*THE FLIGHT AND DISPERSAL OF SHOT-HOLE BORER OF TEA (*XYLEBORUS FORNICATUS* EICHH., COLEOPTERA : SCOLYTIDAE)

D. Calnaido

The flight of *Xyleborus fornicatus* Eichh., a serious pest of tea in Ceylon, was studied, and it is concluded that the beetle is a migrant in which the flight habits are an evolved adaptation for aerial dispersal.

The beetles fly by day, from 08.00 hours to 17.00 hours, and this flight periodicity was determined by the numbers of insects emerging from galleries in tea stems and taking off. Most of the "emerging" borers do not "flit" or "hover" over the crop, but fly upwards in a slow fluttering flight, oriented to light. The borers' flight speed is 0.3 to 0.6 m/sec and the observed maximum duration of flight was 24 min, while the estimated duration of flight was less than one hour. Estimates of the borer populations in the air, their vertical distribution and possible deposition are discussed.

There are few published observations on the flight and dispersal of *Xyleborus fornicatus*. Gadd (1941 and 1944) and Cranham (1963) considered that the beetle's flight capacity was weak and that it probably flew only over short distances. However, Judenko (1958), who trapped the beetles on sticky boards, concluded that females were distributed by air currents up to 3.4 - 4.3 m, and that since the majority of beetles flew above crop level, they may spread to neighbouring tea fields. Additional information on the flight behaviour and dispersal of *X. fornicatus* has now been obtained by experiment and by direct observations in the tea field.

Materials and Methods

Xyleborus fornicatus, a serious pest of tea in Ceylon, was caught in flight over a tea field and collected from galleries in tea stems. The species was distinguished from the other species collected by its size and the shape of its abdomen, although *X. asperatus* Blandf. and *Arixyleborus marginatus* Egg. looked very similar to it.

The experimental site was at Hantane Estate, Kandy, Ceylon, at an elevation of about 762 m above sea level. Suction traps were set up in the centre of a mature tea field of about 2 hectares, which was surrounded by tea fields on all sides; bordering it to the east was a 2.4 hectare block of tea, sprayed with dieldrin on the 6th February 1963 and further beyond to the east was more unsprayed tea and then a forest reserve of mixed vegetation, which was about 320 m away from the trapping site (Figure 1).

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SKETCH MAP ILLUSTRATING THE EXPERIMENTAL AREA

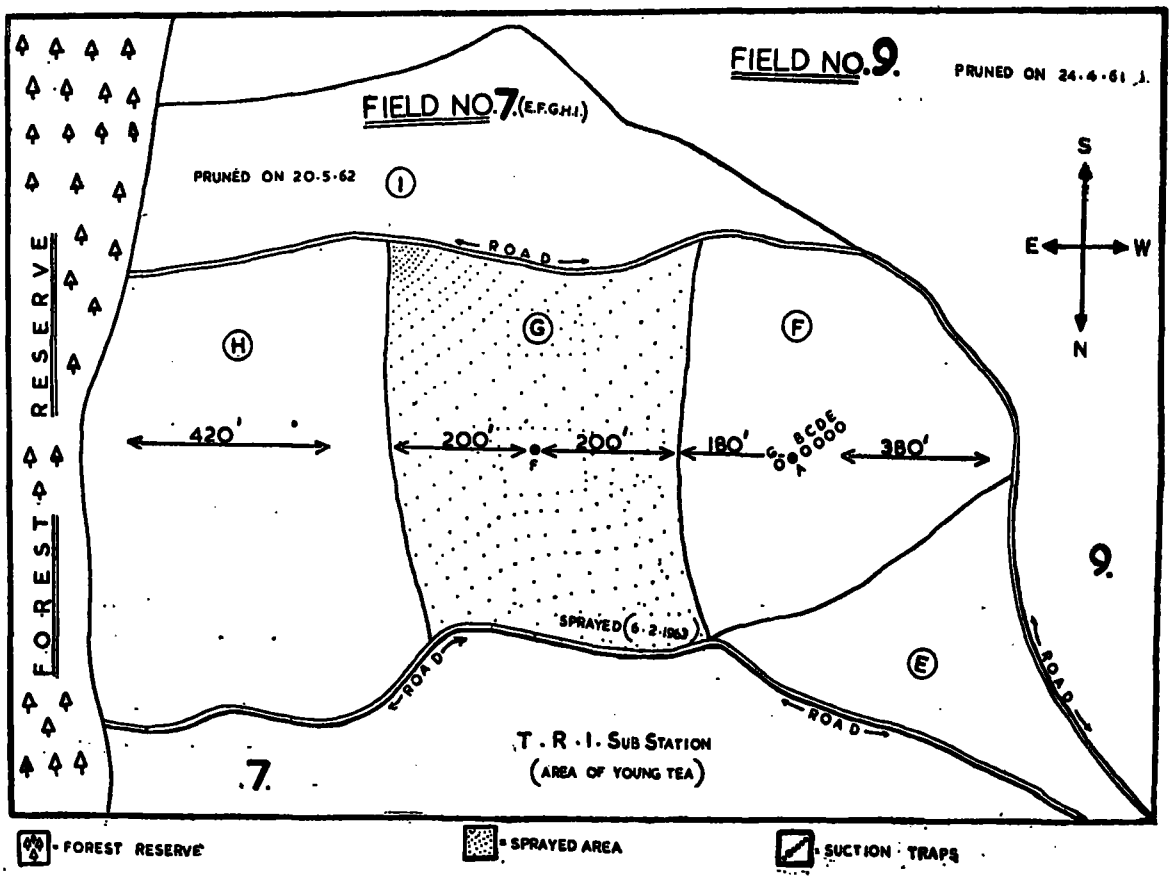

FIGURE 1—*A sketch map illustrating the location of the experimental site—The vertical series of traps (A, B, C, D & E) are in the centre of tea field, F*

The aerial density of *X. fornicatus* was measured with suction traps of various kinds (Johnson & Taylor 1955a & b), and results were standardized to give numbers of insects/28.3×10^3 m^3 of air (Taylor 1955 ; 1962). A vertical series of five suction traps, one of the 22.9 cm Vent-axia model and four of the 45.7 cm propeller type were set up on the 4th April 1964, arranged in the following order; a 22.9 cm Vent-axia at crop level (0.91 m) and 45.7 cm propeller types at 1.83, 2.74, 7.01 and 13.72 m (Figure 2). Initial trapping at ground level was discontinued, as very few borers were caught there.

The traps were changed daily at 08.00—09.00 hours, but from 7th April to 15th June, 1964, they were changed hourly from 08.00 to 16.00 hours (CST), as the flight of the borer is confined to these hours (Calnaido 1964). The hourly insect samples were preserved in 70% alcohol, from which *X. fornicatus* was sorted and recorded (Table I A).

Emergence of beetles from galleries in tea stems

The tea field was 24 to 26 months old in its pruning cycle and was heavily infested with the borer. Each day from 7 April to 15 June, 5 groups of 15 branches, collected at random, were placed in 5 muslin bags (0.9 m x 0.6 m) and hung in

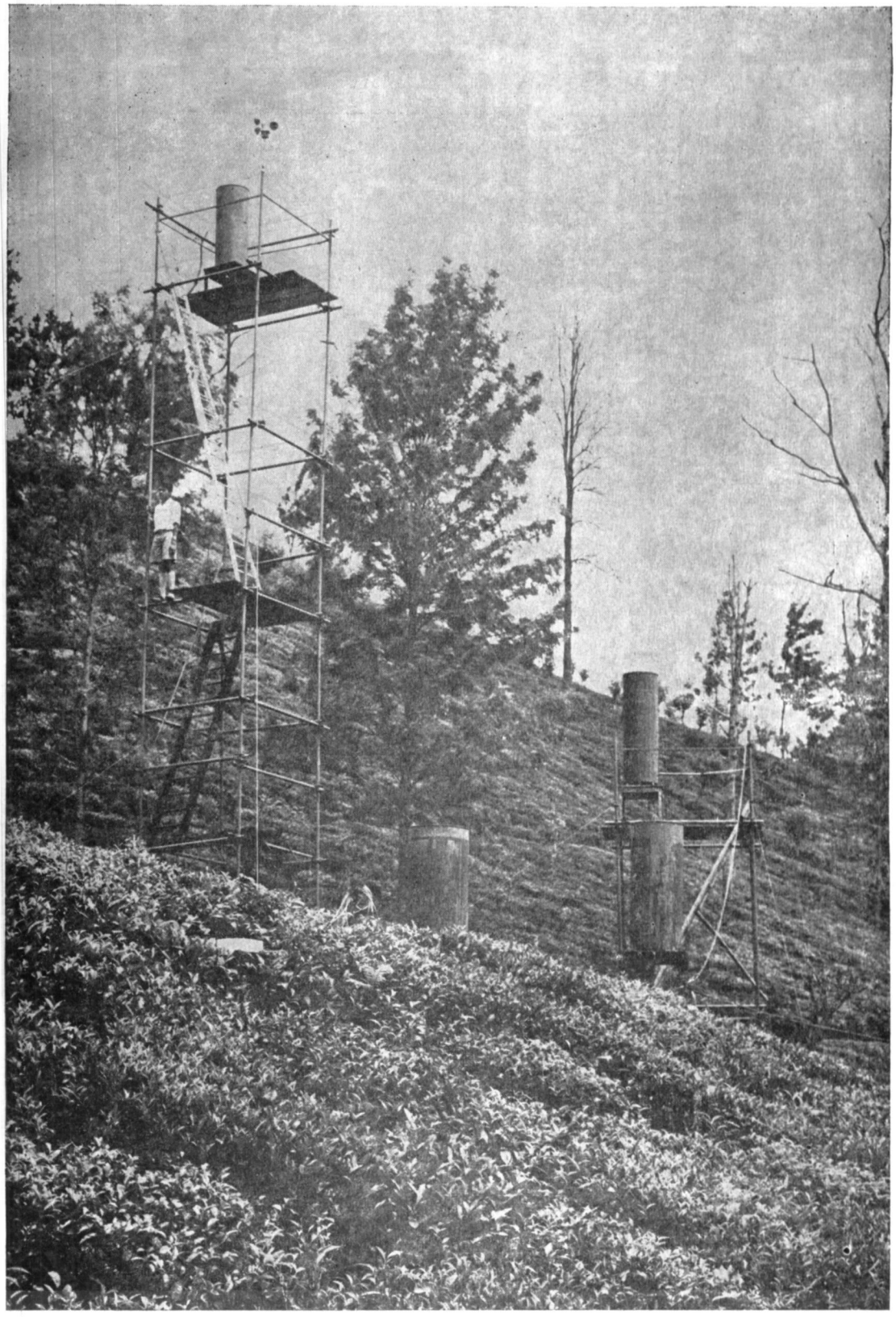

FIGURE 2—*The vertical series of suction traps erected in a mature tea field—The trap at ground level, at the extreme left of the picture, is concealed by the crop—The 22.9 cm Vent-axia trap, at crop level, is seen at the bottom left of the picture—(A band of white paper is attached to the mouth of this trap to demarcate it)—The other 45.7 cm propeller type are at 1.83, 2.74, 7.01 and 13.72 m—Note that the highest trap at 13.72 m is above the shade trees*

TABLE 1A—*Total numbers of* Xyleborus fornicatus *caught simultaneously in suction traps at different heights for 46 days (7 April to 15 June, 64); mean emergence (7 April to 15 June, 64), and total "take offs" from galleries in tea stems (3 March to 14 March, 64), with mean take-offs/hectare (calculated)*

Trap height in metres	Hours C.S.T. 08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	Total
0.9	1	3	5	19	37	31	26	8	130
1.8	0	1	8	110	231	105	41	6	502
2.7	1	2	4	78	147	66	13	8	319
7.0	0	0	0	22	30	7	1	0	60
13.7	0	1	0	5	19	8	0	1	34
Total	2	7	17	234	464	217	81	23	1045
Mean No. emerging/ hectare/h	133	922	1043	3199	5595	2275	493	0	13660
Total No. of "take-offs" (observed)	0	2	2	53	123	36	7	0	223
Mean No. of take-offs/ hectare (calculated)	0	0	502	2399	3538	1063	62	0	7564

TABLE 1B—*Proportion of beetles taking-off on emergence from galleries* 1B—1 *Data for 32 days (27.7.64–8.9.64)*

	Hours C.S.T.								Total
	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	08-16
Total No. Emerged	7	13	25	40	68	15	8	0	176 (100%)
Total No. taking-off	0	0	12	30	43	7	1	0	93
% take-off	0%	0%	48%	75%	63%	47%	13%	0%	53%

1B—2 *Hourly distribution of take-off*

		Hours C.S.T.							Total	Proportion of daily emergence taking-off
Take-offs	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	08-16	
Observed Total (12 days)	No. 0	2	2	53	123	36	7	0	223	
(3-14 March, 1964)	% 0%	1%	1%	24%	55%	16%	3%	0%	100%	53%
Calculated Mean/hectare (45 days)	No. 0	0	502	2399	3538	1063	62	0	7564	
(7 April-15 June, 1964)	% 0%	0%	6%	32%	47%	14%	1%	0%	100%	55%

the shade. The beetles that "emerged" from the galleries in these tea stems, were collected hourly, from 8 am to 4 pm. The number of beetles emerging/hectare/day was calculated from these samples, on the basis of 7400 tea bushes/hectare and 27.8 ± 2.17 branches per bush (95% confidence limits), (Table 1 A). An analysis of variance indicated that the data showed no significant variation between groups and therefore the sample was representative of the population (δ^2 group = 0.027 ; δ^2 time = 0.103*** ; δ^2 error = 0.023).

In this work "emergence" refers to beetles coming out from their galleries and not to eclosion.

"Take-off" studies

The "take-off" of beetles from infested tea stems was observed in the laboratory for 12 days, from 3rd March to 14th March 1964 (Table 1 A). Entire fresh branches of tea stems, cut at pruning time, were collected daily, placed in an empty room, and when beetles flew between 08.00 & 16.00 hours, they were caught with a nylon-net and released in the open air, where they were followed by a group of eight persons, until they flew out of sight. The free flight velocity of the beetles was calculated from measurements of the time and distance of flights made from a sheet of white paper in the centre of the room to the ceiling or windows. Take-off was also studied at the trapping site, as beetles flew from the tea bushes.

The duration of flight from "take-off" to first alighting was measured by releasing adult female beetles in a room, which had large glass windows around the sides. Most of the beetles flew upwards to the white ceiling and kept on striking it (not alighting) in several 'U' shaped flights until they were exhausted and dropped to the ground. In another room, with a grey roof, the beetles still flew upwards ; so stimulation from the white ceiling alone did not account for this characteristic upward flight.

The numbers of beetles, emerging and taking-off from galleries in tea stems/hour, were observed for a period of 32 days from 27th July to 8th September 1964, and the mean percentages taking-off/hectare/hour were calculated (Table 1B).

Treatments of samples

Absolute estimates of the aerial population were obtained using the vertical series of traps. Catches were converted to insect density in 28.3×10^3 m^3 of air, and corrected for the percentage efficiency of each trap (Taylor 1962). The vertical distributions are expressed as profiles of density on height and the changes in the slope of these profiles were measured to ascertain the movement of the aerial population. The vertical density profiles were extrapolated to 76.2 m and by graphical integration (Johnson *et al*, 1962) the total borer population in a column of air of base area 92,900 m^2 and 76.2 m high was obtained for each hour (Calnaido 1964) (Table 2).

Results

Periodicity, character and velocity of flight

Xyleborus fornicatus is a day flier ; and only females fly. The male has rudimentary metathoracic wings and is incapable of flight. The main flight period is from 08.00 to 17.00 hours, but between 08.00 and 09.00, and 16.00 and 17.00 hours, a few insects fly. Over 85% of the total daily catch occurred between 11.00 and 14.00 hours, and half of it between 12.00 and 13.00 hours (Figure 3). There is a marked diurnal rhythm in the numbers caught at crop level and in the integrated total numbers up to 76.2 m.

TABLE 2—*Mean hourly densities (No. 28.3 × 10 n.³/h) calculated from the catch of 46 days (7.4.64 to 15.6.64)*

Trap height in metres	Hours C.S.T.								
	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	Total
0.9	3.5	10.3	17.2	65.5	127.4	107.0	91.6	18.8	451.3
1.8	0	0.2	1.9	25.6	53.8	24.4	9.8	1.5	117.2
2.7	0.2	0.5	0.9	18.2	34.7	15.4	3.1	2.0	75.0
7.0	0	0	0	5.1	7.0	1.6	0.2	0	13.9
13.7	0	0.2	0	1.2	4.4	1.9	0	0.2	7.9

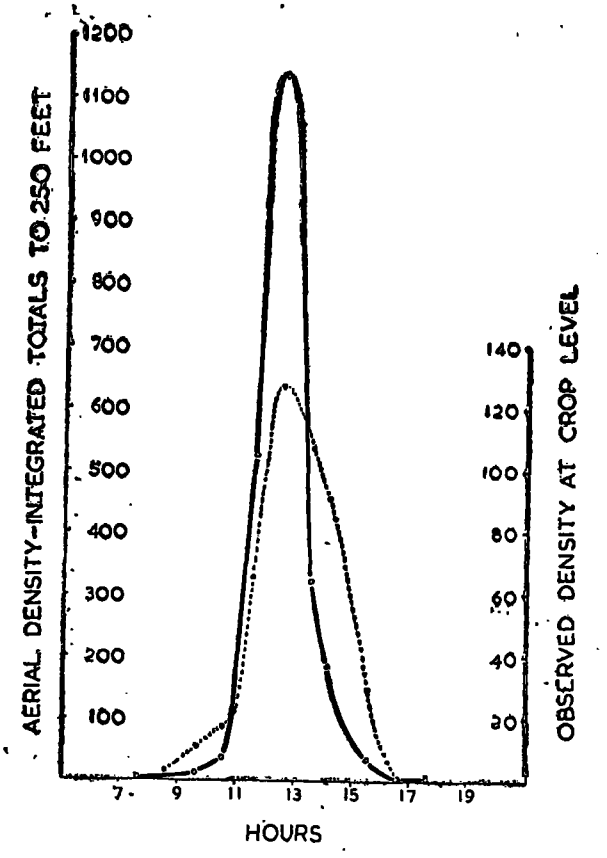

FIGURE 3—*The observed density in flight at crop level* (.------.) (*No. of insects in* 28.3×10^3 m^3 *of air/h and the integrated total aerial numbers up to* 76.2 *m* (.——.) (*in an air mass* $76.2 \times 92{,}900$ m^3)

Over 50% of the beetles that come out of their galleries walk up the tea stems, spread their wings once or twice, and take-off vertically upwards in a slow fluttering flight. The fluttering appearance of the flight is due to the beat of the elytra. The beetles taking-off around mid-day fly vertically upwards, but a few (less than 5% of the daily total) that "take-off" before 11.00 am and after 4 pm tend to fly laterally and settle down (Table 1 B). The borers could be seen against the sky, and in calm weather they flew upwards to 6 to 9 m when they rapidly disappeared from sight. Beetles released in strong wind were swept away laterally, to great distances, and were perhaps blown to neighbouring fields.

In the still air of the room the free flight velocity of beetles that flew straight averaged 0.3 to 0.6 m/sec. In few instances the beetles traced successive circles as they flew up. The maximum duration of continuous free flight after take-off till first alighting was 24 min, but it is likely to be much more than this because the beetles may have been prematurely exhausted by the repeated striking on the ceiling. Therefore, the borers could fly 430 m to 860 m without assistance from the wind.

The relationship of "emergence", "take-off" and flight

As with other insects, the flight of *X. fornicatus* was very closely related to the numbers emerging from galleries and leaving the crop. Over half the numbers emerging per day take-off (Table 1 B). Figure 4 shows the relation of the pattern

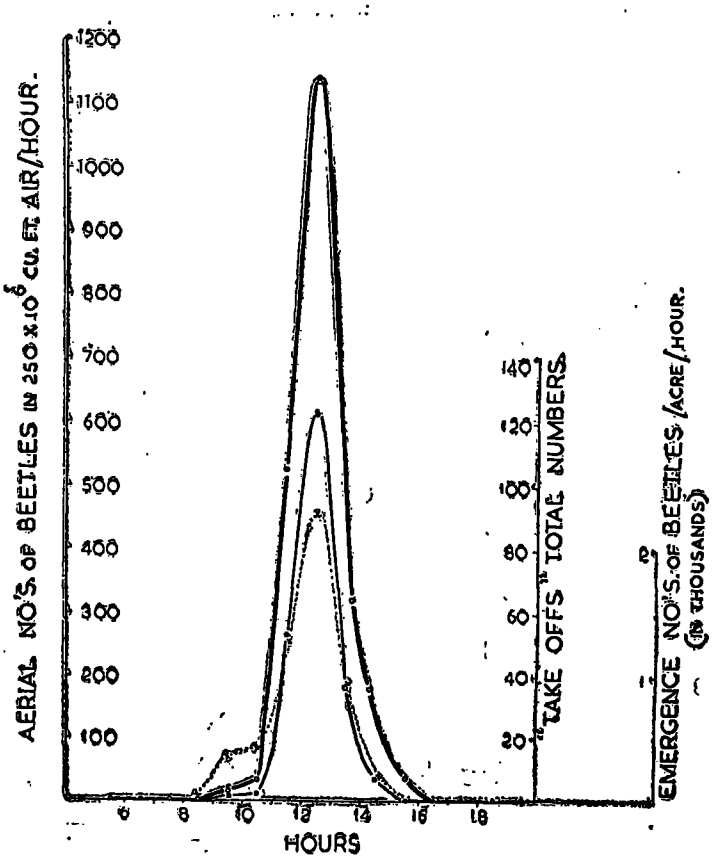

FIGURE 4—*The numbers of beetles "emerging" from galleries in crop* (×----×), *the numbers "taking off* (. ——.), *and the integrated total aerial numbers up to 76·2 m* (o —— o)

of emergence and take-off to the numbers in flight. The curves, for emergence take-off and flight are similar with a distinct peak at 12—13 hours. This suggests that most beetles come out of their galleries, take-off, and contribute to the numbers in the air, and that this process is at a maximum at noon. The smaller bump in the emergence curve indicates that most beetles emerging from galleries between 07.00 to 10.00 hours do not fly. The diurnal pattern of emergence of both males and females are illustrated in Figure 5.

Adults, emerging from galleries, are positively oriented towards light. Very few borers were caught in a suction trap at ground level or in water or sticky traps at crop level. Further evidence from direct observations and the different methods of trapping suggests, that borers take-off and fly vertically upwards from the source and do not "flit" or "hover" within or over the crop. Repeated flights following alightment were not observed either in the laboratory or in the field.

The diurnal patterns of vertical distribution

Figure 6 gives the mean hourly density profiles of *X. fornicatus* and indicates the vertical distribution and changes in the aerial borer populations, during the day. The gradients of the profiles are steeper in the early hours, become flatter towards

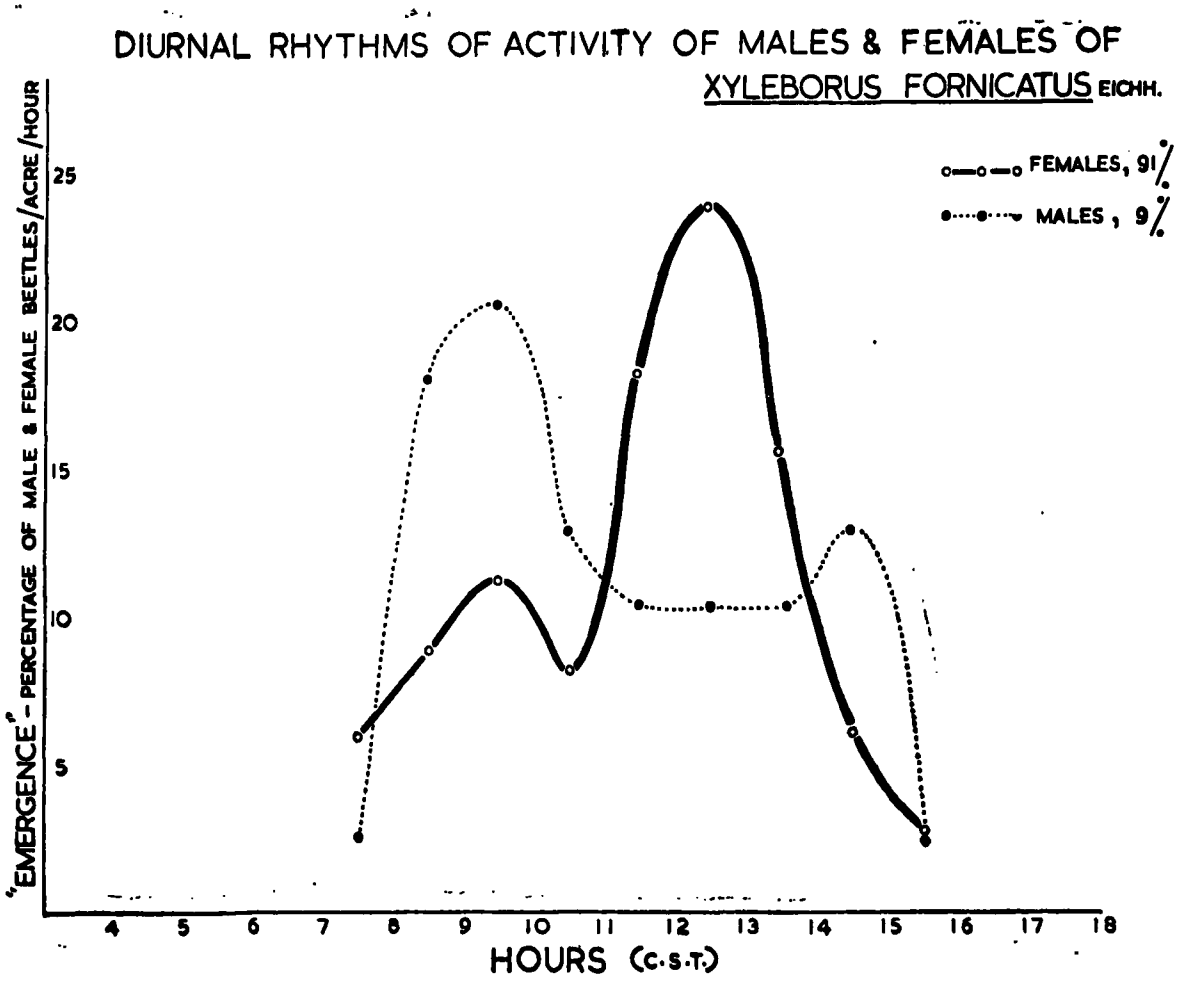

FIGURE 5—*The 'emergence' of males and females from galleries in tea stems—Two peaks of emergence are shown for the males, which come out of their galleries and walk on the tea stems—For the females the 1st small peak suggests emerging and mainly walking and the 2nd, emerging and "taking-off" in flight*

mid-day and steeper again in the afternoon hours indicating the rise and fall of the aerial population. The fitted regression coefficient (b) increases from—5.46 at 09 to 10 hours, to — 1.31 at 12 to 13 hours and decreases again to — 4.33 at 15 to 16 hours. This shows that the few flying at 09 to 10 hours are mainly confined below 3 m. At 10 to 11 hours numbers in flight increase, with 50% of the population (between ground level and 76.2 m) above the 1.2 m level. Around noon there is abrupt and maximum upward flight of the population, when at 11 — 12 hours 50% of the population fly above 4.5 m and at 12—13 hours 50% fly above 6.1 m (up to 76.2 m). Thereafter the aerial population settles down gradually, when at 15—16 hours 50% of the population is below 1.2 m and there is no flight after 17 hours (Table III). Thus there is an upward movement of the aerial borer population at mid-day, similar to that of aphids, *Aphis fabae* (Johnson 1957a & b) and frit-fly, *Oscinella frit* (Johnson *et al* 1962 ; Calnaido, French & Taylor 1965).

TABLE 3—*The hourly gradients (expressed as values of b) of aerial density in relation to height; the integrated totals representing the numbers of Shot-hole Borer in an air mass, 76.2 × 92,900 m³ over the crop, and median height of flight (the approximate height above which 50% of the population fly)*

	Hours C.S.T.								
	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	Values per day
The gradients of the density profiles (Regression co-efficient b)	—6.90±.26	—5.46±.21	—2.88±.19	—1.45±.11	—1.31±.06	—1.61±.24	—3.13±.40	—4.33±.09	— 1.208 (Mean of 46 days)
Total numbers in the air — in 76.2 × 92,900 m³	3	13	33	529	1138	320	180	36	2252 (Total/ day)
The approx % of flight during the hour	0.1%	0.6%	1.5%	23%	51%	14%	8%	1.8%	100%
The approx. median height of flight (in m)	0.9	0.9	1.2	4.6	6.1	1.8	1.2	1.2	3.0

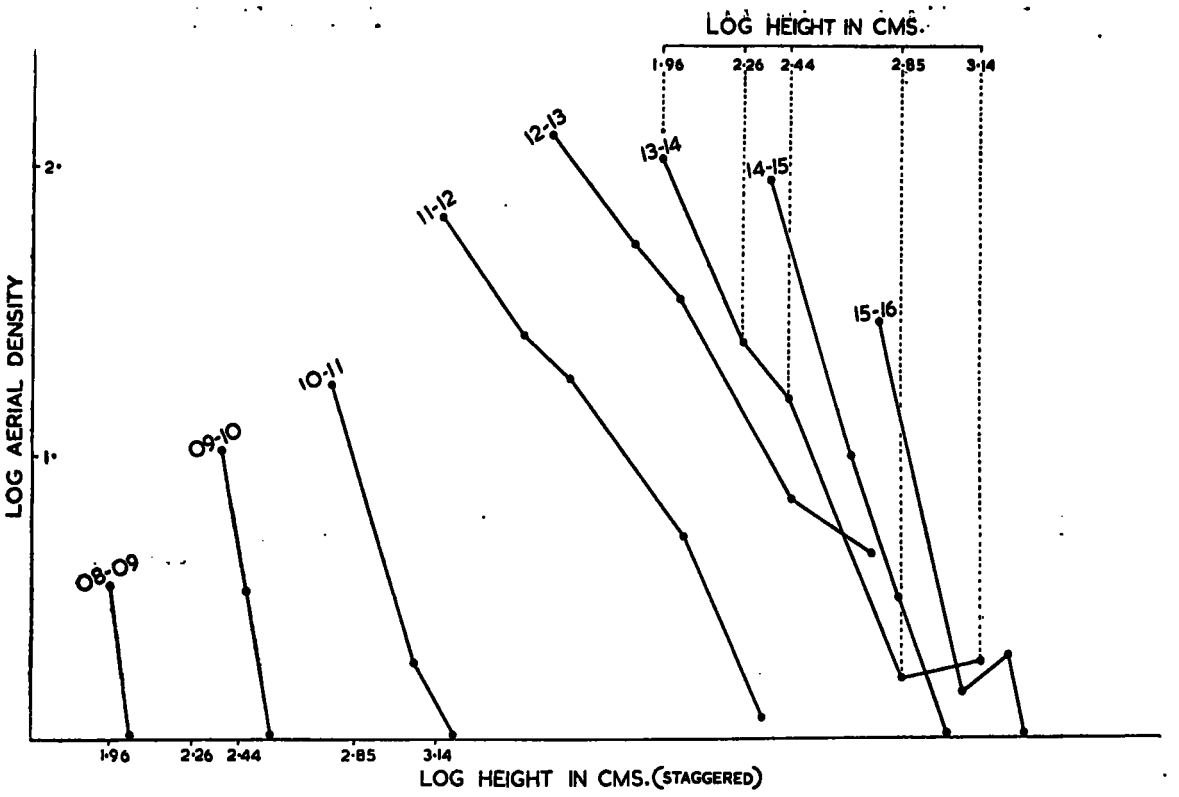

FIGURE 6—*The observed mean hourly density profiles or gradients (not extrapolated) from crop level to 13.72 m—The gradients are consistently displaced to the right to avoid overlap—The figure beside each graph denotes the hour*

The diurnal cycle of total numbers in flight, the flight duration and the rate of deposition of the population

Estimates for the hourly distribution of the aerial population in terms of relative quantities and in relation to height are given in Table 3. However, insects are ascending and descending all the time, so the difference in time between the peak of density near the ground and that of the estimated total aerial population would give an estimate of the mean duration of flight. The density curve at crop level coincided in time with that for total numbers up to 76.2 m and this suggests, that the average flight lasts less than one hour (Figure 3).

All the beetles in the air will eventually alight. Since the daily curve of total numbers in the air is made up of many flights of short duration, the number of beetles deposited on 92,900 m^2 from the air between 0 and 76.2 m will equal the sum of the integrated totals for each hour of the day. Therefore the total number of insects deposited or alighting was about 2250/92,900 m^2/day or 242 borers/hectare/day (*ie* an average of 1 beetle in about 41 m^2/day). The numbers deposited from air above 76.2 m are unknown.

Discussion

These results provide evidence, that *X. fornicatus* may be dispersed long distances, because it flies most around noon when atmospheric instability is greatest. Thus its control may be more than a local problem and current control methods may need revision.

Much evidence suggests that the borer behaves like other migrants. The density on height profiles are similar to those of frit-fly and aphids, though the general height of flight is much lower. The diurnal curves for 'emergence' from the crop, "take-off" and flight are all similar in slope and indicate how the sequence of these events, may lead to dispersal.

The aerial populations and the populations in the crop are comparable, except that the aerial population calculated here is an underestimate because the total aerial population sometimes extends above the heights considered (the height to which the extrapolations are made is 76.2 m). Further, all beetles that 'emerge' from galleries in tea stems do not fly and the aerial population, although mainly composed of the numbers emerging from the crop below, may also include a few of the beetles immigrating into the field. Attempts are being made to work out the quantitative relationship of these populations.

Previous opinions about the flight of this insect may be due to the fact that the beetles usually live within the galleries in tea stems and do not fly when taken out of them. Beetles taken from galleries in tea stems had poorly developed flight muscles while those caught in flight, had their flight muscles fully developed. Although beetles taken out of tea stems do not fly immediately, when the tea branches were left for 2 to 3 days, large numbers of beetles "emerged" and flew. This suggests that in *X. fornicatus* there is perhaps both autolysis and regeneration of flight muscles, as in some other Scolytidae (Atkins & Farris 1962), which could bring about re-emergence and second flights. This aspect of the problem is being investigated.

It was observed that beetles that "took off", on emergence from galleries, had the black shining texture of young adults, while the beetles that did not "take off" had the dull black colour of old adults. This fact, and the sequence of emergence from galleries, take-off and flight indicates, that the majority of beetles taking off are probably post-teneral individuals on their first flight. The length of the teneral period is unknown but observation indicates, that after emergence it lasts several days (the teneral period of one beetle was 15 days and two beetles lived as long as 18 days and died without "taking off"). Beetles probably "take off" only after being fertilized and if so, this explains, how the female lays its first batch of eggs, after its migratory flight, without needing a mate. It is also likely that the polygamous habit of the males would overcome the unequal sex ratio (male : female = 1 : 9), but there is no experimental evidence to support this.

The free flight velocity of the beetle (0.3—0.6 m/sec) and the maximum duration of flight (24 min) measured in the limited condition of a room, are conservative estimates. Even so, estimates suggest that the time taken for the beetles to reach 76 m, in the absence of upward air currents is only about 4 min, and it is possible, that in calm weather, they could reach very high altitudes in the air by their powers of flight alone (at 0.6 m/sec in 24 min they could travel to 864 m). As the flight speed of the beetles (less than 1 m/sec), is less than the prevailing wind speeds (1.8—2.7 m/sec), they will be carried by the wind and spread to considerable distances.

Acknowledgement

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