite reliable results, but that an estimate of the efficiency of any preservative should not be made solely from the results of any toxicity test.

A number of American workers have used sawdust or wood pulp as a medium instead of wood blocks in order to get a more uniform distribution of the antiseptic. The difficulty of such tests is to estimate the amount of growth which takes place in the sawdust, and, on the whole, the use of sawdust instead of wood seems to introduce more difficulties than it avoids.

Agar Tests

I do not wish to go into any details concerning the agar or petri dish test, but it is worth referring to it briefly, since it is useful in that it gives a quick indication of toxicity, particularly in the case of water-soluble salts, and also it is of value for comparing the toxicity of a series of closely related chemical compounds. The basis on which preservatives are compared is the " toxic point " or minimum quantity of the preservative in the medium which inhibits all growth of the test fungi. Various amounts of the preservative either in the form of aqueous solution or, in the case of oils, in an emulsion with gum-arabic are added to definite amounts of 2 per cent. malt agar, the total volume being kept constant in each case. A series of concentrations is prepared and the preservative, well mixed with the medium, is then poured into petri dishes which are inoculated, when the medium has solidified, with a small transplant from an active culture of the test fungus. The dishes are kept under observation for 4 weeks, and the concentration of preservative which just inhibits growth is noted. It is very important that the preservative should not be sterilized in contact with the medium, since during the heating a reaction may take place which reduces the effective amount of preservative.

A number of test fungi must be used, since fungi vary greatly in their resistance to antiseptics—a fungus which is resistant to one antiseptic may be sensitive to another ; for instance, *Lentinus lepideus* is resistant to creosote but very sensitive to zinc salts. *Coniophora* is sensitive to creosote but resistant to zinc. In all our tests at Princes Risborough 3 or 4 test fungi are used.

Wood-Block Tests

In principle the wood-block test is quite simple. Small blocks of sterilized wood are treated with various concentrations of the antiseptic under test and then exposed to severe fungal attack under controlled conditions. In practice certain difficulties of technique are met with. Firstly, there is the difficulty of obtaining uniform treatment of the wood, and secondly of maintaining sterile conditions so that the blocks in the pure cultures of the test fungi do not become contaminated with moulds.

The test blocks, which measure $5 \times 2{\cdot}5 \times 1{\cdot}5$ cms., are cut from a selected piece of uniform timber. It is essential to use for the test pieces some wood which itself is readily decayed, that is to say, one which has a very low resistance to fungal attack. The two timbers which have been found most satisfactory are Scots pine sapwood and the outer wood of beech ; both of these readily take up preservatives.

After sterilization and drying in an oven at 100° C. for 18 hours the blocks are weighed to the nearest centigramme and then treated with the wood preservative solution. The impregnation of the blocks is carried out by exposing them to vacuum for 10 minutes while submerged in the liquid in which they are then allowed to soak for 2 hours. In the case of water soluble salts, aqueous solutions of these at various strengths are prepared, but in the case of oils a volatile solvent such as acetone can be used. The blocks are weighed after treatment to determine the amount of preservative absorbed. After treatment with an aqueous solution the moisture content of the blocks must then be reduced from saturation to a point suitable for growth, *i.e.* to about 40 per cent. of the oven-dry weight, or, if they have been treated with the preservative in an organic solvent, this must be completely evaporated. After treatment the blocks should not be exposed to high temperatures, and we carry out this drying in a special oven maintained at 50° C. and provided with a forced circulation with filtered air. The treated blocks are exposed to fungal attack by placing them in flasks containing an actively growing culture of a wood-destroying fungus growing on 5 per cent. malt agar. They are usually supported on small frames so that they come into contact with the fungal mycelium, but not with the medium into which the preservative might leach away.

The flasks containing the test blocks are kept in an incubator at 22° C. for 3 to 4 months, sterile water being added occasionally to the reservoir in the necks of the flasks to keep the air inside saturated with moisture. At the end of this period the blocks are removed from the flasks and examined for signs of fungal growth and decay. They are then freed from any superficial mycelium, weighed, and, after oven-drying, reweighed. If any appreciable decay has occurred it will be shown in a loss of dry weight, which may be determined by subtracting the final dry weight from the initial dry weight, allowance being made for the weight of preservative absorbed, only when the strength of the treating solution is over 1 per cent. A difficulty may arise when the preservative itself is partially volatile, in determining the true loss in weight of the wood itself, and in such cases it is best to determine by visual and manual inspection whether a block is at all decayed. A loss in weight of less than about 3·0 per cent. should not be considered as significant.

The toxic point which is the basis on which preservatives are compared is the minimum quantity of the preservative in the wood which prevents all decay ; this should be expressed as weight of preservative per unit volume of wood, *e.g.* kgs. per cubic metre of wood. It is useful also to quote the strength of solution which was required to give this concentration in the wood. The toxic point should be expressed as the interval between the concentration which just allows slight decay and the concentration next above it in the series at which no decay takes place.

Comparison of Tests in Agar and in Wood

It is obvious that the physical and chemical reactions which take place between an antiseptic and a colloidal jelly such as malt agar must be quite different from those which take place between the antiseptic and wood.

The results which are obtained from tests in agar media may bear only a distant relation to the efficiency of the preservative in wood. A single example will suffice to illustrate this point: mercuric chloride is shown by agar tests to be extremely toxic to wood-destroying fungi, the toxic point to several fungi lying about 0·01 per cent. If now we test this substance in wood, we find that a concentration of preservative about 10 times as great is required to check all fungal growth. This may be explained by the fact that mercuric chloride is adsorbed by the cell walls of the wood, becoming to some extent "fixed." Comparing now the toxic point for sodium fluoride in agar and wood, we find that they are approximately the same, *i.e.* about 0·2 per cent. This means that if we were using the agar test as a basis of comparison we should consider mercuric chloride about 10 times as toxic as sodium fluoride, while actually we find that in wood they are only about equally toxic.

The argument that has always been levelled against the wood-block test is that it is impossible to get accurate, closely reproducible results with it. That is so—the results that are obtained may vary sometimes by as much as 25 per cent., but they are always *of the same order of magnitude*, and do not lead to a practical error of 1,000 per cent., which is what we are actually facing when we compare the effective toxicity (*as a wood preservative*) of sodium fluoride and mercuric chloride in agar media. Tests of antiseptics in artificial media such as agar may be of great value in fundamental studies of toxicity, but they cannot be used to gain an indication of the toxicity in practice of a wood preservative. We must distinguish in our minds between tests that may be used in purely scientific studies and tests which bear some relation to actual practice.

Choice of Test Fungi

The test fungi chosen must have certain characteristics. They should be :—

1. Able to cause rapid decay in the species of wood used.
2. Highly resistant to antiseptics.
3. Fungi of economic importance.
4. Easily cultivated and not unduly sensitive to slight variations in environmental conditions.

For tests on Scots pine sapwood we use :—

Coniophora carebella, Pers., one of the "dry rot" fungi which is responsible for extensive decay of structural timbers under very damp conditions.

Lentinus lepideus, Fr., the chief fungus responsible for the decay of imperfectly creosoted poles, sleepers, and paving blocks. It is very resistant to creosote.

Poria vaporaria (Eberswalde Strain), one of the fungi which cause extensive and rapid decay in pit props.

For tests on beech :—

Polystictus versicolor (Linn.), Fr., the most important fungus causing decay in hardwoods out-of-doors in this country.

Different isolations of the same fungus may vary in their resistance to antiseptics, and it is desirable to carry out tests in different laboratories with standard strains of the same fungi, which have all been obtained from some central source.

Tests of Permanence

It depends very largely on the purpose to which the treated timber is to be put as to whether the preservative should possess a high resistance to leaching or washing out with water. If the treated timber is to be used under cover in buildings there is no objection to its being soluble in water, since the timber will never be exposed to continuous washing ; similarly if the preserved timber is to be painted the preservative will be protected against washing out. On the other hand, where the treated timber is to be used in an exposed position out-of-doors, it is most important that the preservative should possess a high resistance against leaching.

No wholly satisfactory standardized test for determining this resistance to leaching of preservatives in the wood has yet been devised. It is, of course, quite easy to determine if a preservative can readily be dissolved out of the treated wood by simply exposing it to a stream of running water, but it is difficult to decide which of two substances both moderately resistant to leaching is likely to withstand weathering for the longer period. It is so difficult to imitate in the laboratory the varying effects of rain, sunlight, drying winds, frost, etc., to which timber in the open is exposed. An interesting attempt to combine the effects of heat, washing, and ventilation on the weathering of creosote was made by Gillander and others (1), who devised a " weathering machine," by means of which the treated samples were alternately exposed to washing in running water and to drying in a current of hot air. They concluded that this machine is able to bring about the same changes in the characteristics of a creosote as would be expected to occur under service conditions, and that the machine furnishes standard weathered blocks that may be used for direct exposure tests against cultures of different fungi.

I think one can to some extent use the results of such tests to predict the behaviour of a preservative in wood exposed to the weather, and it would be safe to conclude that any preservative which remained in the wood in sufficient quantities to protect it from decay, after such an exhaustive weathering process, did possess a fairly high resistance to leaching and would give effective protection over a number of years.

Application of Results of Laboratory Tests to Practice

Since the whole reason for carrying out tests on wood preservatives in the laboratory is to determine whether the substances will afford timber protection in service, it is necessary to examine what relation the results of these tests bear to the behaviour of the preservative in practice. How do the substances which have been proved to be satisfactory preservatives in practice show up in our wood-block tests? Generally speaking, one may say that all show a high toxicity when tested by the wood-block method. It must be remembered that the conditions of this test are severe—the treated wood being exposed to an active growth of fungus under conditions very favourable for its development. The infection is in fact more severe than is usually found in practice. It is reasonable to conclude, therefore, that any preservative which gives the wood protection under these conditions would effectively protect it under service conditions, always provided that its concentration does not become reduced by evaporation or leaching. So I think we may feel fairly confident that any preservative which is found to be highly effective in our wood-block tests would certainly prove to be satisfactory for internal use under cover. By means of leaching tests one can, then, form some idea as to how it would behave in use on timber exposed to the weather, but until further work has been done to correlate the results of these leaching tests with the results of service trials, we are not justified in concluding that a preservative is perfectly suited for the preservation of external woodwork from the results of laboratory tests alone. But we can now by laboratory tests eliminate from our field trials all the materials except those which are most promising and likely to give satisfactory results.

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THE CONTROL OF THE *LYCTUS* BEETLE

By Dr. S. E. Wilson, M.Sc., Ph.D., D.I.C.
(Chief Executive Officer and Secretary, National Home Grown Timber Council)

In recent years the *Lyctus* or Powder-Post Beetle has spread enormously through this country's stocks of certain hardwood timbers, both home-grown and imported, causing damage which represents a serious financial loss to merchants and manufacturers.

The extent of the infestation was described in 1932 by the Forest Products Research Laboratory in a publication entitled "A Survey of the Damage caused by Insects to Hardwood Timbers in Great Britain," from which we learn that the timber found to be damaged by *Lyctus* came mainly from Europe and America, especially the latter country.

One of the trade journals recently reported a speech by a Liverpool hardwood importer at the annual convention of the Hardwood Lumber Association in Chicago. The speaker stressed the necessity for vigorous action to deal with the ravages of the *Lyctus* beetle, which he referred to as "this terrible scourge," and he said "One of the biggest consumers in the old country told me he would have to quit using American hardwoods because he was having so much trouble and loss over *Lyctus*." For reasons which will be obvious to most of my hearers, the infestation of timber by *Lyctus* does not receive a great deal of attention in the press. Unlike the Death Watch Beetle, it has no popular news value. The occurrence of *Xestobium* in a church roof can be made to help in raising money for repairs to the building, while the blame for its presence cannot very well be laid at the door of any individual. On the other hand, *Lyctus* affects traders and manufacturers whose difficulties are in a very different category, because they cannot be made the basis for a sentimental appeal to the liberality of a sympathetic public.

Lyctus only infests recently prepared timber (for reasons which I shall shortly explain), and the responsibility for the damage so caused has to be accepted by people still alive and in business. Consequently the settlement of claims takes place without publicity, as the matter is the concern only of parties immediately interested.

Entomologists have, however, paid considerable attention to *Lyctus* in recent years, particularly in this country, and as a result of their work on the habits and life history of the beetle they have put forward recommendations calculated at least to reduce the extent of *Lyctus* infestation. One such recommendation is to carry out the sanitary measure of clearing away from timber yards any waste wood of the kind which might provide a source of supply of the beetle. This advice does not, however, assist those timber stockists who habitually keep their yards and sheds in a clean and tidy condition. Another recommendation is to use a heated chamber for killing off *Lyctus* already present in timber. The heat treatment necessary for this has been worked out for certain dimensions, so that such wood can now be satisfactorily sterilized. The use of this method implies that a certain amount of damage has already taken place and has been discovered, and that the timber is of suitable dimensions, *i.e.* of handy size and not too thick. There is a further serious consideration, viz. : that this sterilization by heat does not confer any immunity from reinfestation, so that the risk of further damage to the same timber remains. Heat sterilization is, therefore, of limited scope, of doubtful value, and also, in my view, of questionable morality. The reasons why I venture to criticize the recommendation will be appreciated when the life history of the beetle is borne in mind. I will here give only a brief account, and will illustrate, by means of lantern slides and samples of damaged timber, the stages through which the beetle passes during its life, its habits, and the damage it causes. The subject is already familiar to many of my audience.

It is the grub, or larva of the beetle, sometimes called "the worm," which does the damage, because that is the feeding stage in the life of the individual beetle. When hatched from the egg, which was laid by the parent beetle a short distance below the surface of the wood, the larva is a minute maggot-like creature. It at once begins to bite off and swallow exceedingly small bits of the surrounding wood, and as it eats so it bores a cylindrical tunnel, turning meanwhile on its long axis by using its rather feeble legs. All the time the bits of wood which it has bitten off with its jaws pass through its gut and are left behind in the tunnel, constituting what is known as "frass." By continually pushing against the frass behind it in the tunnel the grub gets sufficient purchase for nibbling away the wood in front of it. As it feeds it grows, so that the tunnel gets bigger in cross-section and ultimately is about the diameter of a darning-needle. There are usually several larvæ tunnelling in the same piece of wood. The result of their activities is that the whole of the solid sapwood becomes reduced to a fine powder, which is the "frass," except for a thin layer of undamaged wood which it leaves uneaten at the surface. The larvæ triturate the sapwood down to the heartwood line, but not beyond, so the heartwood remains undamaged.

The life of the grub, from hatching to the full-grown stage, normally occupies from Summer to Spring, and then the full-grown larva pupates where it finished feeding. During the resting period the larval form gives place to the adult beetle, which eats its way through the thin crust of wood at the surface, emerges through the flight-hole so formed, and crawls or flies away. Mating takes place between the two sexes, after which the females proceed to lay eggs in the pores or cracks in such sapwood as they deem suitable for the growth of the next generation. Sometimes two or more years are required for the full growth of the larvæ. Although summer is the normal season for emergence and egg laying, it has been found that in buildings and covered sheds the adult beetles may be about at almost any time of the year, so that, although the adults do no direct damage to the wood, new generations of larvæ, that is fresh infestations, may be starting all round the year.

Now to come back to heat treatment. How can you decide when to apply this treatment? It is true that you can kill off any of the living stages present in the wood by a process equivalent to roasting alive, but can you honestly use the already damaged wood afterwards? And, if you decide to work it up into some saleable commodity, how are you going to prevent later infestation? I am willing to admit that heat treatment does reduce the actual damage being done, and that to adopt that method is better than doing nothing. No doubt, if carefully timed, it is a feasible scheme of *partial* control. I understand that sterilization by heat has proved useful with such timber as oak furniture squares, walnut veneers, and other small dimensioned stock in which *Lyctus* had been found to be active. By taking steps to work up the treated material quickly after sterilization, and to get the finished products varnished or in some other way covered so as to prevent further egg laying, timber which would otherwise have become useless has been put into service with a much reduced risk of reinfestation. But heat sterilization is not a method which can be applied satisfactorily to heavy timbers, owing to the cost of handling and kilning, and the difficulty of getting thick pieces sufficiently hot right through, which must be done for the process to be effective. In any case, since only the sapwood can benefit by such treatment, it necessarily involves kilning large volumes of heartwood also, possibly to no good purpose.

The use of insecticides presents similar difficulties, as well as several others in addition, and it seems unlikely that much progress can be looked for in that direction. It must be borne in mind that any preventive or ameliorative treatment which is to be put into general practice must be such as will easily fit into the normal trading and handling of timber. It is obviously necessary to start applying any selected method at some clearly defined stage in the history of the timber as it travels from the felling of trees in the forest through the sawmilling, seasoning, reconverting, kilning, or air-drying and manufacturing processes into the finished article. One important feature of the handling of various timbers is the great variation in the time normally spent in its various stages, log by log, or piece by piece. We cannot in this country handle the whole of the winter's felling simultaneously or at all uniformly; and what, for example, are we to do with imported woods in which *Lyctus* may be present at any of its several stages at the time of arrival ? Where and when can you effectively apply any one selected treatment ?

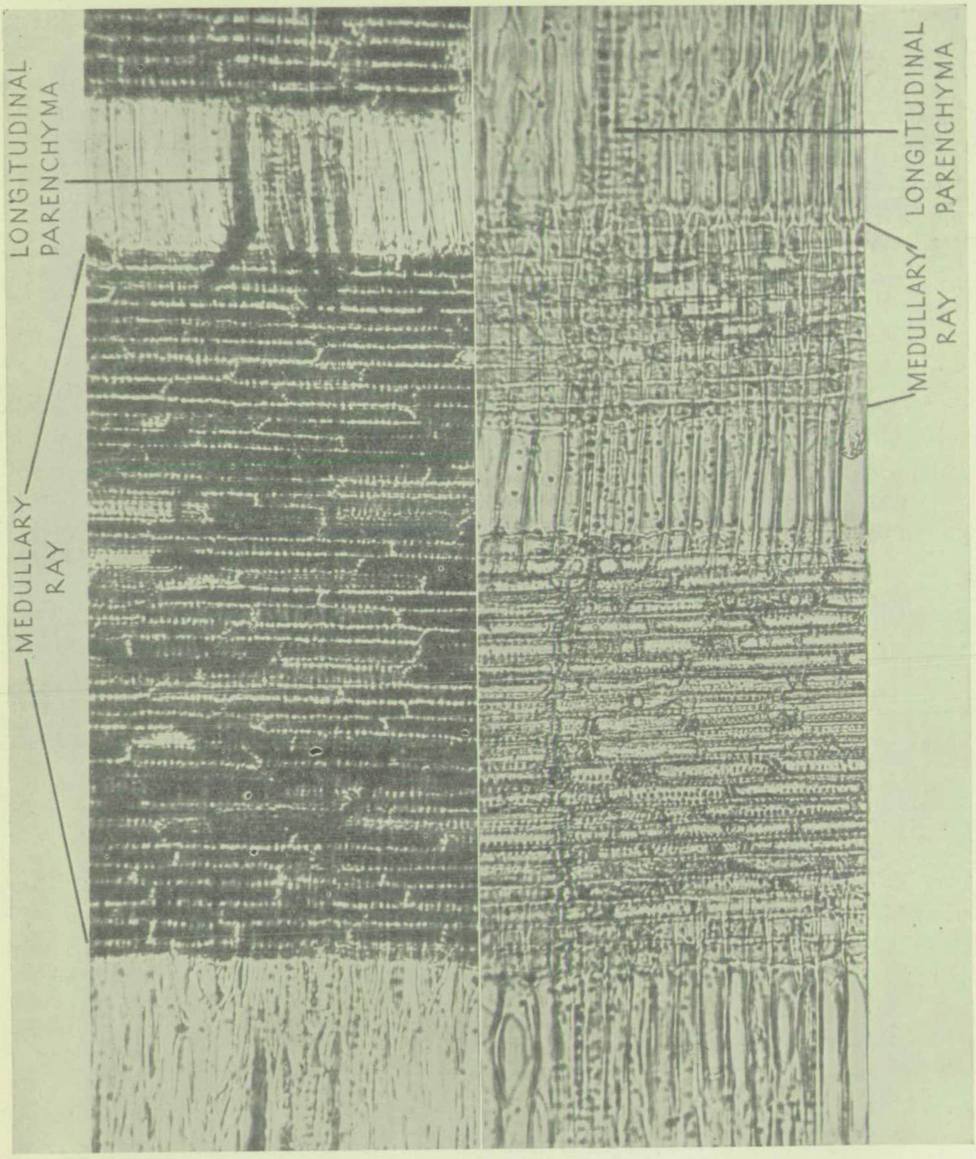
Another factor in the situation can now be mentioned. It is true that *Lyctus* infests only the sapwood of a limited number of kinds of timber. In this country, for example, the susceptible species are oak, ash, walnut, sweet chestnut, elm, sycamore, willow, and possibly a few others, but it is an undoubted fact that thousands of cubic feet of the sapwood of these so-called " susceptible " species pass each year safely into service entirely untouched by *Lyctus*, although freely exposed to infestation during the process of handling and preparation. This always has been so and is so to-day. Whatever the explanation for this striking fact may be, and we shall shortly see exactly how it comes about, it obviously puts out of court the need for any universal treatment of sapwood by heat or chemicals as being largely unnecessary and therefore unwarranted, thus confirming what I have just said, that to treat already damaged sapwood by heat or insecticides is not a scientific method of control, because it is always started too late, that is only after some damage has been done !

It was this striking variability in the incidence of *Lyctus* infestation, *i.e.* finding infested and uninfested pieces among material apparently identical in all respects when examined superficially, which led me to look for the fundamental cause of this apparent immunity. The question really was " By what natural means was this uninfested sapwood resistant to *Lyctus ?* " for it is impossible to believe that *Lyctus* would casually ignore the seemingly plentiful supplies of its natural food lying ready to hand.

Superficial examination proving inadequate, I turned to the microscope, and I applied micro-chemical tests to thin sections of the two lots of wood, the infested and the uninfested. A striking difference was thereby immediately revealed : the one contained starch in plenty, and the other none. Starch being an excellent food substance for many insects—many beetle larvæ feed on starch in various situations—this appeared to be the first stage in solving the riddle. After further examination of samples of several species of wood I was satisfied that starch is at any rate the principal food of *Lyctus*, that it eats sapwood only when it contains starch, uses the starch for nutriment, and discards the wood-substance as frass. Here also was an explanation of the fact that *Lyctus* limits its attention to sapwood, for starch does not occur in the heartwood.

Following up the " starch in sapwood " clue, the next discovery was the great variation in the amount of starch in different samples of sapwood, and in the different regions of the same piece of timber. Correlating this with the former, it was an obvious conclusion that the nutritional value of sapwood for *Lyctus* is determined by the quantity of starch it contains. So far, so good. But it was necessary to answer

PLATE V



Photomicrograph of thin radial section of sycamore sapwood, as at felling. Treated with iodine: starch shown black. × 200

The same after depletion. Starch absent. × 200

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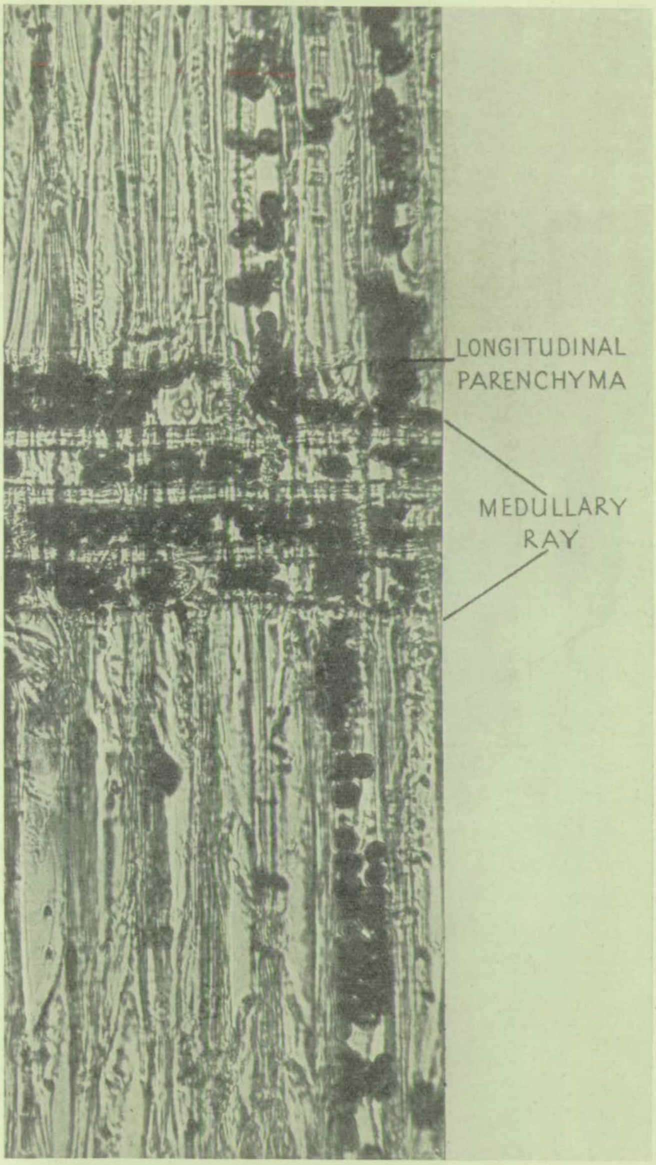
PLATE VI



The same as Plate V, more highly magnified, showing individual starch grains. ×535

(*Reproduced, by permission, from* FORESTRY, *the Journal of the Society of Foresters of Great Britain, Vol. IX, No. 2*) the important question : Why does the starch-content of sapwood vary so ? and if I could solve that, was there not a chance of *causing* the starch to vary, in short, of *eliminating* the starch from all sapwood by designedly applying the factors or conditions, could they but be discovered, which cause *some* sapwood to be starch free ? My aim now became the scientific immunization of all sapwood to *Lyctus* infestation, and I found I had embarked on a very big problem—one which, in fact, occupied much of my time for six or seven years before I was able to publish the whole story and to offer a commercially feasible method.

Time does not permit the retelling of that long story now. Indeed, it has not yet been fully told, though the principal events are related in my papers in the *Annals of Applied Biology of* 1933,* and the *Journal of the Society of Foresters of* 1935.†

I might in passing just mention that the working out of the method involved activities and facilities not usually available to entomologists. The plan of campaign necessitated acquiring land with growing timber and erecting a sawmill in order to be able to do exactly what I liked with my trees, and just when I liked as well—all that in addition to arranging research facilities in a science laboratory.

I must, however, mention a few of the main points in the story if I am to make my method of immunization intelligible.

Starch is the principal reserve food substance of some trees—not of all kinds, but notably of those mentioned earlier as being susceptible to *Lyctus* attack. Other trees store their reserves in the form of vegetable fat ; while others again have both starch and fat, either mingled or in separate zones. These reserve substances are located in the living " food cells " which occur only in the sapwood.

In the living tree, the quantity of starch varies with the season of the year—for example, reserves in the branches and trunk of a deciduous tree are heavily drawn on in Spring for leaf building. Similarly, a heavy seed crop in Autumn reduces the reserves of food in the sapwood. At felling time, that is, in winter, the sapwood of most of these trees contains a large quantity of starch, at times as much as 5 per cent. of the dry weight of the wood.

What happens to the starch when the tree is felled depends entirely on whether the food cells die quickly or stay alive for some time.

The starch is in the form of minute grains, normally transparent, but capable of being made visible by reason of the dark blue colour which starch attains when treated with iodine in a watery (not alcoholic) solution. When plentiful it is then visible to the naked eye. Smaller quantities can be seen by means of a lens or a microscope.

* Wilson, S. E., " Changes in the Cell contents of Wood, and their relation to the respiration of wood and its resistance to *Lyctus* attack and Fungal Invasion." *Ann. Appl. Biol.*, xx, 4, 1933.

† Wilson, S. E., " The Fate of Reserve Materials in the Felled Tree." *Forestry*, Vol. IX, No. 2, 1935.

The process of cutting a tree off its root does not kill the sapwood cells. Indeed, I was able to demonstrate by special methods, in suitable conditions, that the food cells continue to live and to breathe for a long time, until they have used up the whole of the reserve starch, at which stage they die, as the cells are then without any food reserves. Those necessary conditions are provided by retaining the timber in log form and with the bark on. On the other hand, if the log is cut up soon after felling and the pieces put away for air drying or are kiln dried, the food cells are killed and the original quantity of starch remains in them. By piling the freshly felled logs off the ground so that air circulates freely around them there is little or no risk of damage by decay during the de-starching process. No other treatment is necessary, and the added cost is only that of waiting some months before sawing up the timber. The species which have narrow sap, viz.: oak, chestnut, and elm, become de-starched and therefore immune to *Lyctus* in about seven or eight months after felling, the starch disappearing more quickly in warm weather than in winter. Species with wide sapwood, ash, walnut, and sycamore, require longer.

Events are very different, however, if the log is sawn up before complete de-starching has taken place, for as the timber dries out the food cells are killed by desiccation. It is important to bear in mind that whatever starch is in the cells at death remains unchanged, whatever happens afterwards, and it stays there as long as the wood remains intact.

Here we are presented with a possible clue to the increase in *Lyctus* damage during the present century, for the most striking change in the timber industry in recent times has been the speeding up of the handling of timber at all stages. To-day speed appears to be everything, especially in America, where most of the *Lyctus* ridden hardwoods come from. The rapid conversion of logs soon after felling must necessarily lead to the retention of much starch, and therefore to greater liability to infestation by *Lyctus*. One might say that by accelerating the handling of timber we play into the hands of the powder-post beetle.

In this connection an obvious difficulty arises in relation to ash and willow for sports goods, because it is usual to convert both these timbers very quickly after felling, the ash for bending while green and pliable and the willow to avoid spoiling the colour—pure white being the effect aimed at. Both these timbers are subject to *Lyctus* attack, the willow in the outermost annual ring only, *i.e.* the starch zone.

Both difficulties can, I believe, be overcome. I feel certain that sports ash can be steamed and bent quite well after log seasoning, and that the de-starching of willow takes such a short time (a matter of a few days) that loss of colour can be avoided by careful timing. I recommend sports goods manufacturers to try out these methods, for I am certain that losses due to *Lyctus* can be greatly reduced thereby, even if not entirely eliminated.

A few other important points should now be mentioned. One is that, as de-starching takes place, something resembling heart-substance forms in the food cells and the colour of the sapwood is thereby darkened. There is no objection to this, except perhaps in the case of sycamore which tends to lose its shining, white appearance, a change which detracts somewhat from its commercial value.

In order to discover when the de-starching is complete, it is necessary to apply the aqueous-iodine test to the innermost sapwood where it is at its widest, *i.e.* generally at the upper end of the log. This can be done by boring or cutting at a correctly selected place.

In some woods, *e.g.* walnut, even a very small amount of starch will suffice to attract *Lyctus*, although in such conditions the larvæ will develop only very slowly and may take several years to reach full size—or they may fail to keep going and die off. It would be an advantage to know just how much starch is permissible in the various timbers while avoiding risk of infestation.

The process of felling and cross-cutting the log exposes certain surfaces of the timber to rapid drying, and a shallow zone of starchy wood remains at such sapwood faces. There is no risk of more than negligible damage thereby, as *Lyctus* does not penetrate deeper into the log while de-starching is proceeding. *Lyctus* is not an insect that infests the living tree, and apparently it cannot feed on living sapwood, no matter what the quantity of starch present. As we have seen, in the log the sapwood only dies as it is de-starched.

I call this way of de-starching sapwood " Log seasoning." The term " seasoning " is not here intended to mean " drying "—a small amount of drying does occur during the process, but the timber is not by any means fully dried out thereby. After conversion, it has still to be dried to a usable moisture content. But log seasoning always should be, in my opinion, the first stage in the full and correct seasoning of the starchy hardwoods.

As mentioned, it is fairly easy to find out when the log is completely de-starched. But it is a matter requiring skill for the buyer of plank or dimension stock to make sure he is getting starch-free timber. The way to test the wood is to apply the iodine solution to a newly exposed face (the radial surface is best) at the innermost zone of the sap adjoining the heart, for that is the last zone to be de-starched on the log. Any one trying this method soon becomes adept at " spotting " the blue-black starch and deciding as to its presence or absence.

I want to deal with one or two noteworthy objections which have been put forward in relation to the " log-seasoning " method of de-starching wood.

There is the matter of the risk of decay taking place during the period of log storage. This point certainly requires careful watching. The felling season may affect this, but correct storage conditions are of prime importance. If the logs are gathered together and piled well off the ground at a roadside dump or in an open place, the damage of fungal attack is slight. Fears of attack by pin-hole borers during log storage have also been announced. These beetles bore into oak logs, penetrating both sap and heartwood. Their habits are very different from *Lyctus*, since, as they are fungus feeders, they only infest logs of high moisture content. Several instances of pin-hole borer damage have occurred in the South of England in recent years, but so far as I am aware this beetle has never appeared in any oak logs drawn out of the wood and stacked as I have described.

Anobium, the common furniture beetle, often attacks seasoned sapwood, not, however, for its starch. The extended use of sapwood, de-starched for immunity from *Lyctus*, may, it is suggested, favour *Anobium*. This is quite a possibility. But until our knowledge of the habits and particularly the feeding methods of *Anobium* is further advanced, we cannot know whether by making sapwood usable we are or are not increasing the risk of *Anobium* damage in the future.

I must now mention in passing two other possible methods of de-starching sapwood which have recently been the subject of experiment. One method aims at removing starch from the sapwood before felling the tree, and the plan being tried is to girdle the tree some months before felling, as is done with teak in India and Burma. So far results are not very encouraging. The other method is to speed up the de-starching process by keeping the sapwood at a temperature equivalent to a warm summer's day. This has been tried with some success, the material being freshly felled ash cut into boards about one inch thick. The timber was found to be de-starched in from two to three weeks. Either of these methods may in due time be found practicable, but their development is still at an early stage.

My present endeavour is to direct attention to the log-seasoning method of de-starching wood, and to present it as a commercially practicable scheme. I do not pretend that it can be carried out without a certain amount of care and intelligence, but I do hold that the requirement is not beyond the capacity of timber workers in these days of rapid progress in the application of technological discovery to commercial practice.

In this belief, I am fortified by the undoubted fact that the production of a good deal of de-starched sapwood is even to-day the rule rather than the exception wherever timber is handled in what may be called the old-fashioned way. For instance, in the South of England it is usual to store prime oak logs for several months before converting them, because by so doing the planks and boards from such logs are rendered less liable to twist or split. Oak and elm logs for cutting into coffin boards, for example, are best left for a year or more before conversion.

In the course of a preliminary survey I have inspected several large stocks of hardwood logs and plank racked for seasoning, and I am able to state that there are in existence at certain sawmills extensive and valuable stocks of oak, ash, and other planks which are entirely free from starch and from liability to *Lyctus* attack—although this latter fact is not known or appreciated as yet by the owners.

Among the piled planks there are generally to be found a few pieces whose sapwood is infested by *Lyctus*, and on inquiry one finds that those logs were planked very soon after felling, contrary to the usual practice of the yard. The fact that *Lyctus* is an old-established inhabitant of timber yards, and that it is widespread, if not ubiquitous, in England, must surely mean that any seasoned timber containing starch has a very good chance of receiving the attention of the beetle during the first summer, or at any rate the second summer, after conversion. Now it is usual to keep the planks two or more years " in stick " before the timber is regarded as ready for use, the thicker grades requiring several years' seasoning to be suitable for indoor work. But if, as I suggest, all non-immune sapwood becomes infested almost straightaway, it follows that sapwood still undamaged after several years *must have been immune from the outset*. Here we have a very reasonable explanation of the phenomenon often remarked by entomologists, viz. : that *Lyctus* attacks only newly seasoned timber.

That brings me to an interesting thesis which I put forward for consideration. It is that the best of all test for immunity is *Lyctus* itself. If you keep your plank and other converted timber two years or more, while making sure that a plentiful supply of *Lyctus* is given access to it, then whatever sapwood is still uninfested after another year or two is certain to be immune. This is also the best way of proving the efficacy of your log-seasoning practice, and you can safely offer the plank which is still sound after four years as " warranted immune from *Lyctus* damage for all time." Perhaps after all it would be a mistake not to have at any rate a *few Lyctus* about the place ! As I have previously hinted, I am prepared to back *Lyctus* beetles to search out any and all sapwood suitable for their larvæ. The beetles are thoroughly well up to their job, whatever may be said about timber people in that connection.

Conclusion.—The question now remains : Who is to set this log-seasoning method going ? We are often told that " the man who pays the piper calls the tune," and, in my opinion, it should be the *user* who should demand starch-free timber. The architect, the furniture manufacturer, the sports goods maker, the builder, the coachbuilder, and all others who buy converted timber should require it to be warranted starch free. The sawmiller should examine his stocks and find out which do and which do not fit the specification, and should modify his milling procedure to get all possible timber de-starched before conversion. The importer of foreign hardwoods is now in a position to throw the responsibility back upon the shipper, and he in his turn upon the overseas sawmiller.

The statutory prohibition of the import of *Lyctus* infested or infestible timber is surely quite unnecessary, since the importers and merchants now have the whole matter in their own hands if they care to make a stand. They can specify starch-free timber and take steps, technical, legal, and otherwise, to ensure that the goods are as per contract. I am sure that if all buyers and users of hardwoods were now to take proper steps they could compel the sawmillers to attend to this matter of de-starching and could very quickly bring *Lyctus* under effective control.

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