STUDIES OF THE "POPULATION - ECOLOGY" OF THE SHOT - HOLE BORER - *XYLEBORUS FORNICATUS* EICHH.—IN TEA, IN CEYLON

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Xyleborus fornicatus, commonly called the Shot-hole Borer, is known to live and breed in the tea plant. If he did only this, then we would not bother about him, but unfortunately for us (and for the Shot-hole Borer) this life of his in our tea does affect the health of the tea plant and consequently our purse. Hence, since the beginning of this century, many entomologists have worked on the Shot-hole Borer and the culmination of this knowledge is the reasonable success of the chemical control of the borer.

However, our knowledge of the "population ecology" or "the abundance and distribution of numbers" of this beetle is scanty. This knowledge is useful in forming any programme for the successful control of this pest, because, to bring about an effective control of any pest, it is important to know how environmental conditions influence the chances of the pest to survive and multiply. The search for an answer leads, on the one hand, to the examination of the insects physiology and behaviour, and, on the other, to the study of the four basic components of environment; weather, food, other animals, and "a place in which to live" (Andrewartha and Birch, 1954).

The entomological work at the T.R.I. Sub-Station, at Hantane Estate, Kandy, is directed towards this end, and of bridging the gaps in our knowledge of the borer. Attempts are being made to answer questions such as:

(i) what factors control the population build-up?;

(ii) what are the dimensions of these populations, in space and in time?;

(iii) are there any fluctuations—diurnal, seasonal or annual—in numbers, and what are they dependent on?;

(iv) how do they move to colonize new areas or spread themselves to build up larger populations?;

(v) are there any factor or factors, such as weather or cultural practice, that encourage the build-up of populations?; and so on. It is apparent that the answer to these and other similar questions will help in our attempts to control this beetle pest.

We have not yet found answers to all the questions we would like to find answers to. However, this paper explains what little has been achieved so far by giving you a brief description of some of the experiments now in progress, and presenting some of the results obtained to-date.

2. Experiments

In the study of populations, of insect pests, the traditional method was to confine this study, to the population within the crop. However recent workers, especially Johnson and his colleagues at Rothamsted Experimental Station, in England, in evolving the suction trap and the refinements in techinques in the analysis of data obtained from suction traps, have enabled a wider scope in the study of pest population. These suction-traps and techniques are being utilized to work out the population dynamics and dispersal of Shot-hole Borer.

2.1. Sampling with suction-traps may be considered as the most up-to-date method of measuring aerial populations of insects. The suction trap (Johnson and Taylor, 1955a,b) illustrated in Figure 1 and Plate I is essentially a device for collecting insects in the air and arriving at the absolute population per unit volume of air, at any particular time.

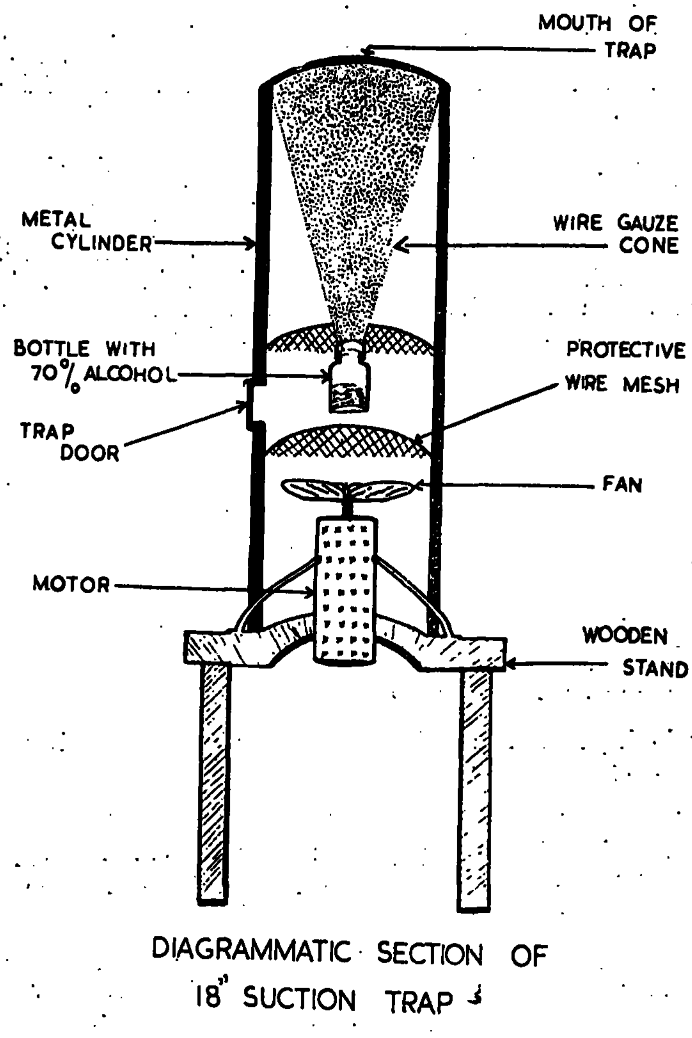

Fig. 1.—Illustration of suction-trap—a cross-section of the 18" propeller type.

A vertical series of 6 such suction traps, Plate II, was set up within a tea field (pruned on 20th May, 1962), in Hantane Estate, Kandy. The surroundings of the trapping site, at an elevation of about 2,500 feet, are illustrated in Figure 2. The arrangement of traps and the dates of operation are as follows;

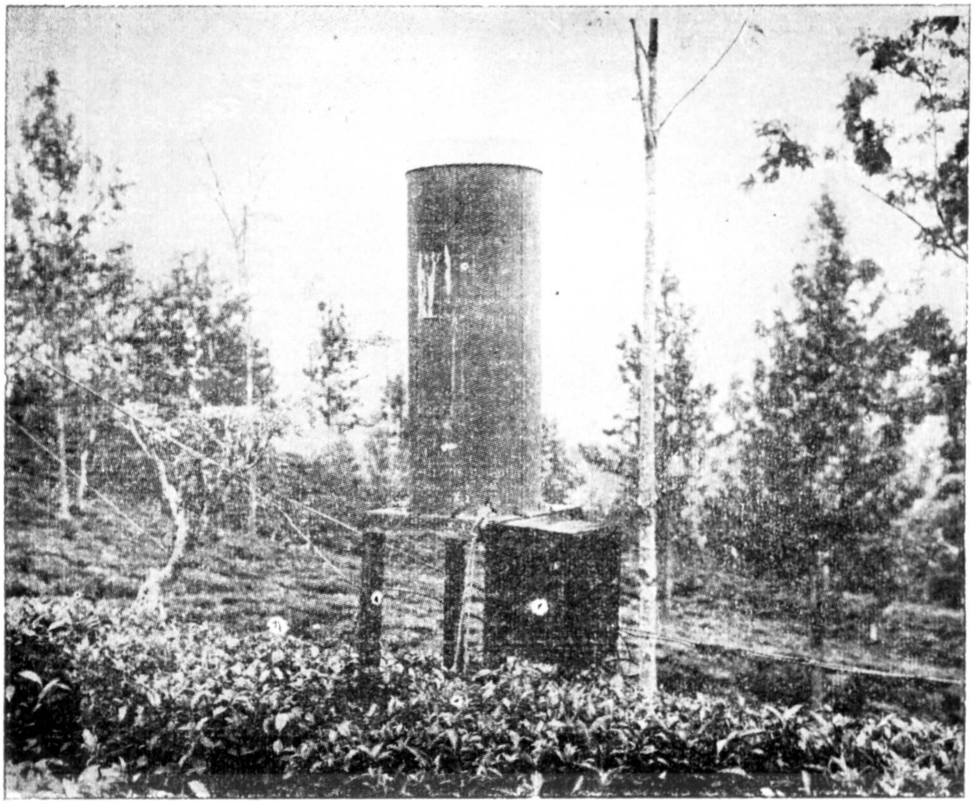

PLATE I

PLATE II

Trap	Diameter of fan	Volume of air Sampled	Height of traps	Trapping Started
G	9″ Vent-axia	293 cu. ft/min.	Ground level	2-5-63
A	,,	,,	Crop level	3-12-62
B	18″ propeller type	2510 cu. ft/min.	6 ft.	3-12-62
C	,,	,,	9 ft.	3-12-62
D	,,	,,	22 ft.	to be started
E	,,	,,	45 ft, (tree-top level)	25-4-63

The aerial population of the borer over the tea field is sampled by the simultaneous working of this series of suction-traps, which are emptied daily at 08.00—09.00 hours, C.S.T. The samples collected on any one morning are recorded as that of the previous day. From 13-8-63 to 18-10-63, a continuous period of 31 days, exclusive of holidays and heavy rainy days, the traps were worked at every half hour, during the day. The insect samples are preserved in 70% alcohol, from which *Xyleborus fornicatus* Eichh. is sorted, identified and recorded. The half-hourly samples were converted to mean hourly numbers caught in the suction-traps (Tables I and II). Hourly, suction-trap catches of *Xyleborus fornicatus* and other insects, were also obtained by working a 9″ Vent axia trap (disc dropper) from 7-3-63 to 11-4-63, and an 18″ propeller type from 18-3-63 to 11-4-63, in field No. 9 at crop level. (Field No. 9 was two years from pruning at this time). The traps were worked for 24 hours of the day and the samples were collected at every hour of the day (including the night), mechanically from the 9″ trap and manually from the 18″ trap.

Daily records of temperature, rainfall, wind-speed and sunshine are maintained.

TABLE 1.

Total numbers of Xyleborus fornicatus caught simultaneously in suction traps at different heights for 25 *days* (13-8-63 *to* 18-10-63).

	HOURS C.S.T.											
Height in feet	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18
0′	0	0	0	0	1	8	6	5	3	1	0	0
3′	0	0	0	1	2	9	20	10	4	1	0	0
6′	0	0	0	0	11	46	48	23	10	1	0	0
9′	0	0	0	1	1	22	36	12	8	2	0	0
45′	0	0	0	0	1	6	6	2	0	0	0	0

TABLE 2.

Mean hourly densities (*No.*/10^6 *cu ft/h.* = 283 × 10^3 m^3/h) *calculated from the catch of* 25 *days* (13-8-63 — 18-10-63).

	HOURS C.S.T.											
Height in feet	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18
0′	0	0	0	0	6.3	51.8	32.7	31.9	16.4	6.3	0	0
3′	0	0	0	6.3	12.7	58.2	127.3	63.8	25.4	6.3	0	0
6′	0	0	0	0	4.7	19.7	20.6	10	4.3	0.43	0	0
9′	0	0	0	0.43	0.43	9.4	15.6	5.1	3.5	0.86	0	0
45′	0	0	0	0	0.43	2.2	2.2	0.86	0	0	0	0

Estimates of aerial density

The numbers of borers caught in the suction-traps were converted to aerial density (mean number of borers /10^6 cu ft /h = 283 × 10^3 cu. m/h) by allowing for the amount of the air sampled by the traps and their efficiency in capturing insects in various wind speeds (Taylor, 1955, 1962).

Vertical density profiles

The aerial population of insects is a dynamic system. The total number of insects in the air ultimately depends on how many leave the terrestrial habitat. Yet, the relative abundance at different heights will depend on the insect's flight behavior, periodicity of flight, flight duration, the rate of "take-off" and the rate of "landing", and the degree of atmospheric stability.

By the simultaneous trapping of insects at various heights and the conversion of the numbers caught into density per unit volume of air, the vertical distribution of the aerial population can be shown by density on height profiles. Insect density diminishes with height and these density on height profiles vary in steepness or slope, depending on the type of insect, the time of the day or year and the influence of weather factors. The total numbers of insects in the air between any two heights can be calculated from the density on height profiles, either mathematically (Johnson, 1957 a and b; Taylor, 1960 b) or graphically (Johnson *et al*, 1962).

The changes in the aerial distribution can be measured by the changes in the regression coefficient of log density on log height (values of b) or the slope of the density on height profiles, which will indicate the relative proportions of the airborne population at the different heights in the air. If the slope of the density profile is shallow, tending to become parallel with the height axis (that is the regression coefficient is small) relatively more of the population is in the upper air, than when the density profile is steep. The extent to which the insects use the upper air as a vehicle of dispersion can be gauged by the slope of the density profile (the value of b). (Johnson 1960 and Johnson *et al.*, 1962).

The data on the aerial samples of borers were treated by the above described methods; the extrapolations of the density on height profiles were made only up to 250 feet and the integrated values for the total borer population in 250 × 1000 × 1000 cu./ft. were obtained by the graphical method. (Tables II, III and IV). The extrapolations were made only up to 250 feet, and not higher, so as to obtain more reliable estimates of the aerial populations calculated. (Calnaido, 1962).

TABLE 3.

The density values from fitted curves used in integration

	Hours C.S.T.											
Height in feet	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18
0′	0	0	0	0	6.3	51.8	32.7	31.9	16.4	6.3	0	0
3′	0	0	0	6.3	12.7	58.2	127.3	63.8	25.4	6.3	0	0
5′	0	0	0	1.4	7.0	27.2	28.5	16.7	6.7	1.6	0	0
10′	0	0	0	0	0	8.1	10.0	4.5	3.3	1.03	0	0
20′	0	0	0	0	0	3.8	4.4	2.2	1.9	0	0	0
30′	0	0	0	0	0	2.8	3.2	1.4	1.3	0	0	0
40′	0	0	0	0	0	2.3	2.4	1.10	1.08	0	0	0
50′	0	0	0	0	0	2.0	2.0	1.03	0	0	0	0
60′	0	0	0	0	0	1.8	1.8	0	0	0	0	0
70′	0	0	0	0	0	1.7	1.7	0	0	0	0	0
80′	0	0	0	0	0	1.6	1.6	0	0	0	0	0
90′	0	0	0	0	0	1.6	1.5	0	0	0	0	0
100′	0	0	0	0	0	1.5	1.4	0	0	0	0	0
130′	0	0	0	0	0	1.3	1.2	0	0	0	0	0
160′	0	0	0	0	0	1.18	1.1	0	0	0	0	0
200′	0	0	0	0	0	1.08	1.05	0	0	0	0	0
230′	0	0	0	0	0	1.03	1.03	0	0	0	0	0

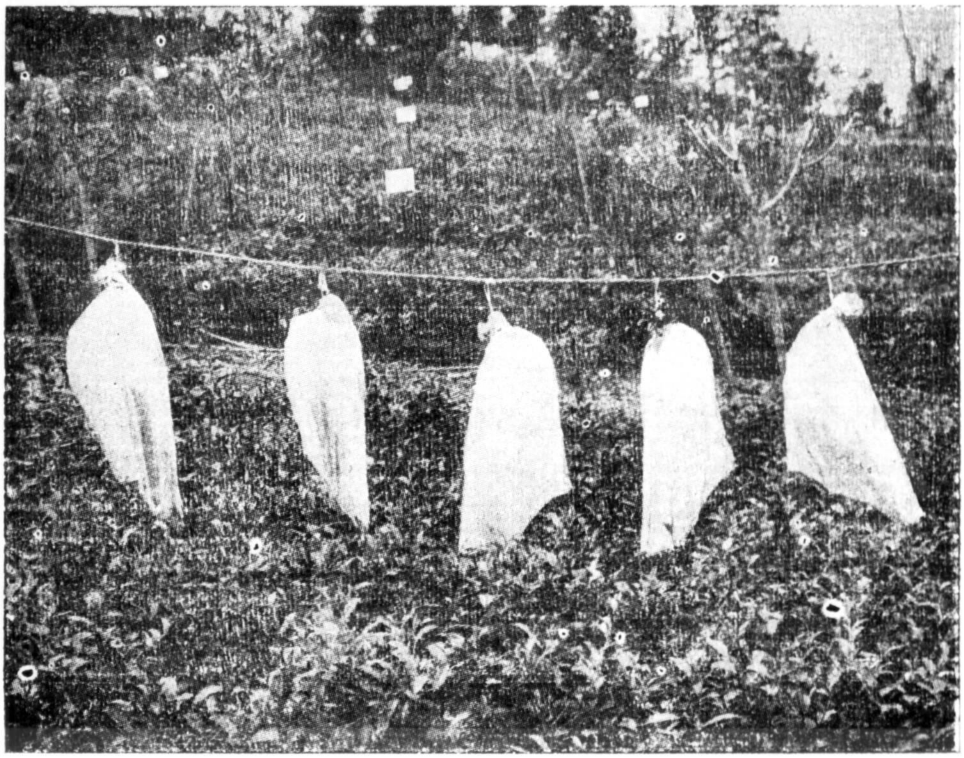

PLATE III

TABLE 4.

Numbers of Xyleborus Fornicatus at various heights over Tea Field

Integrated totals, representing numbers in the air mass 250 × 10^6 cu. ft. the proportions of this total *above* 3', 5', 10', 50', 100', and 200' during the hour and the mean height of flight—the height above which 50% of the airborne population is distributed.

	HOURS C.S.T.							Total per day (250×10^6 cu ft of air)
	09-10	10-11	11-12	12-13	13-14	14-15	15-16	
Total *Xyleborus fornicatus* in the air	21	68	720	993	430	174	34	2,490
% of Total daily flight (approx.)	<1%	<3%	29%	40%	17%	7%	<2%	100%
Height above								
3'	50%	56%	77%	70%	65%	65%	41%	70%
5'	14%	26%	65%	53%	39%	48%	18%	52%
20'	0	0	53%	41%	26%	33%	0	41%
50'	0	0	34%	26%	8%	0	0	21%
100'	0	0	22%	17%	0	0	0	16%
200'	0	0	6%	5%	0	0	0	4%
Approx. median height of flight	3	> 3	20	5	<3	<3	<3	5

2.2. "Emergence" records

From 10-7-63 to 23-10-63, observations at the times at which beetles emerged from gallaries in tea stems were made by the 'bagged' method (Plate III), where, branches, collected at random from field No. 9 (pruned on the 24th April 1961) were put in muslin bags (3' × 2') and hung in the shade. The bags and their contents were examined for 'emerged' beetles every hour, from 7 a.m.—4 p.m. The borers were collected, identified and recorded.

Five such bags, of 15 branches each, formed a sample from which the 'emerged' beetles were collected for about 10 days; after which the entire branches were dissected and the number of galleries and beetles (all stages) were recorded. In all there were 6 large samples of 6 bags each, 53 sampling days and 15,900 observations. These samples were also utilized to work out tentative estimates of the total borer population in field No. 9.

3. Results

3.1. *Diurnal Flight Periodicity*

All beetles caught in flight in the suction-traps were caught between 09.00-16.00 hours, C.S.T., indicating that *Xyleborus fornicatus* flies only by day (with no flight by night) and that flight is confined to a period of only 7 hours of the day. Only adult females were caught in flight, and this is because the males, being wingless, do not fly. Figure 2 shows the regular diurnal flight curve with a distinct peak at 12.00-13.00 hours (C.S.T.) and approximately 40% of the total daily flight is at this hour.

When the log density half-hourly-catches were plotted, the flight curve had the same shape as that of Figure 2. Also, the diurnal flight curves obtained in March-April and in August-September were identical. This confirms the shape of the diurnal periodicity of flight curve, illustrated in Figure 2.

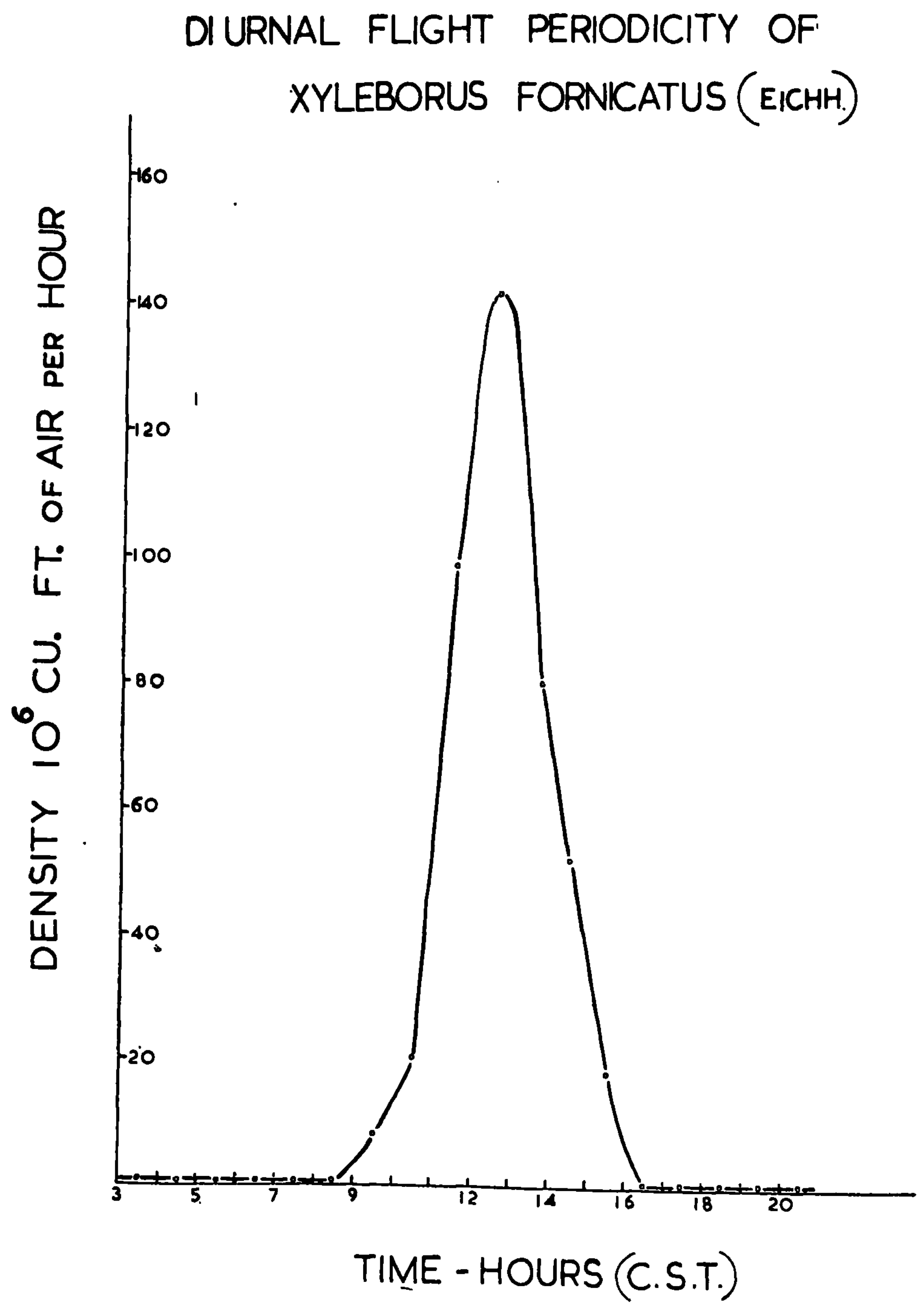

Fig. 2.—The pattern of daily flight of Shot-hole Borer.

3.2. *Diurnal emergence periodicity*

Figure 3 shows the diurnal 'emergence' curve (number of beetles/acre/hour) and the diurnal flight curve (numbers in 250 x 1000 x 1000 cu/ft of air/hour). It is important to note that, what is referred to here as 'emergence', is emergence from galleries in tea stems and not "eclosion" or "take-off". ("Eclosion" denoting emergence from the pupa, and "take-off" meaning the first flight after emergence. These will be worked out in due course as they are important in the study of population ecology).

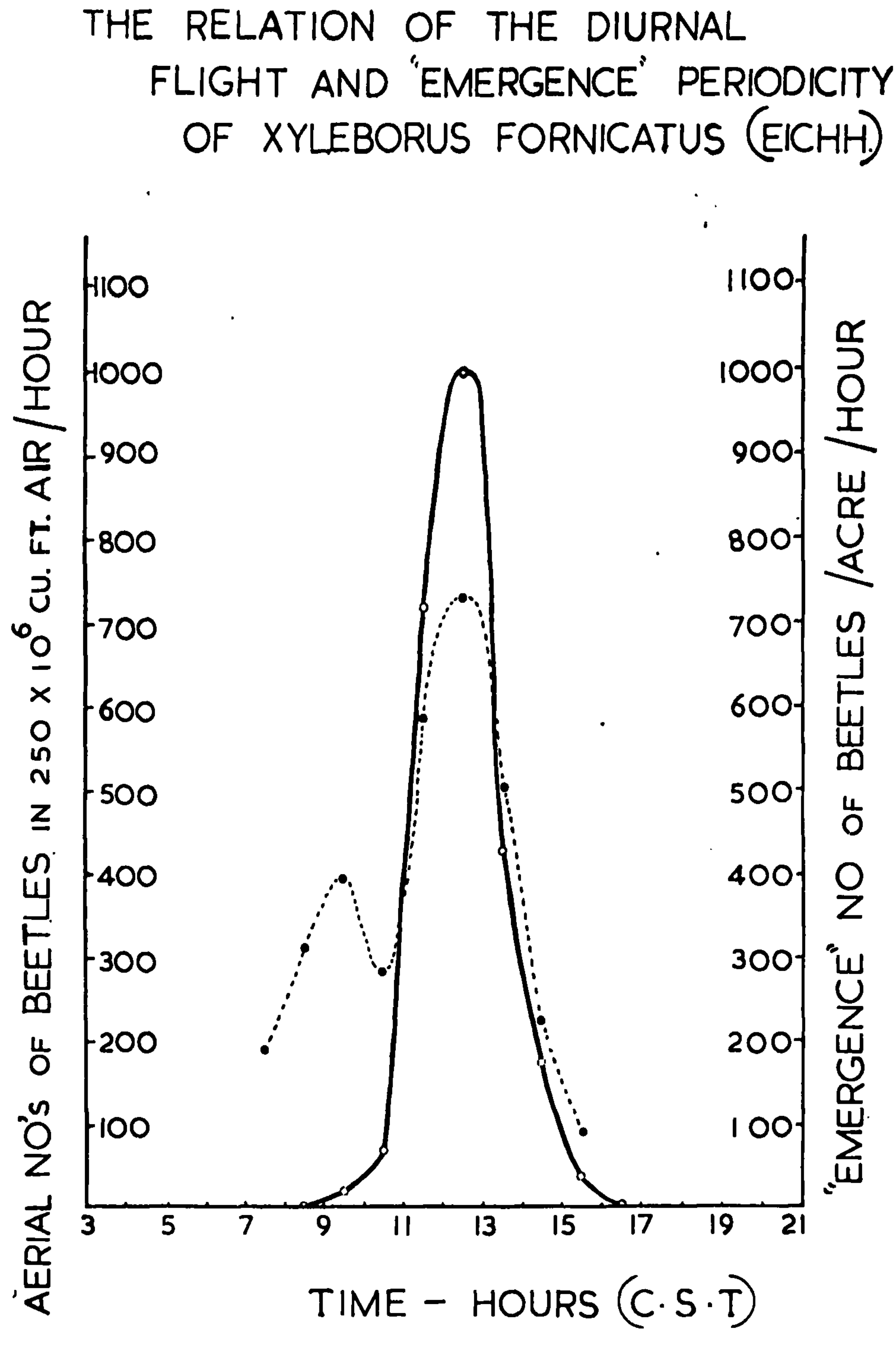

Fig. 3.—The relation of the pattern of the daily 'emergence' of Shot-hole Borer, from the gallereis in tea stems, to its pattern of daily flight. (The dotted line denotes "emergence" curve and the continuous line the flight curve).

The flight curve and the emergence curve are more or less similar in shape. It is most likely that the peak of emergence of the borers from the galleries and their rapid "take-off" causes the flight peak at 12.00-13.00 hours. However, until we know something about "eclosion", the length of the teneral period, "take-off" and the temperature-threshold for flight, this relationship is not very clear.

3.3. *Some tentative estimates of borer population*

3.3.1. *The absolute borer population in a tea field (Field No. 9, Hantane Estate), in its 27-29th month from pruning.*

Judenko (1958) and Cranham (1963) have worked out a method for the assessment of infestation of tea by Shot-hole Borer. This is very useful in assessing relative populations of the borer, especially in determining the effectiveness of control methods or the need for control. However, to-date, we have no idea of the absolute population of the borer per unit area of tea, which is essential in studies on population ecology. In an attempt to construct such estimates the following tentative figures were arrived at.

Field No. 9 at Hantane Estate in its 27th-29th month from pruning had a total borer population (all stages) of 616 to 1,118 thousand per acre. The physical damage that this enormous borer population had caused the tea, was the presence of $4.4 \pm .0392$ galleries per branch (95% confidence limits), or approximately 461 thousand galleries per acre. Further, in the same field 3,592 to 5,265 adults (both sexes) "emerged" per day, per acre. Our investigations also revealed that approximately 9% of the adult population were males (that do not fly) and only 40% of the 'emerged' females had 100% flight muscle development. It was observed that all beetles caught in flight had 100% flight muscle development.

Therefore, assuming that all adult females that 'emerged' and had 100% flight muscle development, dispersed, there would be a total production and discharge into the air of approximately 1,300 to 1,900 adult females per acre, per day, in No. 9 field. Field No. 9, 76 acres in extent, was pruned about the same time (April-May 1961), therefore, from this one field in Hantane Estate alone, there would be discharged into the air 99 to 145 thousand borers per day. Bearing in mind these tentative figures, for the terrestrial populations, let us take a look at the aerial populations and their movement, over an adjoining tea field, field No. 7. F. (in 16-17 months from pruning).

3.3.2. *Estimates of aerial population and their dispersion rates*

Figure 4 gives the hourly profiles of *Xyleborus fornicatus* and is an illustration of the diurnal cycle of vertical distribution. It shows that flight begins at 09.00-10.00 hours and the density profile is very steep, when 50% of the population is below 3 feet. At 10.00-11.00 hours the profile is less steep, with the median height of flight above 3 feet. At 11.00-12.00 hours, the gradient is least steep (where $b = -1.180 \pm 0.1710$), and is the hour of maximum upward lift of the population, with 50% of the population above 20 feet. At 12.00-13.00 hours the gradient becomes steep again, where the mean height of flight is only 5 feet. From then on, at 14.00, 15.00 and 16.00 hours the gradient become steeper, with the mean height of flight below 3 feet, till there is no flight after 16.00 hours. This indicates a mass upward movement of the population during the day, when it reaches a maximum at 11.00-12.00 hours, and then the population settles down again in the afternoon. This process is usually assisted by atmospheric currents.

MEAN HOURLY PROFILES OF XYLEBORUS FORNICATUS (OBSERVED).

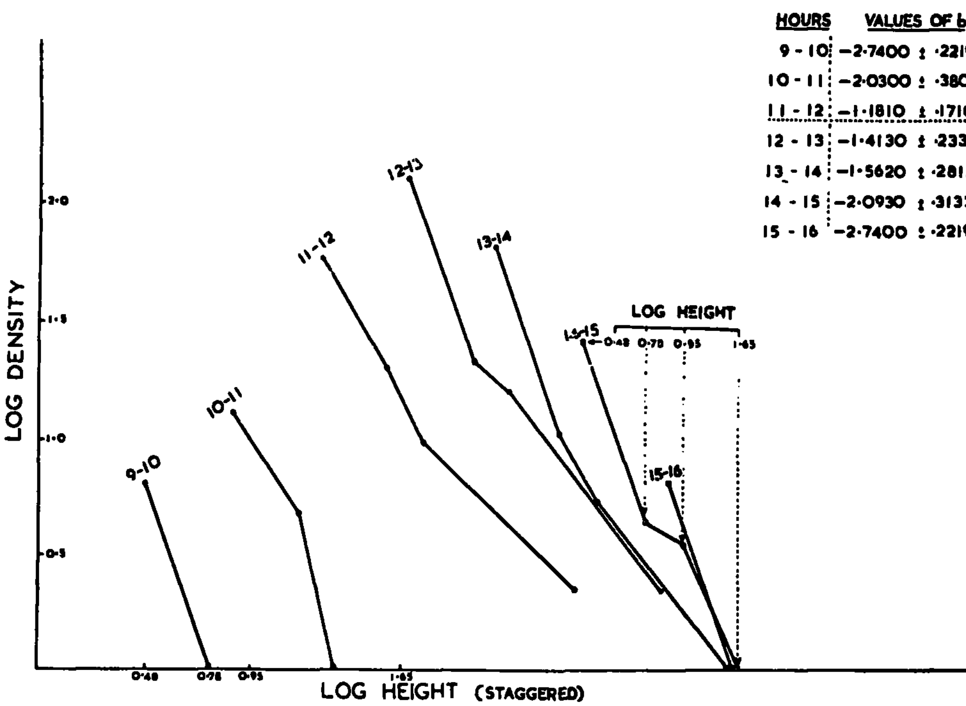

Fig. 4.—The daily patterns and changes in the vertical distribution of Shot-hole Borer, from hour to hour. (The gradients are on a double log scale each being slightly displaced to the right to avoid overlap).

Table 4 gives the number of *Xyleborus fornicatus* at various heights over the eat field; the integrated totals during the hour (from 09.00-16.00 hours) in an air mass, 250 x 1000 x 1000 cu/ft; the proportion of this total above 3′, 5′, 10′ 50′ 100′ and 200′ during the hour and the mean height of flight — the height above which 50% of the population occurs.

TABLE 5.

An Index of Dispersion.

Insect Type	Time	Regression of Log density on Log Height (Value of b;P=0.05)	Approximate % of population in Upper Air
1. Aphids (*Aphis fabae*)	Summer Days (In England)	-0.33 To - 1.1	90 % To 30 % Above 60 ft.
2. Frit-Fly (*Oscinella frit*)	11.00 - 12.00 Hours G.M.T.	-0.5 To-0.6*	89 % Above 20 ft. 87 % Above 60 ft.
3. Shot-hole Borer (*Xyleborus fornicatus*)	11.00 - 12.00 Hours C.S.T.	-0.44 To - 1.92	50 % Above 20 ft.† 32 % Above 60 ft.†

*The significance of this value is not available.

†(Only 250 feet in height is considered for Shot-hole Borer, whereas, thousands of feet have been considered for Aphids and Frit-fly).

Table 5 compares the dispersion rates of *Xyleborus fornicatus*, with that of Aphids (*Aphis fabae*) and Frit-fly.(*Oscinella frit*),(Johnson 1957 and Johnson *et al*, 1962). Shot-hole Borer has the least dispersive rate of the insects compared, with only 50% of the population over 20 feet and 32% of the population over 60 feet, at 11.00-12.00 hours, C.S.T. (when only 250 feet, in height, is considered). However, it must be remembered that the other two insects — Aphids and Frit-fly — are well known for their rapid rate of high altitude migration.

The tentative estimates of the terrestrial population of field No. 9, revealed that there is likely to be a discharge, into the atmosphere, of 99 to 145 thousand borers per day (assuming, that 40% of the adult females that emerged "take-off"). One could imagine the magnitude of the aerial population adrift, if 50% of this population were over 20 feet and 32% over 60 feet, at 11.00-12.00 hours. However, it should be noted that this consideration of the terrestrial population of one place and the aerial population of another, is questionable. Attempts will be made to relate the terrestrial population to the aerial population in field No. 7. F, (where, with the aid of the vertical series of the suction-traps the aerial population could be estimated, as done at present) when this field has built up its borer population to the 25th to 30th month from pruning, for at present this field is only in its 19th month from pruning and has not yet built up its terrestrial population, sufficiently. When this is done, more substantial estimates of population production and aerial dispersal can be obtained.

With weak flying insects such as *Xyleborus fornicatus* (whose flight is likely to be not more than 2 m.p.h.) once they are taken over the tree-top level (and the highest trap was at tree-top level), they are at the mercy of the winds (at most times wind speeds being greater than 2 m.p.h.) for their distribution or rather they make use of the wind as a vehicle of dispersal. At 11.00-13.00 hours, approximately 340 borers (in 150 x 1000 x 1000 cu/ft/h) were above 100 feet, when the average wind speed was 4-6 m.p.h.; assuming that the borer's flight-speed is 2 m.p.h., they could (with wind speeds of 4-6 m.p.h. prevailing at the time) be dispersed many miles from Hantane, possibly as far as Madulkelle and Hunnasgiriya to the north-east and Gampola and Nawalapitiya to the south-west, depending on the main direction of the air currents.

Therefore, however difficult to visualize this at first, it is likely that the dispersal of borers from one estate, could effect re-infestation and recolonization of an estate miles away. In view of this, if we are to successfully control Shot-hole Borer from our estates by chemical means, a combined effort by all estates appears desirable and perhaps, preventive measures, by timed chemical control of young tea, would be advisable.

4. Summary and Conclusions

4.1. The importance of the ecological approach to the study of Shot-hole Borer is briefly explained and some of the experiments designed for this purpose, now in progress at Hantane Sub-Station, are described.

4.2. The daily flight periodicity and the daily 'emergence' periodicity of the borer and their relationship are briefly discussed. The borer flies only by day, for about 7 hours, 9 a.m.-4 p.m., with maximum flight at 12 noon to 1 p.m. The rapid "take-off" of beetles emerging from the galleries in tea stems appears to be the cause of the daily pattern of flight.

4.3. Some tentative estimates of the borer population in tea and the atmosphere above are given. Studies on the movement of this aerial population and their possible effect on recolonization and reinfestation of sprayed areas are briefly outlined. The high population production of borers per acre per day (in the order of 1,300 to 1,900 borers) and the evidence for the high rate of the aerial migration of this beetle pest is presented.

4.4. In view of this aerial dispersal of Shot-hole Borer and its possible effects on the recolonization and reinfestation of tea fields, it is considered advisable for estates to make a combined effort in the chemical control of Shot-hole Borer and to protect young tea by timed chemical control.

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