166. A CHEMICAL STUDY OF THE BEARING OF
DECAY BY *Phellinus cryptarum* KARST.
AND OTHER FUNGI ON THE DESTRUCTION
OF WOOD BY THE DEATH-WATCH BEETLE
(*Xestobium rufovillosum* DE G.)

BY WILLIAM GEORGE CAMPBELL AND
STEPHEN ARNOLD BRYANT

*From the Section of Wood Chemistry, Forest Products Research Laboratory,
Princes Risborough, Aylesbury, Bucks*

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THE chemical aspect of the destruction of oak wood by the death-watch beetle was first discussed some years ago by one of the authors [Campbell, 1929] and the conclusion was then reached that the larval diet consisted essentially of the carbohydrates, cellulose and hemicelluloses. Since, however, the composition of the original wood and the loss in weight due to insect attack could not be determined from the material available, it was pointed out that the full effectiveness of the application of chemical analysis to the elucidation of feeding habits could not be realized because the true extent of depletion in each wood component could not be assessed. The general conclusions of this preliminary work were confirmed in the following year by Ripper [1930] and more recently by Norman [1936]. In all of this early chemical work little or no significance was attached to the long established observation that the natural habitat of *Xestobium* is in dead—and in many instances decayed—parts of hardwood trees. Fisher [1935] came to the important conclusion that fungal decay, among other factors in a suitable timber, can have a marked influence on the duration of the life-cycle of the insect, and in later work [Fisher, 1937; 1940] was able to rear it under laboratory conditions in oak sapwood which had previously been decayed by various fungi in pure culture. Fisher established that as the severity of fungal decay increased, the duration of the life cycle of the insect became less. The first indication from the purely chemical standpoint that, in wood attacked by the death-watch beetle, there can be fungal decomposition of the same order both in the material consumed by the larvae and in the residual wood which is not comminuted by them, is afforded by Norman's results [1936]; but, as will be shown later, this author apparently failed to appreciate their full significance. Thanks to the aforementioned work by Fisher it is now possible to rear *Xestobium* in large numbers and in reasonably short periods of time in weighed samples of wood of known composition, so that the essential prerequisites originally postulated [Campbell, 1929] for the effective chemical investigation of feeding habits have now been met.

The white rot fungus, *Phellinus cryptarum*, has from time to time been identified in wood infested with *Xestobium*, and in the first part of the present study the ultimate chemical effect of this fungus on wood has been determined for the first time. The bearing of fungal decay on the availability of oak wood to *Xestobium* has been examined from a number of points of view and the

results of previous chemical work on the feeding habits of the insect have been carefully reconsidered.

The experimental material was made available through the co-operation of Mr K. St G. Cartwright of the Mycology Section and Dr R. C. Fisher of the Entomology Section of this Laboratory, to whom grateful acknowledgement is here made. The original wood consisted of a series of carefully matched pieces of air-dried English oak (*Quercus* sp.) sapwood, each of which measured approximately $15 \times 4 \times 4$ cm. and weighed approximately 120 g.

EXPERIMENTAL

It has been observed previously [Campbell, 1929] that the frass of *Xestobium* contains a considerable proportion of material which passes a standard 120-mesh screen. It was therefore necessary to ensure, by mechanical grinding where necessary, that all the material submitted to analysis passed this screen despite the conclusion of Campbell & Bryant [1937] that grinding of wood to a fine powder for most analytical purposes is open to certain objections. These objections are entirely overcome, however, if the analytical data which follow are only used for comparative purposes among themselves.

Four pieces of the original wood were selected at random and comminuted to pass the 120-mesh screen. The analysis of the thoroughly mixed flour is given in Table 1. In this table are also recorded the analyses of a series of samples

Table 1. *Composition of oak sapwood at different stages of decay by Phellinus cryptarum*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Loss of wt. by decay (%) (original sound wood)	(Sound wood)	14.9	22.65	30.8	36.9	44.8	51.2	60.3	74.6
Soluble in:									
Cold water	4.00	6.78	6.01	7.17	6.97	6.76	7.03	8.18	10.59
Hot water	6.45	10.53	8.45	9.65	9.19	9.11	10.72	12.21	16.54
1% NaOH	24.18	30.02	27.45	30.20	29.37	31.07	31.62	35.20	40.20
Alcohol-benzene	2.54	4.04	3.23	3.80	4.27	3.43	4.86	5.53	5.71
Cellulose	51.30	51.60	52.65	54.05	53.68	55.21	50.40	50.96	51.65
Pentosans:									
In cellulose	13.26	13.93	13.42	12.90	14.30	13.50	12.24	13.02	11.50
Not in cellulose	11.31	11.32	12.07	11.37	11.26	10.87	12.27	11.35	9.92
Total	24.97	25.24	25.49	24.28	25.55	24.36	24.51	24.37	21.42
Lignin	19.80	18.65	18.57	16.78	18.22	16.99	18.63	17.88	14.85
Methoxyl:									
In lignin	4.20	3.88	3.93	3.53	3.76	3.57	3.77	3.69	3.01
Not in lignin	2.16	2.21	1.37	1.98	2.05	1.78	2.23	2.51	1.99
Total	6.36	6.09	5.30	5.51	5.80	5.34	6.01	6.20	5.00

which had been exposed to decay by the fungus. A further series of pieces of the original wood which had been exposed to fungal decay and then sterilized by dry heat at 105° were selected in groups of 4 for exposure to insect attack according to the percentage loss in weight sustained during decay. The technical operations involved in the biological aspects of this work will be described elsewhere. By plotting the percentages of the various wood components against the losses in weight (Table 2) a series of curves was obtained from which the average composition on a sound wood basis of any set of decayed samples submitted to insect attack could be determined. In all, seven groups of specimens

Table 2. *Composition of oak sapwood at different stages of decay by Phellinus cryptarum*

Results expressed as percentages by weight of oven-dry original sound wood									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Loss by decay	(Sound wood)	14.9	22.65	30.8	36.9	44.8	51.2	60.3	74.6
Soluble in:									
Cold water	4.00	5.77	4.65	4.96	4.40	3.73	3.43	3.26	2.69
Hot water	6.45	8.96	6.54	6.68	5.80	5.03	5.23	4.85	4.20
1% NaOH	24.18	25.55	21.23	20.90	18.54	17.15	15.43	13.97	10.21
Alcohol-benzene	2.54	3.44	2.50	2.63	2.69	1.89	2.37	2.20	1.45
Cellulose	51.30	43.91	40.73	37.41	33.87	30.47	24.59	20.23	13.12
Pentosans:									
In cellulose	13.26	11.85	10.38	8.93	9.02	7.45	5.97	5.17	2.92
Not in cellulose	11.31	9.63	9.34	7.87	7.10	6.00	5.99	4.50	2.52
Total	24.97	21.48	19.72	16.80	16.12	13.45	11.96	9.67	5.44
Lignin	19.80	15.87	14.36	11.61	11.47	9.38	9.09	7.09	3.77
Methoxyl:									
In lignin	4.20	3.30	3.04	2.44	2.37	1.97	1.84	1.47	0.76
Not in lignin	2.16	1.88	1.06	1.37	1.29	0.98	1.09	0.99	0.51
Total	6.36	5.18	4.10	3.81	3.66	2.95	2.93	2.46	1.27

which had been exposed to insect attack after having been decayed by *Phellinus cryptarum* were examined. The loss in weight due to fungal decay being known, the net loss due to insect attack was determined for each group. In each case frass was separated mechanically from the decayed wood which had not been disintegrated by the larvae, in order to obtain the data recorded in Table 3.

Table 3. *The effect in terms of loss in weight of Xestobium rufovillosum on oak sapwood at various stages of decay caused by Phellinus cryptarum*

Average loss of weight by decay (% sound wood)	25.86	30.21	36.48	40.04	50.47	59.76	73.40
Decayed wood exposed to insect attack (g., oven-dry)	323.23	266.27	251.56	245.50	150.63	126.71	90.94
Undisintegrated wood after insect attack (g., oven-dry)	229.67	164.4	136.40	134.40	63.61	56.63	31.41
Wood disintegrated (by difference) (g., oven-dry)	93.56	101.87	115.16	111.10	87.02	70.08	59.53
Frass (g., oven-dry)	60.53	72.63	87.60	87.60	71.62	58.39	51.44
Loss by insect attack (by difference) (g., oven-dry)	33.03	29.24	27.56	23.50	15.40	11.69	8.09
Loss by insect attack as % wood disintegrated (abstraction coefficient)	35.30	28.70	23.93	21.15	17.70	16.68	13.59

In each of two cases proportional parts of frass and undisintegrated wood were comminuted, mixed and analysed (Table 4) and a sample of frass from each of the two groups in question was analysed separately (Table 5) in order to obtain somewhat magnified values for the small percentage losses incurred during the insect attack.

For comparative purposes the analytical processes applied to the wood samples were also applied to a sample of *P. cryptarum* mycelium taken from the surfaces of some of the oak sapwood specimens. The mycelium was difficult to comminute and no attempt was made to grind it to pass a 120-mesh screen. It

Table 4. *Composition of oak sapwood decayed by Phellinus cryptarum, before and after attack by Xestobium rufovillosum*

Results expressed as percentages by weight of oven-dry original sound wood. B=before insect attack. A=after insect attack. Figures in column B obtained graphically from the results in Table 2.

Loss by decay	(1) 36.48		(2) 40.04	
	B	A	B	A
Loss by insect attack	—	6.07	—	5.08
Soluble in:				
Cold water	4.44	3.84	4.26	3.56
Hot water	6.00	4.94	5.80	4.56
1% NaOH	18.84	16.90	18.05	16.54
Alcohol-benzene	2.52	1.93	2.41	1.58
Cellulose	34.28	30.84	32.65	30.79
Pentosans:				
In cellulose	8.51	7.96	7.99	7.42
Not in cellulose	7.21	6.68	6.80	5.57
Total	15.72	14.64	14.79	12.99
Lignin	11.19	10.44	10.33	9.52
Methoxyl:				
In lignin	2.36	2.17	2.18	2.06
Not in lignin	1.30	1.17	1.23	0.91
Total	3.66	3.34	3.41	2.97

Table 5. *Analytical comparison of decayed wood available to Xestobium, the material digested therefrom, and the mycelium of Phellinus cryptarum*

All % are based on oven-dry material. Loss of weight by fungal decay:

(a) 36.48% of sound wood; (b) 40.04% of sound wood.

	Decayed wood ingested by insect		Frass % of decayed wood ingested (2)	Material digested by insect						Mycelium %, own basis (5)
	Calc. from graphs, %, own basis (1)			% of decayed wood ingested (by difference) (3)		%, own basis (4)				
	a	b		a	b	a	b	a	b	
Soluble in:										
Cold water	6.99	7.11	5.42	5.14	1.57	1.97	6.56	9.32		6.71
Hot water	9.45	9.67	7.16	6.85	2.29	2.82	9.57	13.33		11.32
1% NaOH	29.66	30.11	23.76	24.80	5.90	5.31	24.60	25.11		50.29
Alcohol-benzene	3.97	4.02	2.69	2.04	1.28	1.98	5.35	9.36		6.50
Cellulose	53.96	54.46	40.87	44.54	13.09	9.92	54.68	46.90		61.54
Pentosans:										
In cellulose	13.40	13.32	10.91	10.35	2.49	2.97	10.40	14.05		2.36
Not in cellulose	11.35	11.35	7.37	7.87	3.98	3.48	16.63	16.45		3.75
Total	24.75	24.67	18.28	18.22	6.47	6.45	27.04	30.50		6.11
Lignin	17.61	17.23	14.81	13.59	2.80	3.64	11.70	17.21		3.30
Methoxyl:										
In lignin	3.72	3.64	3.13	2.90	0.59	0.74	2.47	3.50		0.05
Not in lignin	2.05	2.05	1.40	1.28	0.65	0.77	2.72	3.64		0.52
Total	5.76	5.69	4.53	4.18	1.23	1.51	5.14	7.14		0.57
Methoxyl in lignin, % lignin	21.1	21.1	21.1	21.3	—	—	21.1	20.3		1.6

is not claimed either that the data obtained from mycelium represent its exact composition or that the substances estimated are identical with those present in wood.

Nitrogen determinations (Table 6) were carried out by the method recommended by Campbell & Hanna [1937] on mycelium, sound wood, a sample of decayed wood and a sample of decayed wood after insect attack. The mycelium

Table 6. *Total nitrogen contents of oak sapwood, Phellinus cryptarum mycelium and Xestobium rufovillosum larvae respectively*

Results for wood expressed as percentages by weight of original sound wood

	N, % oven-dry weight
Sound wood	0.16
Wood decayed to a loss in weight of 36.48 % before insect attack	0.12
Wood decayed to a loss in weight of 36.48 % after insect attack	0.10
Mycelium of <i>P. cryptarum</i>	0.68
<i>Xestobium</i> larvae	3.91

was found to contain 0.5 % of its oven-dry weight of acetyl groups, the method described by Schorger [1926, p. 530] for wood being used for the determination.

DISCUSSION

As a result of previous studies on the chemistry of the white rots of wood it has been shown [Campbell, 1930; 1931; 1932] that, on chemical grounds, they can be subdivided into three classes. The present results (Tables 1 and 2) show that the white rot produced by *Phellinus cryptarum* falls into the class in which cellulose and lignin are decomposed simultaneously from the commencement of decay and furthermore that the various wood components are decomposed in approximately the same proportions in which they occur in the original wood. For this reason, the existence and extent of decay are not readily revealed by chemical analysis of the decayed wood alone. The highest loss in weight due to decay observed in the present investigation was approximately 75 %, and since the decayed wood at this stage still contained lignin, simple but conclusive proof is here afforded that, in white rots of wood, lignin cannot constitute the sole source of fungal nourishment.

Turning now to the material assimilated from the decayed wood by the insect, it is observed from Table 4 that the larvae digest a proportion of each of the components determined by analysis. The composition of the diet may also be assessed by comparing the composition of the frass, as distinct from that of the total residue after insect attack, with the composition of the decayed wood submitted to attack (Table 5).

Prior to the present investigation the opinion has been expressed [Mansour & Mansour-Bek, 1934, and others] that lignin, as such, cannot be assimilated by insects, although Norman [1936] apparently accepts this view with some reluctance in the case of *Xestobium*. Certain authors have expressed the composition of the frass of wood-boring insects on the basis of unattacked wood by assuming that the ash constituents [Falck, 1930], or even the lignin itself, have remained entirely unaffected. The assimilation of lignin in addition to extractives and the carbohydrates of wood by *Xestobium* is one of the most important facts

brought to light in the present study. It is probable that the ability of *Xestobium* to break down lignin does not depend on the previous action of any particular type of fungus. Since, moreover, the percentage of methoxyl groups in the lignin removed by the larvae (Table 5) is approximately the same as the corresponding value for the lignin of decayed wood, it is deduced that decomposition is not confined to any particular portion of the lignin molecule. The view that a possible carbohydrate or other non-aromatic portion of the molecule is preferentially digested cannot therefore be sustained.

It cannot be overlooked that lignin may be decomposed in the larval gut and its products not wholly assimilated so that material derived therefrom may occur in the frass and yet not be determined on analysis. That such a condition does not obtain, however, is proved by further consideration of the data in Table 5. The sums of the losses due to insect attack of hot-water extractives, cellulose, pentosans not in cellulose, lignin, and methoxyl not in lignin as calculated by difference from columns (1) and (2) amount to 20.63 and 22.81 % of the respective samples of decayed wood submitted to insect attack, and these agree closely with the respective percentage losses in weight (21.15 and 23.95) which were determined directly. Had the frass contained unassimilated products of lignin, the above calculated percentage losses due to insect attack would have been appreciably greater instead of less than the determined losses.

The question of the food value to the insect of the fungal mycelium in the decayed wood has not been overlooked. In view of the apparent composition of the mycelium of *Phellinus cryptarum* (Table 5) it is obviously impossible to make a direct determination of the amount present in any sample of decayed wood, and such statistical methods as might be used to estimate it indirectly could only lead to rough approximations. It is therefore impracticable to apply corrections to the analytical data for material derived from mycelium. Comparison of the data in Table 5 with the analysis of sound oak wood (Table 1) reveals, however, that the material digested by the larvae is more akin in composition to wood than it is to *P. cryptarum* mycelium so that mycelium can, at most, constitute but a small part of the material digested.

There remains the possibility that fungal mycelium contains a component essential to the beetle but which occurs in amounts too small to affect the analytical results in Table 5. In this connexion the N metabolism of the insect immediately suggests itself, but there is unfortunately no evidence to show whether *P. cryptarum* is a necessary intermediary for the modification of the wood nitrogen to suit the beetle. Little evidence appears to be available concerning the N metabolism of wood-eating insects as a whole, but Hopf [1937] has concluded that the *Lyctus* powder-post beetles can utilize the organic N of oak wood directly and it is possible that *Xestobium* can do the same, especially since the latter is known to develop, albeit slowly, in sound wood. It is noteworthy that the N requirements of *Xestobium* (Table 6) are quite small and that in the average sample of oak wood there is more than enough of this element to meet the requirements of all the larvae it could support.

The effect of previous fungal decay in wood on the economy of the Xestobium larva from an energy standpoint

Having elicited that the diet of *Xestobium* larvae reared in decayed wood consists essentially of wood components and not, to any recognizable extent, of fungus components, it is now necessary to determine the nature of the advantages which accrue to the insect as a direct result of passing its larval stage in decayed as opposed to sound wood. This question can best be approached from

the standpoint of the energy metabolism of the insect, since healthy continuity of the species must clearly depend upon the ability of the larva to derive sufficient energy from its food in order to provide for the succeeding stages of the insect in which further intake of energy from an external source is precluded. Of the total energy derived by the larva from its food, part is conserved as body tissue and part is dissipated in basal metabolism and the work metabolism involved in boring. Growth and development of the larva are only possible so long as the energy dissipated is less in amount than the total energy derived from the food and, other things being equal, they are at an optimum when this energy difference is greatest. Such being the case it is necessary, in view of the finding [Fisher, 1935] that the duration of the larval stage tends to become shorter as the extent of decay in the substrate increases, to determine whether decay renders the components of wood more readily available to the larva as a source of energy so that it is enabled to conserve energy at a greater rate when boring in decayed as opposed to less decayed or even sound wood. From the biological standpoint it would appear, from results about to be published, that fungal decay has such an effect although, as will be seen from the considerations which follow, the causal factors are more involved than might have been expected.

In Table 3 each loss in weight due to insect attack represents the food, and therefore the total energy, abstracted from the substrate by a group of larvae whilst the sum of the weight of frass and this loss in weight is the total weight of wood disintegrated by the group in order to obtain the food. When the loss in weight due to insect attack is expressed as a percentage by weight of the total wood disintegrated by any particular group of larvae a direct measure, which will hereafter be referred to as the "abstraction coefficient", is obtained of the amount of energy abstracted by the group per unit weight of wood disintegrated. It will be observed that the abstraction coefficient is independent of the number of larvae in any particular group and also of the time taken by the group to disintegrate any given weight of wood. Since all seven categories of decayed wood (Table 3) were subjected to beetle attack under the same conditions, direct comparison of the several abstraction coefficients is permissible. It is observed that, as fungal decay in the substrate increases, the numerical value of the abstraction coefficient decreases. This signifies that, over the range examined, the total amount of energy abstracted by the larva per unit weight of wood disintegrated decreases as the extent of fungal decay increases, unless it can be shown that the decline in the weight of food digested per unit weight of wood disintegrated is offset by an increase in the calorific value of the food. The calorific value of oak wood is given as 4390 cal./g. and of cellulose as 4150 cal./g. [Kollmann, 1936]. The calorific value of lignin is of the order of 5000 cal./g. It is unlikely that any component of oak wood has a calorific value higher than that of lignin. The calorific value of the larval diet can therefore increase with increasing extent of decay in the substrate if the proportion of lignin therein increases. If such were the case, a maximal calorific value would be obtained if and when the diet consisted solely of lignin. It is obvious, however, that so long as the abstraction coefficient (Table 3) is numerically greater than the percentage lignin content of the wood disintegrated by the larvae, the diet cannot consist solely of lignin. Moreover, in view of the analytical data in Table 5 it is concluded that a decline in the numerical value of the abstraction coefficient (Table 3) from 35.28 to 21.15 is not accompanied by any increase in the lignin content of the diet of sufficient magnitude to obviate a decline in the total amount of energy abstracted by the larvae, per unit weight of wood disintegrated. By inspection of the analytical data in Tables 1 and 5 it is deduced

that in wood which has lost up to 40 % of its weight by fungal decay the calorific value of the larval diet cannot be much, if any, greater than that of sound wood so that even in the unlikely event of a rapid increase of the lignin content of the diet in samples of wood decayed to losses in weight in excess of 40 % it can be seen that the total amount of energy abstracted from unit weight of badly decayed wood can never exceed that abstracted from moderately decayed wood. The above conclusion concerning the decline in the total amount of energy abstracted from unit weight of wood disintegrated as the extent of fungal decay in the substrate increases is therefore valid. Since the analytical data in Table 1 provide no indication of a decline in the dietetic value to *Xestobium* of oak wood as it becomes more decayed by *Phellinus cryptarum*, it must be concluded that the observed decline in the abstraction coefficient not only connotes an increase in the rate of boring which is not accompanied by a corresponding increase in the capacity of the larval gut to assimilate energy from the wood comminuted, but affords conclusive proof that the prime function of the fungus in this biological succession is *not* to modify the components of wood chemically so that they are more readily digestible by the larva. From this it follows that if the larva is to conserve energy at a greater rate in consequence of previous fungal decay in the substrate, it must do so chiefly in virtue of a combination of circumstances resulting from changes induced in the physical properties of the latter. Such being the case, attention is at once focussed on the effect of fungal decay on the mechanical strength of wood, it being taken for granted that, in view of the depletion induced in the strength of wood by decay, decayed wood offers less resistance to larval boring than less decayed or sound wood. It is fortunately unnecessary to speculate here with regard to the particular mechanical property or properties of wood involved in this boring activity, since depletion, albeit of varying order, is common to all of them during progressive fungal decay. The important point to note, however, is that, as the results of Cartwright *et al.* [1936] and of Scheffer [1936], in particular, indicate, the rate of decline in strength with progressive decay is greater than the rate of decline in density. Herein lies a possible advantage to the *Xestobium* larva from an energy standpoint, since in boring unit distance through decayed as opposed to less decayed wood it may abstract unit amount of energy with less effort and possibly in shorter time. Similarly by a consideration of the data of Scheffer [1936], which relate to a white rot having an effect on the composition of wood which is in all respects similar to that produced by *Phellinus cryptarum*, the authors conclude that the rate of decline in mechanical strength induced by progressive decay in the wood under investigation may at times be greater than the rate of decline in the larval abstraction coefficient over the range examined (Table 3). This factor, were it substantiated, would constitute a further advantage to the larva in that the disadvantage inherent in the observed decline in the abstraction coefficient would be to some extent offset by the diminishing effort required in the comminution of unit weight of wood. It is therefore obvious that if either or both of these possible advantages to the larva were in fact operative, the rate of conservation of energy by the larva as body tissue would increase. But in addition to such possible advantages one other factor affecting the energy metabolism of the larva must be considered. It has been indicated above that as the extent of fungal decay in the substrate increases, the rate of larval boring increases. The possibility therefore exists that provided that the larva maintains a sufficient rate of increase in its rate of boring as decay in the substrate progresses it can not only increase its rate of abstraction, but also its rate of conservation of energy.

Three means whereby the *Xestobium* larva may profit from an energy standpoint through living in decayed wood have been shown to be possible. All depend on depreciation of the mechanical strength of the substrate. How they are correlated, as correlated they must be, and which is the most important, cannot be deduced from the available experimental data, but since the biological observations already referred to indicate strongly that progressive fungal decay renders wood more and more suitable for the development of the *Xestobium* larva, the authors feel justified in emphasizing that predigestion of wood components by enzymic decomposition is not a prime factor, and in indicating the purely physical factors which either singly or in combination might account for the biological results.

The relationship between the destruction by Xestobium of structural timbers in buildings and the presence therein of fungal decay

It should be emphasized that the *Xestobium* frass examined by Campbell [1929], Ripper [1930] and Norman [1936] was in each case obtained from timbers which had been attacked *in situ*, and not from material infected under laboratory conditions as in the present study. Each of these authors established pronounced differences in composition between frass and sound wood and attributed substantial depletions in cellulose and pentosans entirely to the digestive processes of the insect.

The present investigation has revealed, however, that of the wood which it disintegrates the food of *Xestobium* may often represent but a small proportion and it is, therefore, inconceivable that the large losses of wood substance implied in the results of the above authors are attributable to the action of insects alone. There can now be little doubt that the "damaged" wood of Norman [1936] had undergone fungal decay prior to or contemporaneously with invasion by *Xestobium* and that the proportion digested by the latter was almost insignificant compared with that decomposed by fungi. Similar deductions must be made regarding the material examined by Campbell [1929] and by Ripper [1930]. Since a low cellulose content, a low pentosan content, a high lignin content and a high content of alkali-soluble matter are characteristic features of wood decomposed by fungi of the brown rot type it is deduced that fungi of this type were active in the timber from which Campbell [1929] and Norman [1936] obtained their respective samples of frass, as well as in one of the samples examined by Ripper [1930]. That this is somewhat more than a coincidence is shown by the following considerations.

The data in Table 7 were obtained from samples of frass taken from a series of 20 samples of oak wood selected statistically from a stock of infested material accumulated at this Laboratory from various buildings in England over a period of years. It is observed that in 16 out of 20 cases the percentage of frass soluble in 1 % NaOH under standard conditions is over 44. The corresponding figure for sound oak wood is known to vary between approximately 22 and 30 % so that from premises already adduced it can be concluded that in these 16 cases there has been fungal decay of the brown rot type in the wood from which the frass was produced and, moreover, that the extent of decay has varied considerably from piece to piece. In three cases the percentages soluble in alkali lie between 30 and 40 % and can only be taken to indicate that some form of decay was originally present. In the remaining case the percentage soluble in alkali (26.09 %) falls within the range for sound wood, so that the wood from which the frass was produced may or may not have been decayed by a white rot fungus. A more definite conclusion cannot be reached in these latter 4 cases because it has been

Table 7. *The action of 1% NaOH for 1 hr. at 100° on Xestobium frass taken from a series of samples of oak wood infested under natural conditions*

Sample no.	% Dry weight soluble in NaOH
1	45.41
2	53.78
3	37.86
4	77.72
5	55.68
6	53.73
7	55.44
8	50.40
9	46.47
10	60.73
11	51.00
12	48.25
13	39.42
14	54.01
15	44.91
16	57.54
17	50.90
18	32.73
19	59.59
20	26.09

found [Campbell, 1932] that the percentage soluble in alkali of wood decayed by a white rot fungus may vary from a value slightly greater to slightly less than that of sound wood. If the complete set of data in Table 7 be taken as statistically representative of the *Xestobium*-infested oak wood in England it must be deduced not only that such timber is usually more or less decayed, but that, in the majority of cases, the decay is of the brown rot type. It is a matter of experience that brown rots are more commonly found in oak timbers in buildings than are white rots. It is therefore indicated that there is no specific fungus which predisposes oak wood to *Xestobium* attack and that attack is not limited to wood which has attained any particular stage of decay.

SUMMARY

1. The effect of decay by *Phellinus cryptarum* Karst. on the chemical composition of oak sapwood has been studied in detail. The fungus is shown to cause a white rot of the class in which all of the major components of wood are decomposed simultaneously.

2. The bearing of previous decay by *P. cryptarum* on the availability of oak sapwood to the death-watch beetle (*Xestobium rufovillosum* de G.) has been examined.

3. The food of *Xestobium* is shown to consist of extractives, cellulose, hemicelluloses and lignin and it is proved that there is no specific type of fungal decay which predisposes oak wood to attack by the insect..

4. Although decayed wood is the commonest habitat of *Xestobium* this circumstance does not depend on the relative abundance or availability of any particular food component resulting from fungal activity.

5. The wood digested by a group of insects when expressed as a percentage by weight of the wood disintegrated during boring by the same group is termed the "abstraction coefficient". The abstraction coefficient is independent of the number of larvae in any particular group and also of the time taken by the group to disintegrate any given weight of wood. The coefficient is accepted as a

direct measure of the amount of energy abstracted by the *Xestobium* larva per unit weight of wood disintegrated.

6. It is found that as the extent of fungal decay in the substrate increases the numerical value of the abstraction coefficient diminishes over the range of loss of 26–73 % of the dry weight of original wood caused by decay. This is cited as evidence that the prime function of the fungus in the biological succession is *not* to modify the components of wood chemically so that they are rendered more readily digestible by the *Xestobium* larva.

7. It is concluded that the depreciation in the mechanical strength of wood induced by fungal decay is the major factor responsible for the relatively more favourable development of the *Xestobium* larva in decayed as opposed to less decayed or sound wood.

8. Decayed wood offers less resistance to boring on the part of the larva than does sound wood. The fact that during progressive fungal decay the rate of decline in the strength of wood is greater than the rate of decline in density together with the possibility that the rate of decline in the larval abstraction coefficient is not as great as the rate of decline in the mechanical strength of the substrate constitutes an advantage to the *Xestobium* larva so far as its energy metabolism is concerned.

9. It is indicated that as the extent of fungal decay in the substrate increases, the rate of larval boring also increases. The possibility, therefore, exists that the larva may regulate its rate of boring so that as the mechanical strength of the substrate decreases it is enabled to increase its rate of abstraction and conservation of energy.

10. The relationship between fungal decay and *Xestobium* attack in structural timbers under natural conditions is discussed.

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