THE LIFE-HISTORY OF THE SHOT-HOLE BORER OF TEA

C. H. GADD

The Shot-hole Borer beetle (*Xyleborus fornicatus* Eichhoff, *fornicatior* Eggers) has long been known as a pest of tea, yet little is known of its life-history. The difficulty of determining the duration of the early stages of the beetle was pointed out by Green [2] in 1903, namely, that after the galleries have been opened or the infected branches removed, the young insects die for the want of their proper nourishment, which disappears with the desiccation of the surrounding parts.

The males have no wings beneath their wing cases and consequently cannot fly. They live and die within the galleries in which they were reared. The females are larger and have well developed wings capable of carrying the insect through the air for some short distance. Pairing takes place within the gallery in which the beetles are reared, and the impregnated females emerge through the hole which forms the entrance or exit to the gallery. They fly away and start fresh families in other branches.

Each female first bores a characteristic gallery in a branch and then lays her eggs within the tunnel. The eggs later hatch and the developing grubs feed upon the delicate mycelium of a fungus which grows upon the walls of the gallery. The galleries are completed by the parent insect; the grubs never extend them as do some allied species inhabiting dead wood. When full grown the larvae pupate, and later, adults emerge from the pupa cases. These transformations all take place within the galleries, out of sight. Consequently, it is impossible to obtain reliable information concerning the number of eggs laid, and the length of time the insect passes in the various stages, by direct observation.

Speyer[9] in 1917 published the following statement concerning the time expended in the various stages at an altitude of 4,000 feet above sea level:—

	Days
(a) Entrance of female to laying of first batch of eggs	25
(b) Egg stage	4
(c) Larval stage	25
(d) Pupal stage to emergence of adult ...	6
Total	60

Maximum number of young individuals found in one gallery	34
Average number of young individuals found in one gallery	15

The proportion of male to female is as 1 to 5.

No indication is given, however, as to the method by which these figures were arrived at.

In 1936 a further attempt was made to fill some of the existing gaps in our knowledge of the life-history of this Shot-hole Borer.

METHOD

The area selected for observation was in a field on Gonakelle Estate, Passara at an elevation of about 3,500 feet. In July, 1936, it was 21 months from pruning and was due to be pruned again the following October, *i.e.*, the pruning cycle was 2 years. All thin spindly branches were removed from 250 bushes leaving branches, each suitably labelled, of a thickness suitable for invasion by the Shot-hole Borer. These labelled branches were then carefully examined for existing galleries, the entrances of which were distinctively marked to allow any later formed gallery to be recognised. The branches were then examined daily by two observers and the entrance of every new gallery was encircled by a red line and a record made of the date it was observed. Such galleries were considered to be 1 day old at the date they were first observed.

Periodically, a number of attacked branches were cut out of the bush, placed in closed boxes and taken to the laboratory for examination. There the galleries were opened and a record made of their contents and other data. Observations were continued from July 8th to October 10th, a period of 95 days. During this time, galleries of all ages from 1 to 66 days were examined. The galleries of any given age were not all examined on the same day. For instance 8 galleries were examined when 27 days old; the dates of examination were August 16th, 19th, 21st, and 22nd, September 15th (2) and October 8th (2).

POSITION OF GALLERIES

Galleries are most frequently formed in the branches at the nodes, the region of attachment of the leaves. Green [2] observed that the most usual point of attack was at leaf scars, and the writer [1] attributed much of the dieback after pruning of attacked bushes to that fact. In this investigation it was not always possible to determine with accuracy whether some galleries were situated at nodes or not, but of the 509 galleries examined, 318 (or 62 per cent) were at nodes, 13 at internodes and 178 were indeterminate. The internodal region is much longer than the nodal region; consequently, there should be more internodal galleries than nodal galleries, if the attack were entirely haphazard. The above figures show clearly that the beetles exhibit a marked preference for attacking the branches at the nodes.

The diameter of the branches at each gallery was measured in millimetres. The smallest branches had a diameter of 5.5 mm. whereas the mean size was 10.8 mm. (Standard deviation 2.2 mm.) or about half-inch in diameter.

CLASSIFICATION OF GALLERIES

Of the 509 galleries examined, 89 were found to be empty and 8 had been vacated by the female after laying a number of eggs. Other galleries were found to contain insects other than the Shot-hole Borer beetles; these were commonly Drosophilids (58 galleries), Lepidoptera (4 galleries) and Mites (8 galleries). Other galleries showed what has here been termed 'a moist exudation,' the nature of which is not understood, though possibly it is the product of a fermentation process. This 'moist exudation' was observed on 28 occasions, sometimes in galleries occupied by Drosophilids but not always. The significance of intruders and of the 'moist exudation' will be discussed later.

It seemed advisable to exclude the above mentioned galleries together with a few others, such as those in which the parent female beetle was dead, from a study of the borer under normal healthy conditions. In Table I are summarised the results of the daily observations. The galleries excluded temporarily from this investigation are enumerated in Table IA and the contents of the so-called healthy galleries are detailed in Table IB.

TABLE I

Shot-hole Borer Galleries

A.—Classification of Galleries

Age in days	No. of Observations	Empty		Containing Drosophilids			Vacated by female after laying	Excluded for other reasons	Healthy galleries
		No.	%	+S.H.B.	— S.H.B.	Total			
1-7	62	8	13	—	—	—	—	—	54
8-14	61	8	13	—	—	—	—	1	52
15-21	64	8	12	—	1	1	—	3	52
22-28	62	8	13	3	5	8	—	2	44
29-35	52	8	15	5	8	13	1	—	30
36-42	52	11	21	3	9	12	3	—	26
43-49	52	9	17	4	11	15	1	2	25
50-56	46	9	20	3	3	6	3	3	25
57-63	47	17	36	2	1	3	—	4	23
64-66	11	3	27	—	—	—	—	1	7
Total	509	89	—	20	38	58	8	16	338

B.—Contents of Healthy Galleries

Age in days	No. of healthy galleries	Females			Offspring					Mean			
		Non-layers No.	Non-layers %	Layers	Eggs	Larvae	Pupae	Adults	Total	Offspring	Hatch	Pupation	Adults
1-7	54	54	100	—	—	—	—	—	—	—	—	—	—
8-14	52	27	52	25	75	5	—	—	80	1.5	.1	—	—
15-21	52	15	29	37	243	66	—	—	309	5.9	1.3	—	—
22-28	44	5	11	39	233	191	4	—	428	9.7	4.4	.1	—
29-35	30	3	10	27	128	168	15	5	316	10.6	6.7	.7	.2
36-42	26	1	4	25	72	211	34	11	328	12.6	9.8	1.7	.4
43-49	25	1	4	24	54	166	45	50	315	12.6	10.4	3.8	2.0
50-56	25	2	8	23	48	115	24	61	248	9.9	8.0	3.4	2.4
57-63	23	3	13	20	36	83	17	37	173	7.5	6.0	2.3	1.6
64-66	7	—	—	7	5	24	2	13	44	6.3	5.6	2.1	1.9

The healthy galleries enumerated in Table IB have been divided into those which contain females that have laid no eggs, *i.e.*, non-layers, and those that have. The term 'non-layer' as used here, does not imply that such females never lay eggs, only that they had laid none at the time the galleries were examined. The galleries containing non-layers have been expressed as a percentage of the total healthy galleries; those figures show that during the first week the females were 100 per cent non-layers, and that that percentage decreased rapidly during the 2nd and 3rd weeks. The smallest percentage of non-layers (4 per cent) was observed during the 6th and 7th weeks; so it would appear that a few females never lay eggs although they make a gallery and live, apparently healthily, within it. These may be unfertilised females but there is no positive evidence to support such a conclusion.

In order to determine the number of eggs laid by any female, larvae, pupae and young adults must be counted as eggs. Such totals are given in Table IB in the column headed 'total offspring.' The mean number of eggs laid, 'mean offspring', is obtained by dividing each total by the number of healthy galleries opened during that week. The mean is therefore an average of the whole population including non-layers. Similarly the mean number of eggs hatched is obtained by dividing the sum of larvae, pupae and adults by the number of healthy galleries examined that week.

GRAPHS

The mean values given in Table IB are represented graphically in Fig. 1, where it will be seen that egg-laying began during the second week. Actually, eggs were first recorded on the 10th day when two galleries were found to contain eggs; one contained four and the other one egg. In the following weeks the mean number of eggs increased, more rapidly at first, until the 6th week when a mean of 12.6 per gallery was found. After the 7th week the mean number of eggs decreased regularly week by week.

Such a decrease can only be explained by the removal of offspring, either as eggs, larvae, pupae or adults, from the galleries. Larvae and pupae do not leave the galleries of their own free will, but adult females do. Adult offspring began to occur in the galleries in the 5th week but it was not until the 7th week that they were found in appreciable numbers, and at that stage they were ready to emerge from the galleries. It is probable, therefore, that many adults left the galleries in the 8th week and such departures resulted in a short count of offspring in the 8th and following weeks. Such departures would also be reflected in the curves representing larvae and pupae.

The eggs laid during the first week hatched after a given interval. If we assume for the time being that that interval was one week — it will be determined more accurately later — the eggs laid during the first week would be expected to occur as larvae in the second week. Similarly, the same number of eggs found in the second and 3rd weeks should occur as larvae in the 3rd and 4th weeks. If, then, there were no sampling errors, the curve representing larvae would run parallel with that representing eggs. By similar argument it may be shown that the curves for pupae and adults should also be roughly parallel with the egg curve, at least during the early parts of the graphs. It will be seen from Fig 1 that although there is a rough similarity between the curves, they are by no means parallel at their beginnings. The possible causes of their divergence from the parallel will be discussed later.

In the 6th week a mean of 12.6 eggs per gallery had been laid, but at no time was a mean of 12.6 hatched eggs per gallery found. The maximum number (10.4) of hatched eggs (larva curve) was found in the 7th week. At that time adults were emerging from their pupa cases and possibly escaping from the galleries, so it is unlikely that the maximum mean number of larvae found would ever equal the maximum mean number of eggs laid. The difference observed (2.2) however seems too large to be explained merely by the departure of adults from the galleries. A more detailed study of the early part of the graphs may throw further light on this and other problems.

In Fig. 2 are shown the mean daily observations of egg-laying and hatching over a short period. Pupa and adults are given as means of 3 days, because the number of available galleries each day during that period was too small to be of real value. It will be seen that the dotted lines joining these observed values are by no means straight, as might be expected from theoretical considerations alone. The number of galleries opened daily was relatively small, and consequently, the sampling errors are fairly large. The fluctuations in the graph are largely due to sampling errors.

It is possible, however, to calculate formulae to represent the straight lines which best fit each set of observations. The calculated lines have been drawn in Fig. 2 as unbroken lines through a period of 12 days, the data from which were used in making the calculation. Any prolongations of the theoretic lines are made by broken lines.

The formula of each theoretic line is as follows:—

Eggs	...	$y = -5.21 + .623x$
Larvae	...	$y = -7.10 + .463x$
Pupae	...	$y = -7.66 + .251x$
Adults	...	$y = -9.75 + .260x$

PERIODS AND RATES

When the theoretic lines in Fig. 2 are prolonged downwards they cut the X or time axis at definite points. The egg line cuts it at 8.4 days. This indicates that before 8.4 days no eggs are to be expected within the galleries, but after that date eggs may be found. In other words, egg-laying begins, on the average, at 8.4 days, *i.e.*, during the 9th day counting from the time the beetle began to form her gallery. Similarly it may be determined that hatching began at 15.3 days, pupation at 30.5 days and adults began to emerge 37.5 days after the commencement of gallery formation.

From these times are obtained the following average periods.

Pre-egg laying	...	8.4 days
Incubation period	...	6.9 ,,
Larval period	...	15.2 ,,
Pupal period	...	7 ,,

If 2 or 3 days are allowed from the emergence of a female from her pupa case till she starts to form a new gallery, the life cycle of the beetle from egg to egg amounts to about 40 days, not 24 days as stated by King [6]. The figures given here are averages based on galleries examined over a 12-day period, whereas King's figures are the shortest observed.

A comparison with the periods given by Speyer, and quoted earlier, shows considerable differences. In particular, he gives Pre-egg-laying and larval periods of much longer duration than occurred here. Possibly, these differences may be due to the different elevations at which the experiments were made. His data refer to the life history at 4,000 ft. which is nearing the upper limit at which this borer is found.

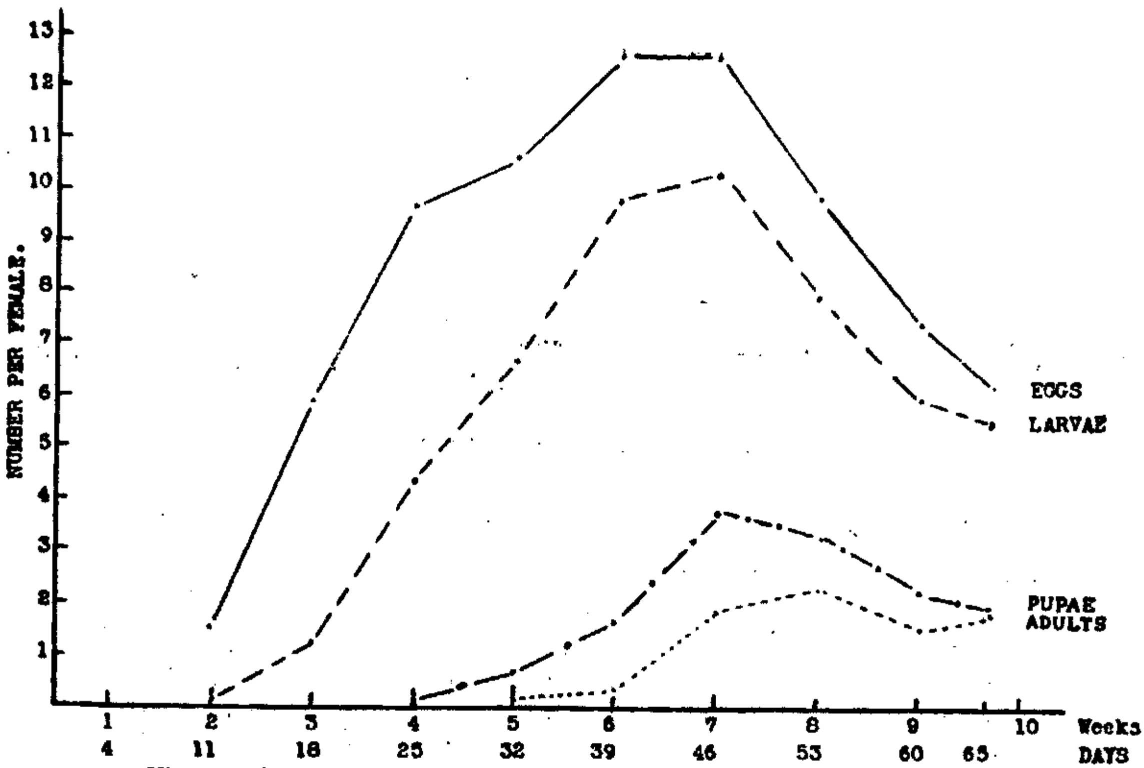

Fig. 1.—Graphs showing the mean number of eggs laid by a Shot-hole Borer population, together with the mean numbers of larvae, pupae and adults which result.

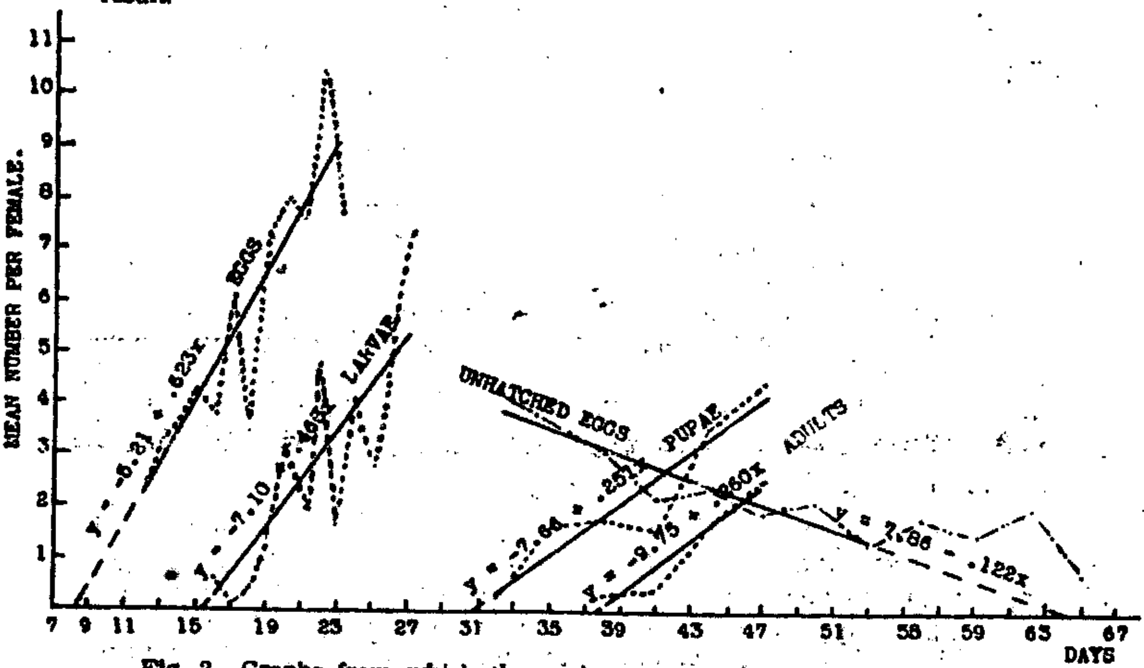

Fig. 2.—Graphs from which the various stages of the life-history of Shot-hole Borer and the mean rates of egg-laying, hatching, pupation and emergence of adults have been calculated.

The equations given above also indicate the rate at which egg-laying, hatching, etc., occur during the periods studied. The term .623x of the equation $y = -5.21 + .623x$ gives the average rate at which the mean number of eggs have increased from day to day, viz. .623 per female. This means that a population of female Shot-hole Borers between the 12th and 23rd days inclusive, after beginning to form galleries, lay eggs at the average rate of .623 eggs per female per day. The rates for egg hatching, pupation and emergence of larvae are given similarly by their respective equations.

The average rates of egg-laying, etc. shown by this population of borers are :—

Egg laying	...	.623 per day
Hatching	...	.463 ,, ,,
Pupation	...	.251 ,, ,,
Adult emergence	...	.260 ,, ,,

These values also indicate to what extent the graphs from which they were obtained are parallel. If the graphs were parallel as theoretically we should expect, these values would be equal. The graphs for pupation and adult emergence are nearly parallel, but the others are not. These figures indicate that although .6 eggs per day are laid, only .3 adults emerge per day, or in other words only 50 per cent of the eggs laid develop into adults.

It has already been mentioned that the value for the egg-laying rate given above gives little indication of individual performances. All females do not begin to lay at the same time. During the first week all females were non-layers; in the 2nd, 3rd and 4th weeks that percentage fell gradually to 52, 29 and 11 per cent respectively. There was therefore an appreciable number of non-layers between the 12th and 23rd days which is the period of egg-laying here studied in detail. The eggs found on those days have been shared, when averaging, amongst all the females, including non-layers. If instead of averaging the eggs amongst all females, they are averaged only amongst those females which have contributed to the total, *i.e.*, layers only, and proceeding as before, an equation, $y = -8.48 + .927x$, is obtained. This gives a mean egg laying rate of .927 eggs per day per laying female. This is a much better estimate of performance by the individual. It means that after a female has started to lay eggs she continues at the rate of .927 or about 1 per day.

How long does a female continue to lay eggs? An estimate of this period may be arrived at from a consideration of the unhatched eggs. In Fig. 2 are shown the mean number of unhatched eggs at 3-day intervals found in the galleries from the 31st to the 66th day, and the straight line which best fits the observations from the 31st to 54th day has been calculated. This has the formula $y = 7.86 - .122x$, showing that unhatched eggs were disappearing from the galleries at an average rate of .122 per day. During that period more eggs were being hatched than were laid. At that rate, eggs would completely disappear from the galleries after 64.4 days. In that event, egg-laying would have ceased 7 days earlier, *i.e.*, on the 58th day because it takes, on the average, 7 days for an egg to hatch.

TABLE II

Contents of galleries containing more than 25 offspring

Days	No. of possible laying days	Eggs	Larvae	Pupae	Adults	Total
35	26	6	18	4	—	28
36	27	6	16	5	—	27
37	28	7	17	3	—	27
39	30	6	18	2	3	29
40	31	3	24	5	1	33
45	36	1	15	7	7	31
51	42	—	13	4	10	27
52	43	9	19	1	5	34
59	50	10	12	4	5	31

As egg-laying started during the 9th day, an estimate of the average egg-laying period of the population becomes 49 days. This is probably an overestimate of the average number of days any *individual* female lays eggs, because as already shown, some females did not begin to lay eggs till the 3rd or 4th week; so the eggs considered in this calculation are probably those of females which were late in starting laying. Allowing therefore that a female borer lays one egg per day it is unlikely that she will lay as many as 50 eggs.

The highest number of offspring found in any gallery was 34 on the 52nd day (*cf.* Speyer who gives the same maximum number). In only 9 galleries were more than 25 found. Details of these are given in Table II, arranged in order by the age of the gallery. By deducting 9 days from the gallery age, *i.e.*, the average period taken in making the gallery before egg-laying, an estimate of the possible number of laying days is arrived at. For the first 5 galleries in the list there is fairly close agreement between the number of offspring and the number of possible laying days, which indicates, if the female has laid at a uniform rate during the whole period, an egg-laying rate at 1 per day. This is very near the average rate given earlier. Assuming then, a uniform rate of 1 egg per day we should expect the numbers of eggs, larvae and pupae in individual galleries to equal roughly the number of days in the incubation, larval and pupation periods respectively, viz. 7, 16 and 7 respectively. Note that this expectation depends upon a fairly uniform laying rate, and not on eggs being laid in batches, as indicated by Speyer by his reference to the 'first batch of eggs.' The females in the first 4 galleries had evidently each laid an egg for the last 5 or 6 days, so presumably had not reached the end of their egg-laying periods. The female in the gallery 40 days old appears to have ceased laying 1 or 2 days earlier, and the female in the gallery 45 days old 4 or 5 days earlier. In that case the egg-laying periods of these beetles were 30 and 33 days respectively. The beetle in the gallery 51 days old must have stopped laying more than seven days earlier, possibly 9 or 10 days earlier, judging from the shortage of larvae. That again gives an estimate of the egg-laying period of individual females as about 32 days.

The number of eggs in the galleries 52 and 59 days old seem unduly large, and suggests that more than one female is contributing to the number. The age of the galleries makes it possible that at least some of the eggs are being laid by female offspring. It would, however, be unwise to draw any definite conclusion about offspring laying eggs in the parent gallery from these two observations alone. It will be sufficient to accept them as indications of the possibility. Green has noted that occasionally an impregnated female may extend its original home though that procedure appeared exceptional.

The numbers of pupae found in all the galleries given in Table II except for the gallery 45 days old are somewhat smaller than expected. Our estimate for the pupation period may therefore be a little too large.

The maximum number of offspring found in any one gallery was 34, and from the foregoing it seems unlikely that number would rarely be exceeded.

MALE-FEMALE RATIO

In all, 141 pupae were found in the galleries and of these 33 or 23.4 per cent were males. Also, 177 adult offspring were examined; of these 48 or 27.1 per cent were males. The difference between these two estimates is not of statistical significance ($\chi^2 = .57$) and the observations may therefore be amalgamated. In this population, then, 81 males occurred for every 237 females or 1 male to 3 females.

Rutherford [7] has given two estimates of the male-female ratio of Shot-hole Borer. The first, derived from a few galleries was 1 to 5 which agrees with Speyer's estimate, and the second from another and larger count, 1 to 12.25. In arriving at these estimates he appears to have included parent females in the count, and that naturally increases the number of females. The estimate given above is calculated entirely on brood and so gives a more reliable estimate of the ratio in which males and females are born.

It has already been shown that although eggs were laid at the rate of .623 per day, adults emerged only at the rate of .26 per day. The rates of pupation and emergence of adults were approximately equal. Eggs amounting to .363 per day remain unaccounted for. The hypothesis that some adults left the galleries before being counted does not afford an entirely satisfactory explanation, because even by the 27th day, before adults began to emerge from the pupa cases, a loss of .16 eggs per day (egg rate minus larval rate) remains to be accounted for.

The most likely time at which losses might occur is while the young are in the grub or larval stage. Also it seems probable that because of the enclosed space in which the borer lives and raises a family, she must pay considerable attention to general hygiene. It would not be surprising therefore, if and when deaths occur, the female should remove the bodies from the gallery. To leave the dead bodies of larvae within the gallery to decay would be a serious menace to the health of the rest of the brood. Bodies removed by the female parent cannot be counted and consequently an estimate of the number of eggs hatched would be lower by that number, which in turn would reduce the estimate of the rate of hatching.

TABLE III

Effect of Female Parent on the Number of dead larvae within galleries

		No. of galleries	Ratio to living larvae
Galleries *with* living female	With dead larvae	5	9:21
	All larvae alive	144	—
Galleries *without* living female	With dead larvae	7	18:2
	All larvae alive	3	

If, as suggested, the female parent removes dead bodies from the galleries, more dead bodies should be found in those galleries which for some reason or other contain no female parent than in those in which the female is active. In Table III all galleries containing larvae, alive or dead, have been classified according as they contained a female parent or not. From the data given there it is evident that in the absence of the female parent a much higher percentage of galleries contain dead larvae, namely 70 as compared with 3.4 per cent when live females are present; and the ratio of dead to living larvae is higher.

The writer has been unable to find any reference in literature to direct evidence of the removal of dead larval bodies from the galleries by this borer beetle, but in view of the evidence given here it appears probable that something of the sort does happen.

It must be pointed out, however, that the evidence concerning the difference in egg-laying, hatching and adult emergence rates was collected from 'healthy' galleries alone, and in them one dead larva only was observed, whereas the data given in Table III was collected from all galleries, some of which contained Drosophilids. The question therefore naturally arises concerning these Drosophilids, and to what extent they themselves cause death amongst larvae.

DROSOPHILIDS

Drosophilidae are a family of small flies. Many of them are attracted to decomposing fruit, cider presses, wine vats, etc., to which they are attracted by certain products of fermentation. Eggs are laid in rotten fruit and in decomposing matter of all kinds. That many species of flies "are attracted by various individual by-products produced as a result of fermentation of different kinds" [3] and that the larvae of one species of *Drosophila* is known to "require a growth promoting substance present in yeast in order to complete their development" [3] suggest that Drosophilids are attracted to Shot-hole Borer galleries, either because of the presence of decaying animal or vegetable matter or because of some fermentation process which occurs within certain galleries.

Rutherford [7] recorded Drosophilid larvae and pupae within shot-hole galleries but was unable to say to what extent they preyed on the beetle colonies. He demonstrated that the Drosophilid larva was an unwelcome tenant of the gallery, as when he tried to introduce a Drosophilid grub into an occupied shot-hole gallery, the female repeatedly ejected the grub by backing out of the gallery pushing the intruder behind her. It does not follow that because Drosophilids are unwelcome they are predaceous on the beetle's progeny; they may be attracted by the ambrosia fungus within the gallery and go there to feed on it. In that case the fly is probably to be regarded as an enemy to the colony because by feeding within the gallery it may serve to diminish the number of beetles reaching maturity.

Senior-White [8] has described a Drosophilid from shot-hole galleries of tea as *Phortica xyleboriphaga* which he says is almost certainly the one referred to by Rutherford. He also states "Recently Mr. F. P. Jepson (Entomologist in charge of Shot-hole Borer investigations) informs me (*in litt*) that he has seen the larva eat a pupa of the beetle, tunnelling completely inside, and sucking it dry in about 20 minutes." Jepson [4] has pointed out the difficulty of studying the habits of the Drosophilid fly in that the larvae perish a few hours after removal from their natural surroundings, but he states that isolated instances have occurred where the larvae have fed upon the larvae and pupae of *X. fornicatus* immediately after removal from the galleries. Such evidence clearly indicates the predaceous habits of this fly.

During this investigation Drosophilids were found in 58 or 11.4 per cent of the galleries examined. Jepson [4] found it in 183 or 5.2 per cent of 3,504 galleries and later [5] in 6.8 per cent of 1,300 galleries examined on another estate. It may be seen from Table IA that the Drosophilid-invaded galleries were found mostly in the 5th, 6th and 7th weeks, when borer larvae were also most numerous.

Some Drosophilids were found in galleries otherwise empty as well as in occupied galleries. It may be seen from Table IA that empty galleries were found even in the first week. These of course were galleries which had been made, partially or wholly, by beetles which left them before beginning to lay eggs. Such galleries amounted to approximately 13 per cent of those examined until the 6th week, when the percentage increased somewhat. Towards the end of the experiment the percentage of empty galleries was at its highest because at that stage some of them were galleries from which the whole colony had emerged.

TABLE IV

Shot-hole Borer Galleries and Drosophilids

	Empty	With Shot-hole Borer	Total
Galleries containing Drosophilids	20	38	58
Galleries without Drosophilids	89	362	451
Total	109	400	509

In Table IV all galleries examined have been classified according as they contained Drosophilids or not, and whether they were otherwise empty or not. Twenty (or 35 per cent) of the Drosophilid-containing galleries were empty whereas only 20 per cent of galleries without Drosophilids were empty. This difference is probably of statistical significance (χ^2 =6.3) because it is likely to occur only about once in 70 times as a result of sampling alone. Drosophilids were found more frequently in empty galleries than would be expected if they entered galleries at random. Do they, then, for some reason prefer empty galleries or do they cause the galleries to become empty, or are the galleries selected for some reason other than their emptiness ?

MOIST EXUDATION

Many Drosophilids are attracted by certain products of fermentation, and mention has already been made of the presence in 28 galleries of a moist exudation which is suspected to be the results of a fermentation process.

Rutherford [7] noted that from certain galleries a sour smelling substance exuded and it was in such galleries that Drosophilids were most frequently found. Jepson [5] also reported that the galleries which contain the larvae of this fly almost invariably emit a putrid odour.

Speyer [10] also refers to a foul-smelling exudation from certain galleries. He writes: "When an incomplete gallery containing insects is about to heal, evidence is shown that the drainage of the tunnel is impaired. A considerable pressure of liquid in which the inmates are drowned forces decaying larvae and 'pellets' of fungus, teaming with bacteria through the entrance . . . . . When the foul-smelling exudation has ceased, the formation of a 'callus' proceeds."

These investigations lend no support to Speyer's view that the exudation results from impaired drainage nor that the exudation precedes healing. That the exudation may cause death amongst the colonies by drowning is evident, but no case has been seen in which the occupants are washed out as he describes. It seems more probable that the exudation is the result of a fermentation process and that the Drosophilids are attracted to galleries owing to that process. Alternatively the Drosophilids may start the fermentation by bringing into the gallery a ferment. Either hypothesis would explain Rutherford's observation that Drosophilids most frequently occur in those galleries which also exhibit the exudation.

TABLE V

Association between Drosophilids and Moist Galleries

	Drosophilids		Total
	Absent	Present	
Galleries *with* exudation	11	17	28
Galleries *without* exudation	440	41	481
Total	451	58	509

The association between Drosophilids and galleries exhibiting a moist exudation is shown in Table V, from which it may be calculated that of the galleries with the exudation 61 per cent also contained Drosophilids, whereas in the absence of exudation only 8.5 per cent contained Drosophilids. The difference is too great to be due solely to chance and we must conclude that there is a close association between the moist exudation and invasion by

Drosophilids. These figures, however, afford no evidence as to which comes first, the fly or the exudation. Taking into consideration the knowledge concerning the feeding habits of other Drosophilids it seems probable that the Drosophilids are attracted to those galleries in which some form of fermentation is taking place as shown by the presence of an exudation.

Of the 28 galleries with exudation, 6 or 28 per cent were empty. Of the remainder, 8 or 36 per cent contained no female, 7 or 32 per cent contained dead females, and an equal number contained living females. Of the 7 galleries with living females 2 had no other contents, 4 contained dead larvae and only one contained no dead bodies. It is evident therefore that the presence of an exudation is associated with high mortality amongst the beetles. This may be entirely due to the exudation drowning the insects, or partly to the Drosophilids which are attracted to such galleries.

OTHER INTRUDERS

Mites were found in 8 galleries and Lepidopterous larvae in 4 galleries. The number of occasions on which these intruders were found in the galleries were too few to be of value in an investigation such as this, so no attempt is made to determine their importance here.

SUMMARY

This paper describes experiments carried out in 1936 on an estate in Passara at an elevation of 3,500 ft. to determine fuller details of the life-history of the Shot-hole Borer beetle of tea.

509 galleries of known ages were opened and their contents examined.

The average times spent by the beetle in its various stages of development were: From commencing boring the gallery to egg-laying 8 days, egg period 7 days, larval stage 15 days, pupal stage 7 days. The life-cycle, egg to egg, is about 40 days.

After beginning to lay eggs a female lays on the average 9 eggs in 10 days and lays a maximum of about 34 eggs. Egg-laying is very unlikely to exceed a period of 49 days.

Some females laid no eggs during the period of observation although they remained within the galleries they had made. Others made galleries and left them before laying any eggs.

More eggs were laid than the number of adults which emerged from the galleries. It is suggested that dead bodies are removed by the parent female.

The borers prefer stems about half-inch in diameter in which to make their galleries and most frequently select the nodes as places for entry.

Fermentation occurs in some galleries and causes an exudation of a sour-smelling fluid. These galleries also attract Drosophilid flies and contain most dead beetles. Deaths may result from the fluid itself and/or from the Drosophilids which have been reported to be predaceous.

ACKNOWLEDGMENTS

The field and laboratory observations were collected by Messrs. G. D. Austin and W. T. Fonseka and acknowledgment is here made of the care and patience with which the data were obtained. The writer is also indebted to Mr. Austin for many of the references to literature quoted in the paper.

REFERENCES

1. Gadd, C. H.—Annual Report for 1928, Tea Research Institute Bulletin No. 3, p. 13, (1929).
2. Green, E. E.—Shot-hole Borer, Circular and Agriculture Journal R.B.G., Ceylon, Vol. II, No. 9, (1903).
3. Imms, A. D.—Recent Advances in Entomology. London, 1931.
4. Jepson, F. P.—Shot-hole Borer of tea, *Tropical Agriculturist*, Vol. 55, pp. 280-289, (1920).
5. — Shot-hole Borer Investigations, *Tropical Agriculturist*, Vol. 56, pp. 23-30, (1921).
6. King, C. B. R.—Annual Report for 1936, Tea Research Institute Bulletin No. 17, p. 34, (1937).
7. Rutherford, A.—Some notes on *Xyleborus fornicatus* Eichh. (Shot-hole Borer), *Tropical Agriculturist*, Vol. 42, pp. 132-139 and 220-222, (1914).
8. Senior-White, R. A.—New Ceylon Diptera, *Spolia Zeylanica*, Vol. XI, p. 381-395 (1921).
9. Speyer, E. R.—Shot-hole Borer investigations, *Tropical Agriculturist*, Vol. 48, pp. 152-155, (1917).
10. — Shot-hole Borer of tea, Department of Agriculture, Ceylon, Bulletin No. 60, (1922).