DEPARTMENT OF AGRICULTURE, SOUTH AUSTRALIA

Agronomy Branch Report

# SAMPLING METHODS AND LIFE-TABLE DATA FOR SITONA HUMERALIS STEPHENS (COLEOPTERA: CURCULIONIDAE)

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Research Officer (Entomology)

Report No. 62

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CONTENTS (Contd.)

## 1. SUMMARY

This report describes the techniques for sampling each life stage of Sitona humeralis Stephens to estimate absolute populations. These estimates will be used in the construction of a life-table which will give a better understanding of the insect' s biology, necessary for determining the best type of parasite for introduction and assessing the value of introduced parasites.

Stratified random sampling (by area) was used and one sample unit selected at random from within each sub-area.

The eggs were sampled by taking soil cores 4.5 cm diameter x 1 cm deep which were washed and the eggs removed by floating in saturated sodium chloride solution. Experiments will have to be done to determine the optimum sample unit size and the number of those sample units necessary to give an accuracy of 90%.

The larvae and pupae were sampled by taking 200 soil cores (11.5 cm diameter x 10 cm deep) and the insects removed by hand sorting. This method gave an accuracy of about 90% except where the population was very low or highly aggregated. A different technique will have to be devised for early instar larvae which occur inside the nodules.

The autumn/winter population of adults was sampled by vacuuming 200 quadrats (50 x 50 cm) but the number of sample units will have to be increased through winter as the population level falls. The spring generation of adults was measured using one hundred emergence traps which were checked weekly and also by counting emergence holes. Vacuuming adults during spring was unsatisfactory because of rapid changes in the population.

## 2. INTRODUCTION

Since it was first recorded in 1966, S. humeralis has become a major insect pest in annual medic pastures and lucerne throughout the agricultural areas of South Australia (Allen and Moulden 1974). In addition to severe damage to foliage by adults during spring and autumn, the larvae attack medic nodules possibly threatening the source of nitrogen for the pasture and ensuing cereal crops.

Eggs of S. humeralis are commonly laid on the ground near the food plant but some are laid on leaves falling to the ground later. Eggs are present from April to mid-November (Allen 1971).

Newly hatched larvae bore into the soil and burrow almost directly for legume nodules (Allen 1971). When the contents of the nodule are devoured and only the cortex remains, larvae exit through small holes. Older larvae feed from the outside of the nodule and leave an empty shell (Manglitz et al. 1963). The older larvae probably also feed on the roots (Danthanaryana 1967). The final stage larvae move to the top 5 cm of soil where they form an earthen cell and pupate. The larvae are completely soil dwelling occurring in winter and spring. Pupation begins in late August and a few pupae can be found in November.

Adults of S. humeralis emerge during October and the females are sexually immature (Allen 1971). In 1972 adults began to emerge at Roseworthy on October 13 with the maximum rate of emergence on October 25 and by November 13, 97% of the population had emerged with the remainder emerging by December 15 (Moulden 1973). Adults aestivate from December to March or April while sheltering in cracks in the soil, under vegetable debris or at the base of plants. Females become sexually mature with the formation of the first eggs during April and oviposition continues until their death. Most adults are dead by October but a few live until December after living as adults for approximately a year (Allen 1971).

The seasonal life history of S. humeralis is summarized in Appendix 1.

The only report seen of intensive sampling of Sitona was by Danthanaryana (1969) who sampled Sitona regensteinensis (Herbst) feeding on broom. Because there was a negative correlation between the number of eggs and the distance from the stem, the eggs, larvae and pupae were sampled by taking soil cores (2.54 cm diameter x 30.5 cm deep) from three annuli centred around broom bushes. This sampling pattern is unsuitable for S. humeralis because of the more homogenous cover of host plants in a medic pasture.

Less intensive sampling of larvae was done by Manglitz and his co-workers (Manglitz and Calkins 1963; Manglitz *et al.* 1963) where only a few soil cores 1 sq ft in area and 6 inches deep were taken to measure larval populations of *Sitona cylindricollis* (Fahraeus) and *Sitona hispidula* (F). Danthanaryana (1969) described three methods for sampling the adult stage of *S. regensteinensis*: by beating a portion of the broom bush; by marking, releasing and recapturing; and by estimating the number of emerging adults with emergence traps (3716 $cm^2$ x 19 cm high).

The most common method for sampling adults of other *Sitona* spp. is by sweeping vegetation e.g. sweeping sweetclover for *S. cylindricollis* (Caulkins and Manglitz 1968) and sweeping red clover for *S. hispidula* (Hansen and Dorsey 1957). The beating and sweeping of host plants are unsuitable methods for sampling adults of *S. humeralis* because of the prostrate habit of annual medics. Sweeping may be suitable for sampling in lucerne.

This report describes the techniques for sampling each life stage of the insect to estimate absolute populations. These estimates will be used to monitor fluctuations in populations due to climatic and biological factors, particularly introduced parasites. Initially the population estimates will be used to construct a life-table giving a better understanding of the biology of *S. humeralis* which will be necessary to determine the best type of parasite for introduction. Important considerations will be: the chief causes of mortality, migration of the insect, overlap of generations and fecundity. This information can be obtained by constructing a life-table which states, for every interval of age, the total population, the number of deaths, the rate of mortality and the expected longevity of the remaining population.

This report also presents raw data obtained from samplings during 1974.

## 3. EGGS

### 3.1 Experiment 1 - Extraction of eggs from soil

Previous attempts to extract eggs of *S. humeralis* from soil samples relied on the method proposed by Danthanaryana (1966). which proved unsuccessful because of the large amount of vegetable debris that was mixed with the eggs. The following experiment was carried out to determine the efficiency of an alternative method.

a) The sample unit consisted of a soil core 4.5cm diameter and was taken by inserting a plastic tube into the soil to a depth of 1 cm over an area where no eggs were present.

b) Twenty eggs were placed in four tubes which contained the soil core.

c) The tubes were filled with water and allowed to stand overnight.

d) The contents of each tube was thoroughly washed through a mesh sieve (fly screen) with water. The washings were retained and the material retained by the sieve was rejected.

e) The washings were filtered through a Buchner funnel under vacuum using 3 layers of tissue paper.

f) The tissue paper and material retained was returned to the plastic tube which was then filled with a saturated solution of NaCl. The tube was shaken vigorously.

g) The contents of the tube were poured into a dish 15cm x 11cm and the tube rinsed with NaCl solution.

h) The eggs floated to the surface and these were picked up with a sable hair brush and placed on moist filter paper in rows then counted.

i) The average recovery of eggs was 93.75% (Range 85-100%).

### 3.2 Experiment 2 - Preliminary field sampling of eggs

Preliminary sampling was carried out at Brentwood on 29 May 1974 to test the suitability of the technique described in Experiment 1 for field sampling. Forty-nine cores were taken - not at random but over medic plants. The extraction technique was the same as described previously. The frequency distribution of number of eggs per sample unit is given in Table 1.

It was concluded that this method of taking samples, even when the sample units were selected at random, would yield enough eggs to obtain a reliable estimate of the egg population. Hatched eggs can also be recovered by this method.

### 3.3 Experiment 3 - Estimation of absolute population of eggs

On 11 June 1974 intensive sampling was carried out to estimate the absolute population of eggs over the sample area. The sample area consisted of 4 ha of medic pasture at Brentwood which had regenerated after a wheat crop in 1973. This sample area was used for all samplings carried out to estimate absolute populations of the different stages of S. humeralis.

Sample units were taken on a stratified random basis, the sample area being stratified by area. The sample area was divided into 200 equal sized sub-areas (20m x 10m) and one sample unit selected at random from within each sub-area.

TABLE 1 – FREQUENCY DISTRIBUTION OF NO. OF EGGS PER SAMPLE UNIT*

| No. eggs per sample unit | Frequency |
|---|---|
| 7 | 4 |
| 9 | 3 |
| 10 | 2 |
| 11 | 1 |
| 12 | 3 |
| 13 | 3 |
| 15 | 5 |
| 16 | 2 |
| 17 | 1 |
| 19 | 3 |
| 20 | 3 |
| 21 | 2 |
| 22 | 1 |
| 23 | 1 |
| 24 | 2 |
| 25 | 2 |
| 26 | 3 |
| 30 | 1 |
| 31 | 3 |
| 41 | 1 |
| 42 | 1 |
| 44 | 1 |
| 58 | 1 |

mean = 19.86 per sample unit

= 1.25 per $cm^2$

= 12,500 per $m^2$

*Sample unit = soil core 4.5cm diameter x 1 cm deep.

It took approximately ½ day for two people to take the sample units and 8 days for 2 people to extract and count the eggs. Because the sorting process was so lengthy it was not possible to repeat egg sampling during 1974.

The raw data for egg sampling on 11 June 1974 is presented in Appendix 3 of this report. The mean number of eggs per sample unit was 8.86 (Range 0-50) (5,570 eggs per $m^2$).

## 4. LARVAE AND PUPAE

This section describes techniques for sampling larvae and pupae to estimate absolute populations. It sets out field work which has led to the selection of the best sample unit, and determination of the number of sample units necessary to give estimates with predetermined accuracy.

### 4.1 Pattern of sampling for larvae

To date there is insufficient information about the geographical or ecological factors influencing the spatial distribution of S. humeralis larvae to design the pattern of sampling in the field which will give the most reliable estimate of density. Stratified random sampling (by areas) was used because it provided a greater chance for all individuals in a population to be sampled and has had wide application in ecological studies (Yates and Finney 1942; Healy 1962).

The sample area was divided into equal sub-areas and one sample unit selected at random from within each sub-area.

### 4.2 The sample unit for larvae

Morris (1955) defined six criteria on which to base selection of the sample unit when estimating absolute populations. These were:

a) Each sample unit in the universe must have an equal chance of selection.

b) The sample unit must be stable e.g. it must not be affected by changes in plant growth habits.

c) The proportion of the insect population using the sample unit must remain constant.

d) The size of the sample unit must provide a reasonable balance between variance and cost.

e) The sample unit must lend itself to conversion to unit areas.

f) The sample unit must be easily delineated in the field and be collected without a serious loss or disturbance of the insect population.

A soil core was considered the most suitable sample unit for older larvae and this fulfilled criteria a), b), e) and f). The validity of criterion c) depended on the depth of the core and the diameter of the core had to be such that criterion d) was fulfilled.

4.2.1 Depth of soil core

The depth of the soil core necessary to give a reliable estimate of the numbers of larvae per sample unit depends on the vertical distribution of larvae. This was tested by taking cores 10cm in diamter at random from an annual medic pasture. Each core was taken in 5 cm sections to a depth of 20cm. Each section was placed in a plastic bag and taken to the laboratory where it was sorted by hand to estimate the number of larvae in each section. On 23 August 1973, forty-six cores were taken containing a total of 210 larvae and on 7 August 1974 thirty five cores yielded 810 larvae.

TABLE 2 - VERTICLE DISTRIBUTION OF LARVAE OF S. HUMERALIS

| | Percentage of larvae in each section | | | |
|---|---|---|---|---|
| | 0-5cm | 5-10cm | 10-15cm | 15-20cm |
| 23 August 1973 | 74.5 | 21.8 | 3.2 | 0.5 |
| 7 August 1974 | 74.6 | 16.7 | 5.1 | 3.6 |

The results (Table 2) showed that the majority of larvae occurred in the top 10cm of soil. A comparison between the ratios of the number of larvae occurring in the 0-10cm section to the 10-20cm section for the two samplings was not significantly different ($P < 0.05$).

4.2.2 Diameter of soil core

The optimum sample unit size (diameter of soil core) is a balance between the cost of taking and sorting the sample units and the variance or reliability of the estimate obtained with those sample units (Cochran 1963).

To determine the optimum sample unit, three sample unit sizes were compared (8.0, 11.5 and 11.7cm diameter) by taking 20 cores, each to a depth of 10cm at random from annual medic pasture at Brentwood. The time to take the samples in the field and to hand sort the larvae was measured together with the number

of larvae per core. Because the frequency distributions showed a contagious distribution (of larvae) the data was transformed by $z = \log (x + 1)$. The cost of sampling and the variance were then compared by estimating the relative net cost for the same precision for each sample unit area (Southwood 1966).

TABLE 3 - COMPARISON OF THE RELATIVE NET COST OF SAMPLE UNIT SIZES FOR SAMPLING LARVAE

| Soil core diameter in cm | Cost in mins. | Variance | Relative net cost ($C_u$ x variance$_u$)* |
|---|---|---|---|
| 8.0 | 190 | 0.1273 | .00805 |
| 11.5 | 280 | 0.1667 | .00027 |
| 11.7 | 290 | 0.3412 | .00053 |

*$C_u$ is the cost per unit area; variance$_u$ is the variance per unit area;

The results (Table 3) showed the 11.5cm diameter core to be the most efficient.

4.3 Number of sample units for sampling larvae

The number of sample units to be taken depends on the level of accuracy required, the population mean and the spatial distribution of larvae.

Eight intensive samplings were made on a stratified random basis where the sample unit consisted of a core 11.7 diameter and 10cm deep. The sample unit used on 8 November 1974 at Brentwood was only 5cm deep because the soil had become dry and hard and it was expected that the majority of larvae had migrated to the surface to pupate. A superficial examination before sampling on 8 November 1974 confirmed this. In six of the eight samplings, 200 sample units were taken but on 6 August 1973 and 27 September 1973, 260 sample units were taken.

The frequency distribution of the number of larvae per sample unit was estimated for each sampling and all distributions were shown to fit negative binomial distributions ($P < 0.05$). In each case the dispersion parameter was calculated by an interative method based on the frequency of sample units with no insects (Anscombe 1949, 1950) and its efficiency tested using the inequality $(\bar{x} + 0.17)(P_0 - 0.32) > 0.20$ (Bliss and Fisher 1953).

Using Rojas' formula (Rojas 1964) the number of sample units necessary to obtain 90% accuracy was calculated. This method is suitable when the distribution of the population fits a negative binomial distribution.

TABLE 4 - SPATIAL DISTRIBUTION OF LARVAE DESCRIBED BY THE MEAN AND DISPERSION PARAMETER WITH THE ESTIMATED NUMBER OF SAMPLE UNITS NECESSARY TO OBTAIN 90% ACCURACY.

| Locality | Date | $\bar{x}$ | $k^+$ | $N^\ddagger$ |
|---|---|---|---|---|
| 1. Roseworthy | 2 October 1972 | 2.655 | 0.27 | 408 |
| 2. Brentwood | 6 August 1973 | 1.765 | 0.86 | 173 |
| 3. Brentwood | 27 September 1973 | 0.744 | 0.82 | 256 |
| 4. Brentwood | 15 July 1974 | 7.755 | 0.49 | 204 |
| 5. Brentwood | 27 August 1974 | 10.041 | 0.84 | 128 |
| 6. Brentwood | 24 September 1974 | 4.320 | 1.05 | 118 |
| 7. Brentwood | 9 October 1974 | 0.745 | 0.72 | 273 |
| 8. Brentwood | 4 November 1974 | 0.080 | 0.32 | 438 |

*$\bar{x}$ is the mean number of larvae per core (11.7 diameter x 10cm deep)

$+_k$ is the dispersion parameter of a negative binomial distribution

$\ddagger N$ is the estimated number of sample units necessary to obtain an accuracy of 90%

The calculation of the dispersion parameter $k$ was 90% efficient for distributions of populations at only four localities (1, 3, 7 and 8 in Table 4).

Where there was extensive aggregation (small value of $k$) or where the population was low then a larger number of sample units was required. In cases 1, 7 and 8, 200 cores were actually taken and using Rojas' formula (Rojas 1964) these gave accuracies of 86, 88 and 85% respectively. In cases 2 to 6 accuracies of 90-92% were obtained.

### 4.4 Sampling for pupae

During larval sampling pupae were found in 5 out of the 8 samplings and this method appeared to be suitable for pupae. When the frequency distributions of the number of pupae per sample unit were estimated for each sampling, they all fitted negative binomial distributions ($P < 0.05$). In all cases the iterative method for calculating the dispersion parameter $k$ (Anscombe 1949, 1950) was at least 90% efficient. The distributions are summarized by the mean and dispersion parameter in Table 5.

TABLE 5 - DISTRIBUTION OF PUPAE DESCRIBED BY MEAN AND DISPERSION PARAMETER

| Locality | Date | $\bar{x}$* | k+ |
|---|---|---|---|
| Brentwood | 27 September 1973 | 1.05 | 0.89 |
| Brentwood | 27 August 1974 | 0.193 | 0.155 |
| Brentwood | 24 September 1974 | 6.00 | 0.55 |
| Brentwood | 9 October 1974 | 4.17 | 0.53 |
| Brentwood | 4 November 1974 | 0.33 | 0.21 |

*$\bar{x}$ is the mean number of pupae per core (11.7cm diameter x 10cm deep)

+k is the dispersion parameter of the negative binomial distribution.

4.5 Relationship between medic and larval and pupal densities

With stratified random sampling, biological knowledge can be used to eliminate strata in which few insects would be found. Such a restricted universe will give a greater level of precision for calculation of the mean than an unrestricted and completely random sample with a wide variance. The most obvious method for stratifying the sample area for S. humeralis is on the basis of medic plant density.

During sampling for larvae and pupae, counts were made of the number of medic plants per sample unit. The results (presented in Appendix 10) need to be transformed before regression analyses can be carried out. In all cases the number of larvae per core should be transformed using the transformation $z = \log (x + 1)$ because of the contagious distributions. On 6 August 1973 and 15 July 1974 the frequency distributions of plants are slightly contagious therefore the transformation $z = \sqrt{x}$ should be used. In the other four cases the frequency distributions of plants are contagious and the transformation $z = \log (x + 1)$ should be used.

5. ADULTS

5.1 Autumn/winter activity of adults

5.1.1 Preliminary observations

The sample area at Brentwood was examined from January to early April 1974 and no S. humeralis adults were present. During this time the area was covered with stubble from a wheat crop grown in the previous year. Several reports were received of S. humeralis activity in the period 12 to 15 April and when the site was examined on 22 April adults were found to be present.

5.1.2 Sample unit size for sampling adults

This method of sampling adults through autumn and winter was by vacuuming the vegetation and litter within quadrats. A "Nilfisk" industrial vacuum cleaner with a 3cm diameter hose was used, being powered by a "Honda 1000E" generator. The vacuumings were emptied into a tin 10cm diameter and 15cm high. The lid and base each had a section of metal gauze to allow aeration. Each sample unit was hand sorted to extract the insects. Where suitable the litter was sieved first. In previous work dry extraction by heating was unsatisfactory because not all of the insects were expelled from the leaf litter.

The requirements for a sample unit laid out in section 4.1 are all fulfilled by vacuuming a given area. The optimum size of the sample unit (area of the quadrat) is a balance between the time to take and sort the vacuumings and the variance or reliability of the estimate obtained with those sample units (Cochran 1963).

To determine the optimum sample unit, four quadrat sizes were compared (5000, 2500, 1000 and 100cm$^2$) by taking 20 sample units of each size using the vacuuming method outlined above. The time to take the samples and to hand sort the vacuumings was measured together with the number of adults per sample unit. The data was transformed to normal distributions using the transformation, $z = x^{0.7}$, calculated from Taylor's Power Law (see Appendix 11). The cost and variance were then compared by estimating the relative net cost for the same precision for each sample unit (Southwood 1966).

TABLE 6 - COMPARISON OF THE RELATIVE NET COST OF SAMPLE UNIT SIZES FOR SAMPLING ADULTS

| Quadrat area in cm$^2$ | Cost in mins | Variance | Relative net cost ($C_u$ x variance$_u$*) |
|---|---|---|---|
| 100 | 60 | 0.518 | 31.08 |
| 1000 | 210 | 7.50 | 15.75 |
| 2500 | 475 | 10.3 | 7.79 |
| 5000 | 1245 | 52.4 | 26.10 |

*$C_u$ is the cost per 100cm$^2$; variance$_u$ is the variance per 100cm$^2$;

The result (Table 6) showed the 2500cm$^2$ quadrat to be the most efficient.

5.1.3 Number of sample units for sampling adults

The number of sample units to be taken depends on the level of accuracy required, the population mean and the spatial distribution of insects.

Five intensive samplings were made on a stratified random basis where the sample unit consisted of 2500cm$^2$ quadrat. In four of the samplings 200 sample units were taken but on 30 July 1974 only 160 sample units were taken. The data was transformed to a normal distribution using the transformation $z = x^{0.7}$ calculated from Taylor's power law (see Appendix 11) and the required number of sample units was calculated using the formula $N = (ts/D\bar{x})^2$ where s = standard deviation, D = acceptable level of error and t is Student's 't' which was approximated at 2 at the 5% level (Southwood 1966).

TABLE 7 - MEAN AND VARIANCE OF ADULT POPULATIONS AND THE ESTIMATED NUMBER OF SAMPLE UNITS NECESSARY TO OBTAIN 90% ACCURACY

| Date | $\bar{x}$* | $s_x^2$* | $\bar{z}$+ | $s_z^2$+ | N‡ |
|---|---|---|---|---|---|
| 13 May 1974 | 20.2 | 176 | 7.81 | 14.6 | 95 |
| 24 June 1974 | 15.9 | 133 | 6.54 | 12.0 | 112 |
| 30 July 1974 | 7.64 | 37.3 | 3.90 | 4.79 | 126 |
| 12 Sept.1974 | 2.58 | 8.51 | 1.68 | 2.16 | 307 |
| 2 Oct. 1974 | 1.26 | 2.76 | 0.946 | 1.08 | 482 |

* mean and variance of untransformed data

\+ mean and variance of transformed data ($z = x^{0.7}$)

‡ N is the estimated number of sample units necessary to obtain an accuracy of 90%.

The results (Table 7) showed the number of sample units necessary to obtain 90% accuracy was about 100 until late winter/early spring when it then increased to 300-500.

5.2 Spring generation of adults

At the beginning of spring one hundred emergence traps were set out at random in every alternate sub-area at the Brentwood site to collect adults as they emerged from the soil. Using 100 sample units was based on the estimation of larval densities at the site which showed that this number was necessary to give 90% accuracy (Brentwood 27 August 1974 and 24 September 1974 in Table 4). Each trap consisted of a tin, 10cm diameter x 14cm high which had the bottom cut out and was set into the ground 2-3cm. This was surrounded by 3 jarrah pegs; two of

them were 25cm long and the third was 120cm long. The inside of the tin was smeared with petroleum jelly to trap insects crawling up the sides of the tin. The lid had a 7cm diameter hole which was covered with wire mesh for ventillation. The traps were checked weekly until mid November and then they were check fortnightly.

When S. humeralis adults emerge, a distinct hole is left in the ground. On 12 November 1974, a comparison of population levels obtained by emergence traps and emergence holes was made by counting the number of emergence holes in 10cm diameter quadrats which was the same size as the emergence traps). One hundred counts were made, one count being made at random in alternate sub-areas which had the traps. The emergence traps were also counted on that day. The population over the 4 ha sample area estimated by counting emergence holes was 25.7 million while the population at the same time estimated with the emergence traps was 16.1 million.

During spring the adult population was also estimated by taking vacuum samples as outlined in section 5.1.2.

Figure 1 shows the results of sampling for spring generation adults using vacuuming and emergence traps. The vacuuming method estimated the peak population over the 4 ha sample area at 7.6 million on 21 October 1974, whereas the emergence traps estimated the total population which emerged at 16.5 million. There is another discrepancy between the two methods that on 21 October 1974 the population estimate from vacuumings was 7.6 million compared with 5.7 million from the emergence traps.

## 6. LIFE-TABLE DATA FOR 1974

The sample area consisted of 4 ha of annual medic pasture which had regenerated from a wheat crop grown in 1973 and was situated on the property of Mr. L.D. Boundy of Brentwood.

All samples were taken on a stratified random basis, the sample area being divided into 200 equal sub-areas and one sample-unit taken at random from within each sub area.

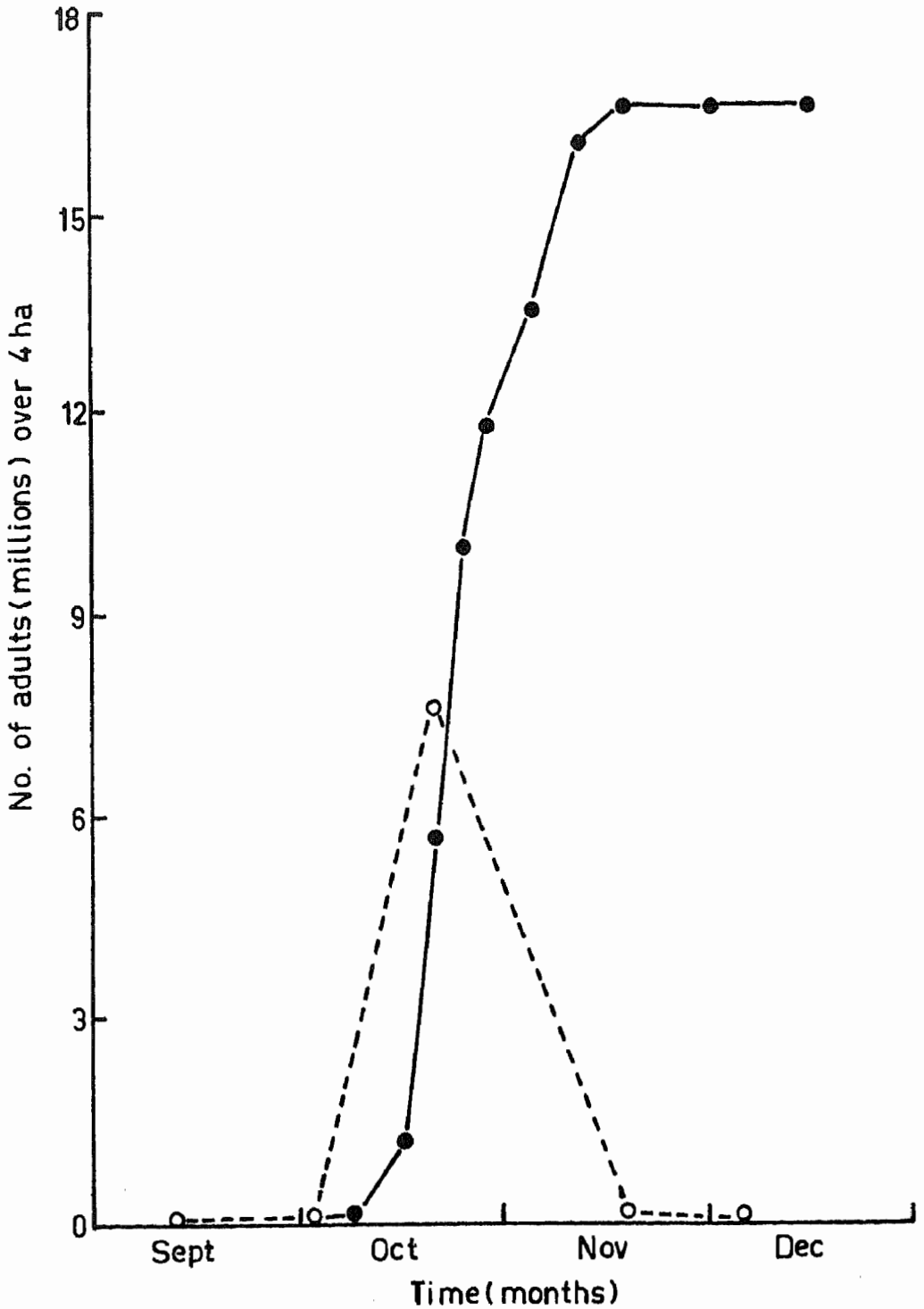
The eggs were sampled as described in section 3.3, the larvae as in section 4.3, the pupae as in 4.4 and the adults as in 5.1 and 5.2. Teneral adults (adults not emerged from the ground) were also recovered from larval and pupal samplings.

The results are summarized in Table 8. The frequency distribution of each sampling are presented in appendices 2-9.

The results of adult sampling by vacuuming through winter showed a definite immigration of adults into the paddock during autumn, at which stage the annual medics had just begun to germinate. There was a steady decline in the population through winter, all the adults having died by late October with very little overlap with the new generation.

Figure 1.

Population changes of spring generation of S. humeralis adults.




●——● Cummulative population estimated from emergence traps

o- - - - - - - -o Population estimated from vacuum samples

TABLE 8 - ESTIMATED NUMBER OF INDIVIDUALS OVER THE 4 HECTARE SAMPLE-AREA (IN MILLIONS)

| Date | Adults | Eggs | Larvae | Pupae | Teneral* Adults | New gen$^{r}$ adults | Cumulative No. adults from emergence traps |
|---|---|---|---|---|---|---|---|
| 15 Jan ) | | | | | | | |
| 29 Jan ) | | | | | | | |
| 7 March ) | *** | | | | | | |
| 15 March) | | | | | | | |
| 5 April ) | | | | | | | |
| 22 April | **** | | | | | | |
| 30 April | 3.31 | | | | | | |
| 13 May | 3.24 | | | | | | |
| 11 June | | 223 | | | | | |
| 24 June | 2.54 | | | | | | |
| 15 July | | | 28.8 | 0 | 0 | | |
| 30 July | 1.52 | | | | | | |
| 27 Aug. | | | 37.3 | 0.717 | 0 | | |
| 12 Sept. | 0.412 | | | | | | |
| 23 Sept. | | | 15.7 | 22.3 | | | |
| 2 Oct. | 0.200 | | | | | 0 | 0.044 |
| 9 Oct. | | | 2.77 | 15.5 | 6.26 | | 0.089 |
| 17 Oct. | | | | | | | 1.11 |
| 22 Oct. | 0 | | | | | 7.59 | 5.69 |
| 25 Oct. | | | | | | | 9.87 |
| 29 Oct. | | | | | | | 11.8 |
| 4 Nov. | | | 0.037 | 1.52 | 0.531 | | 13.6 |
| 11 Nov. | | | | | | | 16.0 |
| 18 Nov. | | | | | | 0.07 | 16.5 |
| 4 Dec. | | | | | | 0 | 16.5 |
| 16 Dec. | | | | | | | 16.5 |

*Adults not emerged from the ground, estimates obtained from soil cores.

**Estimated from vacuuming.

***Examination of sample area showed no adults present.

****On examination adults found to be present.

Only one estimate of the population of eggs was made and in future others should be made during the oviposition period (April-October). On 11 June it was estimated that the population present (2.5 million) had laid 163 eggs per female over the last 3-4 weeks (the average incubation period for eggs at 15-22°C (Allen 1971). Experiments on hatching of field collected eggs in the laboratory showed an average viability of 97%.

The peak number of larvae occurred in late August with the majority having pupated by early October, however larvae were still found on November 4. The total population of larvae was calculated using the method described by Southwood and Jepson (1962). The total time during which larvae were found was divided into 70-day periods, being the estimated developmental time for larvae (Moulden 1973) and field estimates of date of first laying to date of first pupae. The mean population was calculated for each of these periods, and the means summed, giving the total population of larvae as 41.7 million. Even with one egg sampling the results indicate a large mortality from eggs to larvae (223 to 41.7 million).

Pupation began in late August with the peak during late September and the majority had turned into adults by early November. The total population of pupae was calculated as for larvae using a developmental time of 20 days (Moulden 1973) and estimated at 39.6 million, 95% of the larval populations.

The results from emergence traps showed that emergence began on October 1, and by November 11, 96% of the population had emerged, the total emerging population being 16.5 million. This was 41.7% of the pupal population. It should be noted that the emergence traps probably underestimated the emerging population (section 5.2).

Population estimates of the spring generation of adults by the vacuuming method showed an increase in numbers in October and emigration from the paddock soon afterwards, most of the adults having emigrated by November 18.

No direct measurement of the net reproductive rate (the number of times a population will multiply per generation) can be made because there are no total population estimates of the same stage in two successive years for the same population. However a comparison can be made between the adult population immigrating into the paddock in April (3.31 million) and the total emerging population (16.5 million) which shows a five fold increase in the population. This does not take into account any mortality which may have occurred through summer. Another comparison can be made: between the larval population at the beginning of pupation in 1974 (37.3 million) and the larval population over 4 ha estimated in the adjoining paddock in 1973, at the beginning of pupation (6.56 million - estimated from larval density to August 1973, Brentwood in Table 4). This shows a 5.7 fold increase in the population but is not strictly a valid comparison because two separate populations of insects are involved.

## 7. DISCUSSION

### 7.1 Eggs

Although the method described for sampling eggs appears to give satisfactory estimates of the number of eggs, modifications must be sought to shorten the time taken in the extraction process, because several estimates of egg density, as well as other insect stages, will be required for life table data, and the present egg extraction method is too lengthy for this. Also, further experiments are required to determine the optimum size sample unit and the number of those sample units necessary to give the required accuracy.

Fecundity in the field will have to be measured and sampling eggs from caged adults may be an appropriate method.

### 7.2 Larvae and Pupae

From August onwards, a soil core 10cm deep provided the most efficient population estimates of larvae and pupae relative to the volume of soil sorted. However, in June and July only younger larvae are present and further work needs to be done to establish sampling methods .

A smaller sample unit would be more suitable for sampling young larvae which occur inside nodules, because nodules will have to be dissected and examination of a core 11.5cm diameter x 10cm deep would be too time consuming. A preliminary investigation could show the region of the plant where most infested nodules occur, making it possible to determine whether different regions of the root system need to be sampled separately. Then the number of sample units within each region necessary to give maximum efficiency could be calculated.

Calculation of the dispersion parameter, $k$, based on the frequency of sampling units with no insects (Anscombe 1949, 1950) is only efficient (when the mean is below ten) and about one third of the sample units contain no insects or when the mean is larger and the proportion of blank samples is greater (Bliss and Fisher 1953). Where this method of determination of $k$ is inefficient the method of madimum likelihood described by Bliss and Fisher (1953) should be used.

In samplings 1, 7 and 8 (Table 3), a 104, 37 and 119% increase in the number of sample units would have been necessary to obtain accuracies of 90% compared to accuracies of 86, 88 and 85% respectively. However, one must compromise and choose the number of sample units which gives the best attainable accuracy for an acceptable amount of work (Debauche 1962). With the above cases, and other likely to be encountered, the large increase in the amount of work is considered unjustified for the small increase in accuracy obtained.

Hand sorting was used throughout sampling because the soil at Brentwood, a grey mallee (French et al.), was particularly suited to this method of sorting. However, if areas with heavier soils are to be sampled, the soil washing and floatation technique proposed by Salt and Hollick (1944) or the turbulent overflow process proposed by Rand (1973) may be more suitable.

## 7.3 Adults

The number of sample units necessary to estimate the population of adults with an accuracy of 90% was about 100 in autumn and increased to 500 in late winter. These figures only give a guide for the sample unit number necessary in other years because an increase or decrease in the population level will result in a corresponding decrease or increase in the required number of sample units. Similarly the optimum sample size may change depending on the population-increasing with a low population and decreasing with a high one. However, the results give an indication of the order of number and size of sample units necessary and it is clear that the sample size must be increased through winter as the population falls to maintain accuracy of 90%.

Results showed that counting emergence holes may be a more efficient method of estimating the emerging population. The difference in estimates is probably due to changed microclimate in the emergence traps which may influence the rate of development of pupae (Southwood and Siddorn 1965). This could explain the lower populations obtained from emergence traps. Counting emergence holes would be no more time consuming than examining emergence traps and would eliminate the time taken to make and erect the traps. Because additional variation is likely to occur by counting a different set of sample unit sites on each date of measurement, fixed areas for counting emergence holes would be necessary.

Because of the large time interval between vacuum samplings and the marked changes in population resulting from emergence and emigration, sampling adults by vacuuming is regarded as unsuitable. It would be difficult to shorten the time between sampling since it takes two people about 8 days to take and sort 200 samples. An alternative method must be found to measure emigration of the population the most suitable probably being the use of marked insects.

## 7.4 Life table data

The main stage at which mortality occurred was either during the early larval stages. Experiments showed viability of the eggs to be 97% indicating that most of the mortality occurred after hatching. This could be caused by inability of the first instar larvae to find a food source.

To accurately compare causes of mortality several problems must be overcome. Firstly a method must be devised for assessing mortalty through summer, with the main problem to be encountered being that the adults migrate away from the breeding area. Secondly, the frequency of sampling each stage must be increased to obtain a more accurate estimate of the total population. Thirdly more accurate estimates of the developmental time in the field for each stage will be needed to calculate total population. Probably the greatest problem in assessing life table data for S. humeralis is the calculation of a net reproductive rate for one generation since a population does not go through a complete generation at one location, migration occurring in spring and autumn.

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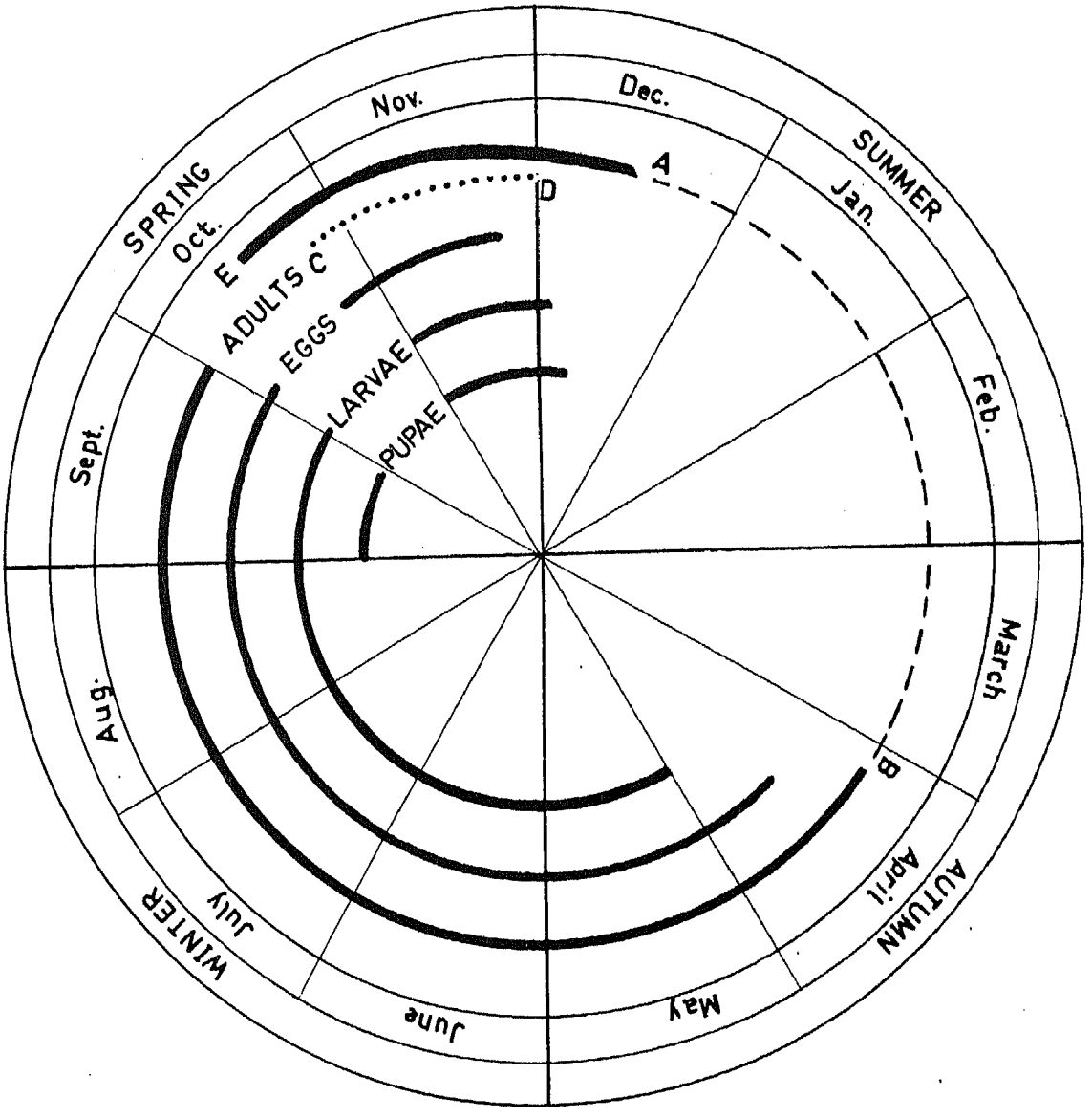
# APPENDIX 1 - Seasonal life history of S. humeralis in South Australia




A - - - B = Adults aestivating

C . . . . . D = Adults in very low frequencies

E ——— A = New generation adults emerging

## Appendix 2. Frequency distributions of autumn/winter generation adults

### A. Preliminary observations

| | |
|---|---|
| 15 January 1974 | 5 sample units 1m x 1m - no sitona |
| 29 January 1974 | Cursory inspection - no sitona |
| 7 March 1974 | 25 sample units 1 sq ft - <u>one</u> sitona |
| 15 March 1974 | 30 sample units 1 sq ft - no sitona |
| 5 April 1974 | 50 sample units 1 sq ft - <u>one</u> sitona |
| (Easter 12 April 1974<br>(17 April 1974<br>22 April 1974 | Sitona active near Warooka - P.G. Allen)<br>Sitona active in medic at Kulpara)<br>7 sample units 1 sq ft - <u>nine</u> sitona. |
| 3 May 1974 | Estimate from sample unit size experiment (20 s.u.'s 5000 $cm^2$, 20 s.u.'s 2500 $cm^2$, 20 s.u.'s 1000 $cm^2$, 20 s.u.'s 100 $cm^2$)<br><br>mean = 82.69 per $m^2$ = 3,307,600 over 4 ha. |

B. Frequency distribution of adults 13 May 1974

| No. adults per sample unit | Frequency |
|---|---|
| 0 | 3 |
| 1 | 2 |
| 2 | 5 |
| 3 | 7 |
| 4 | 5 |
| 5 | 7 |
| 6 | 2 |
| 7 | 6 |
| 8 | 7 |
| 9 | 3 |
| 10 | 4 |
| 11 | 6 |
| 12 | 5 |
| 13 | 5 |
| 14 | 4 |
| 15 | 13 |
| 16 | 5 |
| 17 | 6 |
| 18 | 3 |
| 19 | 9 |
| 20 | 4 |
| 21 | 7 |
| 22 | 5 |
| 23 | 7 |
| 24 | 3 |
| 25 | 5 |
| 26 | 2 |
| 27 | 4 |
| 28 | 3 |
| 29 | 8 |
| 30 | 1 |
| 31 | 4 |
| 32 | 5 |
| 33 | 1 |
| 34 | 2 |
| 35 | 1 |
| 36 | 6 |
| 37 | 4 |
| 38 | 2 |
| 40 | 3 |
| 42 | 1 |
| 43 | 2 |
| 46 | 1 |
| 47 | 2 |
| 48 | 1 |
| 49 | 1 |
| 51 | 1 |
| 52 | 1 |
| 53 | 2 |
| 54 | 1 |
| 57 | 1 |
| 58 | 1 |

N = 199

mean = 20.23 adults per sample units
= 80.93 adults per $m^2$
= 3,237,200 adults over 4 ha
standard deviation = 13.3043
standard error = 0.9731
coefficient of variation = 0

C. Frequency distribution of adults 24 June 1974

| No. adults per sample unit | Frequency | No. adults per sample unit | Frequency |
|---|---|---|---|
| 0 | 5 | 26 | 1 |
| 1 | 3 | 27 | 2 |
| 2 | 5 | 28 | 1 |
| 3 | 4 | 29 | 4 |
| 4 | 13 | 30 | 2 |
| 5 | 6 | 31 | 4 |
| 6 | 12 | 32 | 1 |
| 7 | 5 | 33 | 1 |
| 8 | 7 | 35 | 1 |
| 9 | 6 | 37 | 1 |
| 10 | 4 | 40 | 3 |
| 11 | 10 | 41 | 2 |
| 12 | 10 | 43 | 2 |
| 13 | 6 | 49 | 2 |
| 14 | 6 | 50 | 1 |
| 15 | 7 | 51 | 1 |
| 16 | 7 | 54 | 1 |
| 17 | 11 | 60 | 1 |
| 18 | 13 | | |
| 19 | 5 | | |
| 20 | 1 | | |
| 21 | 6 | | |
| 22 | 4 | | |
| 23 | 4 | | |
| 24 | 8 | | |
| 25 | 1 | | |

N = 200
mean = 15.89 adults per sample unit
= 63.56 adults per $m^2$
= 2,542,400 adults over 4 ha
standard deviation = 11.56
standard error = 0.8171
coefficient of variation = 0.7273

D. Frequency distribution of adults 30 July 1974

| No. adults per sample unit | Frequency |
|---|---|
| 0 | 3 |
| 1 | 17 |
| 2 | 12 |
| 3 | 9 |
| 4 | 11 |
| 5 | 15 |
| 6 | 11 |
| 7 | 15 |
| 8 | 10 |
| 9 | 14 |
| 10 | 2 |
| 11 | 9 |
| 12 | 6 |
| 13 | 3 |
| 14 | 7 |
| 15 | 2 |
| 16 | 4 |
| 18 | 1 |
| 19 | 3 |
| 20 | 1 |
| 22 | 1 |
| 23 | 1 |
| 27 | 1 |
| 32 | 1 |
| 38 | 1 |

$\bar{N}$ = 160
mean = 7.6438 adults per sample unit
= 30.575 adults per $m^2$
= 1,523,000 over 4 ha
variance = 37.34.

E. Frequency distribution of adults 12 September 1974

| No. adults per sample unit | Frequency |
|---|---|
| 0 | 51 |
| 1 | 41 |
| 2 | 33 |
| 3 | 21 |
| 4 | 15 |
| 5 | 14 |
| 6 | 5 |
| 7 | 8 |
| 8 | 2 |
| 9 | 3 |
| 10 | 2 |
| 11 | 1 |
| 12 | 2 |
| 14 | 1 |
| 18 | 1 |

N = 200
mean = 2.58 adults per sample unit
= 10.32 adults per $m^2$
= 412,800 adults over 4 ha
variance = 8.51

F. Frequency distribution of adults 2 October 1974

| No. adults per sample unit | Frequency |
|---|---|
| 0 | 86 |
| 1 | 55 |
| 2 | 26 |
| 3 | 12 |
| 4 | 11 |
| 5 | 4 |
| 6 | 1 |
| 7 | 2 |
| 8 | 3 |

N = 200
mean = 1.255 adults per sample unit
= 5.02 adults per $m^2$
= 200,800 adults over 4 ha
variance = 2.78

N.B. One new generation adult was found.

## Appendix 3 - Frequency distribution of eggs

### Frequency distribution of unhatched eggs 11 June 1974

| No. eggs per sample unit* | Frequency |
|---|---|
| 0 | 24 |
| 1 | 13 |
| 2 | 14 |
| 3 | 14 |
| 4 | 9 |
| 5 | 15 |
| 6 | 12 |
| 7 | 10 |
| 8 | 6 |
| 9 | 8 |
| 10 | 10 |
| 11 | 11 |
| 12 | 3 |
| 13 | 6 |
| 14 | 3 |
| 15 | 4 |
| 16 | 5 |
| 17 | 1 |
| 18 | 5 |
| 19 | 5 |
| 21 | 3 |
| 22 | 2 |
| 23 | 1 |
| 24 | 2 |
| 25 | 1 |
| 26 | 1 |
| 27 | 3 |
| 28 | 1 |
| 31 | 1 |
| 37 | 2 |
| 40 | 1 |
| 46 | 1 |
| 50 | 1 |

N = 198
mean = 8.8586 eggs per sample unit
= 5,567.9 eggs per $m^2$
= 222,716,000 eggs of 4 ha
standard deviation = 8.8839
standard error = 0.6314
coefficient of variation = 1.0029

* Sample unit size = 15.91 $cm^2$

## Appendix 4 - Frequency distributions of larvae

### A. Frequency distribution of larvae 15 July 1974

| No. larvae per sample unit | Frequency |
|---|---|
| 0 | 50 |
| 1 | 21 |
| 2 | 17 |
| 3 | 9 |
| 4 | 13 |
| 5 | 7 |
| 6 | 5 |
| 7 | 5 |
| 8 | 13 |
| 9 | 11 |
| 10 | 3 |
| 11 | 3 |
| 12 | 5 |
| 13 | 5 |
| 14 | 1 |
| 15 | 5 |
| 16 | 2 |
| 17 | 1 |
| 18 | 1 |
| 19 | 2 |
| 20 | 2 |
| 21 | 3 |
| 22 | 1 |
| 24 | 1 |
| 25 | 1 |
| 26 | 2 |
| 32 | 1 |
| 34 | 1 |
| 35 | 1 |
| 39 | 1 |
| 40 | 2 |
| 44 | 1 |
| 52 | 1 |
| 56 | 1 |
| 58 | 1 |
| 76 | 1 |

N = 200
mean = 7.755 per sample unit
= 720.7187 per $m^2$
= 28,828,747 over 4 ha

$k_2$ estimated as 0.4918
Not 90% efficient

B. Frequency distribution of larvae 27 August 1974

| No. larvae per sample unit | Frequency |
|---|---|
| 0 | 23 |
| 1 | 20 |
| 2 | 15 |
| 3 | 20 |
| 4 | 5 |
| 5 | 8 |
| 6 | 5 |
| 7 | 5 |
| 8 | 9 |
| 9 | 11 |
| 10 | 5 |
| 11 | 5 |
| 12 | 10 |
| 13 | 4 |
| 15 | 3 |
| 16 | 1 |
| 17 | 5 |
| 18 | 1 |
| 19 | 6 |
| 20 | 2 |
| 21 | 3 |
| 22 | 3 |
| 24 | 3 |
| 25 | 2 |
| 26 | 2 |
| 27 | 2 |
| 28 | 4 |
| 29 | 2 |
| 30 | 3 |
| 31 | 1 |
| 32 | 2 |
| 38 | 1 |
| 40 | 2 |
| 42 | 1 |
| 43 | 2 |
| 46 | 1 |

N = 197
mean = 10.0406 larvae per sample unit
= 933.1 larvae per $m^2$
= 37,325,328 larvae over 4 ha

$k_2$ estimated at 0.84. Not 90% efficient

C. Frequency distribution of larvae 24.9.74

| No. larvae per sample unit | Frequency |
|---|---|
| 0 | 36 |
| 1 | 30 |
| 2 | 28 |
| 3 | 19 |
| 4 | 25 |
| 5 | 9 |
| 6 | 12 |
| 7 | 8 |
| 8 | 4 |
| 9 | 4 |
| 10 | 4 |
| 11 | 5 |
| 12 | 2 |
| 13 | 3 |
| 14 | 1 |
| 15 | 2 |
| 17 | 1 |
| 18 | 3 |
| 23 | 1 |
| 29 | 3 |

N = 200
mean = 4.320 larvae per sample unit
= 393.1 larvae per $m^2$
= 15,724,768 larvae over 4 ha.

$k_2$ estimated at 1.05. Not 90% efficient

D. Frequency distribution of larvae 9 October 1974

| No. larvae per sample unit | Frequency |
|---|---|
| 0 | 120 |
| 1 | 46 |
| 2 | 14 |
| 3 | 14 |
| 4 | 1 |
| 5 | 3 |
| 7 | 2 |

N = 200
mean = 0.745 larvae per sample unit
= 69.24 larvae per $m^2$
= 2,769,492 larvae over 4 ha

$k_2$ estimated at 0.72. Was 90% efficient.

E. Frequency distribution of larvae 4 November 1974

| No. larvae per sample unit | Frequency |
|---|---|
| 0 | 186 |
| 1 | 12 |
| 2 | 2 |

N = 200
mean = 0.08 larvae per sample unit
= 0.9235 larvae per $m^2$
= 36,940 larvae over 4 ha.

## Appendix 5 - Frequency distributions of pupae

### A. Frequency distribution of pupae 27 August 1974

| No. pupae per sample unit | Frequency |
|---|---|
| 0 | 173 |
| 1 | 15 |
| 2 | 6 |
| 3 | 1 |
| 4 | 2 |

N = 197
mean = 0.1928 pupae per sample unit
= 17.92 per $m^2$
= 716,720 over 4 ha

$k_2$ estimated at 0.155 and was 90% efficient.

### B. Frequency distribution of pupae 24 September 1974

| No. pupae per sample unit | Frequency |
|---|---|
| 0 | 36 |
| 1 | 30 |
| 2 | 28 |
| 3 | 19 |
| 4 | 25 |
| 5 | 9 |
| 6 | 12 |
| 7 | 8 |
| 8 | 4 |
| 9 | 4 |
| 10 | 4 |
| 11 | 5 |
| 12 | 2 |
| 13 | 3 |
| 14 | 1 |
| 15 | 2 |
| 17 | 1 |
| 18 | 3 |
| 23 | 1 |
| 29 | 3 |

N = 200
mean = 4.320 pupae per sample unit
= 393.1 pupae per $m^2$
= 15,724,768 pupae over 4 ha.

$k_2$ was estimated at 0.55 and was 90% efficient

C. Frequency distribution of pupae 9 October 1974

| No. pupae per sample unit | Frequency |
|---|---|
| 0 | 62 |
| 1 | 30 |
| 2 | 23 |
| 3 | 14 |
| 4 | 12 |
| 5 | 12 |
| 6 | 9 |
| 7 | 2 |
| 8 | 5 |
| 9 | 4 |
| 10 | 2 |
| 11 | 2 |
| 12 | 4 |
| 13 | 2 |
| 14 | 1 |
| 15 | 3 |
| 16 | 1 |
| 17 | 2 |
| 18 | 1 |
| 20 | 3 |
| 21 | 1 |
| 25 | 2 |
| 27 | 1 |
| 28 | 1 |
| 35 | 1 |

N = 200
mean = 4.17 pupae per sample unit
= 387.5 per $m^2$
= 15,501,724 over 4 ha

$k_2$ was estimated at 0.53 and was 90% efficient

D. Frequency distribution of pupae 4 November 1974

| No. pupae per sample unit | Frequency |
|---|---|
| 0 | 164 |
| 1 | 23 |
| 2 | 7 |
| 3 | 2 |
| 4 | 1 |
| 5 | 2 |
| 6 | 1 |

N = 200
mean = 0.33 pupae per sample unit
= 38.10 per $m^2$
= 1,523,884 over 4 ha

## Appendix 6 - Frequency distributions of teneral adults

### A. Frequency distribution of teneral adults* 9 October 1974

| No. teneral adults per sample unit | Frequency |
|---|---|
| 0 | 114 |
| 1 | 27 |
| 2 | 10 |
| 3 | 13 |
| 4 | 12 |
| 5 | 4 |
| 6 | 5 |
| 7 | 8 |
| 8 | 2 |
| 12 | 1 |
| 15 | 1 |
| 17 | 2 |
| 20 | 1 |

N = 200
mean = 1.685 teneral adults per sample unit
= 156.6 teneral adults per $m^2$
= 6,263,884 teneral adults over 4 ha

$k_2$ estimated at 0.295 and was 90% efficient.

### B. Frequency distribution of teneral adults* 4 November 1974

| No. teneral adults per sample unit | Frequency |
|---|---|
| 0 | 186 |
| 1 | 11 |
| 2 | 2 |
| 8 | 1 |

N = 200
mean = 0.115 teneral adults per sample unit
= 13.28 teneral adults per $m^2$
= 531,048 teneral adults over 4 ha

* teneral adults are defined as having emerged from pupae but not emerged from the soil.

Appendix 7 - Emergence traps 1974

| Date | No. emerged in 100 tins | No. emerged over 4 ha | Cummulative pop$^{n}$ over 4 ha |
|---|---|---|---|
| 1 October | 1 | 44,464 | 44,464 |
| 9 October | 1 | 44,464 | 88,928 |
| 17 October | 23 | 1,022,736 | 1,111,664 |
| 21 October | 103 | 4,580,084 | 5,691,748 |
| 25 October | 94 | 4,179,880 | 9,871,628 |
| 29 October | 44 | 1,956,540 | 11,828,168 |
| 5 November | 41 | 1,823,140 | 13,651,308 |
| 11 November | 54 | 2,401,208 | 16,052,516 |
| 18 November | 12 | 533,602 | 16,586,118 |
| 4 December | 0 | 0 | 16,586,118 |

Appendix 8 - Frequency distribution of emerged adults*

A. * determined by using emergence traps

| No. emerged adults per trap+ | Frequency |
|---|---|
| 0 | 20 |
| 1 | 19 |
| 2 | 10 |
| 3 | 13 |
| 4 | 9 |
| 5 | 6 |
| 6 | 9 |
| 7 | 2 |
| 8 | 3 |
| 9 | 2 |
| 13 | 1 |
| 14 | 3 |
| 16 | 1 |
| 20 | 1 |
| 28 | 1 |

N = 100
mean = 3.73 emerged adults per trap
= 414.7 emerged adults per $m^2$
= 16,586,128 over 4 ha

+ trap consists of a tin covering an area 89.95 $cm^2$.

B. * estimated by counting emergence holes

| No. emerged adults per sample unit± | Frequency |
|---|---|
| 0 | 14 |
| 1 | 14 |
| 2 | 10 |
| 3 | 9 |
| 4 | 7 |
| 5 | 5 |
| 6 | 6 |
| 7 | 5 |
| 8 | 2 |
| 9 | 3 |
| 10 | 4 |
| 11 | 3 |
| 12 | 7 |
| 13 | 3 |
| 15 | 2 |
| 16 | 1 |
| 17 | 1 |
| 18 | 2 |
| 22 | 1 |
| 32 | 1 |

± area of 89.95 $cm^2$

N = 100
mean = 5.77 adults per sample unit
= 641.4 per $m^2$
= 25,657, 492 adults over 4 ha

## Appendix 9. Frequency distribution of spring generation adults

### A. Frequency distribution of adults* 22 October 1974

| No. adults per sample unit | Frequency | No. adults per sample unit | Frequency |
|---|---|---|---|
| 0 | 5 | 42 | 1 |
| 1 | 3 | 43 | 1 |
| 2 | 3 | 46 | 2 |
| 3 | 3 | 47 | 2 |
| 5 | 2 | 51 | 1 |
| 8 | 1 | 54 | 1 |
| 9 | 2 | 61 | 1 |
| 10 | 3 | 62 | 1 |
| 11 | 1 | 63 | 2 |
| 12 | 1 | 66 | 1 |
| 13 | 1 | 67 | 1 |
| 14 | 3 | 70 | 1 |
| 15 | 3 | 71 | 1 |
| 17 | 1 | 73 | 1 |
| 18 | 3 | 76 | 1 |
| 19 | 3 | 78 | 1 |
| 20 | 2 | 96 | 1 |
| 21 | 2 | 99 | 1 |
| 22 | 3 | 105 | 1 |
| 23 | 3 | 113 | 2 |
| 25 | 5 | 144 | 1 |
| 28 | 2 | 150 | 1 |
| 29 | 2 | 151 | 1 |
| 30 | 1 | 157 | 1 |
| 32 | 1 | 158 | 1 |
| 35 | 1 | 172 | 1 |
| 37 | 1 | 239 | 1 |
| 38 | 2 | 315 | 1 |
| 40 | 2 | 362 | 1 |
| 41 | 1 | | |

N = 100
mean = 47.43 adults per sample unit
= 189.72 adults per $m^2$
= 7,588, 800 over 4 ha

* new generation adults. 48 females dissected: no old generation.

B. Frequency distribution of adults 18 November 1974

| No. adults per sample unit | Frequency |
|---|---|
| 0 | 74 |
| 1 | 17 |
| 2 | 4 |
| 3 | 2 |
| 4 | 2 |
| 5 | 1 |

N = 100
mean = 0.44 adults per sample unit
= 1.76 adults per $m^2$
= 70,400 adults over 4 ha.

This was a large drop in the population from 22 October so the number of dead adults was counted to decide whether this drop was due to mortality or emmigration.

Frequency distribution of dead adults 18 November 1974

| No. adults per sample unit | Frequency |
|---|---|
| 0 | 58 |
| 1 | 24 |
| 2 | 9 |
| 3 | 3 |
| 4 | 3 |
| 5 | 1 |
| 6 | 2 |

N = 100
mean = 0.8 adults per sample unit
= 3.2 adults per $m^2$
= 128,000 adults over sample area.

This does not account for the drop in population from 7,588,900 on 22 October 1974 to 70,400 on 18 November 1974.

C. Frequency distribution of adults 4 December 1974

N = 200

No live adults were found (5 dead adults found)

Appendix 10 - Association between plants and immature insects

A. Roseworthy 28 September 1972

| Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae | No. plants | Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae and pupae | No. plants | Sample unit no. | No. larvae and pupae | No. plants |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 41 | 5 | 0 | 81 | 1 | 0 | 121 | 0 | 0 | 161 | 1 | 0 |
| 2 | 1 | 0 | 42 | 0 | 0 | 82 | 2 | 1 | 122 | 0 | 1 | 162 | 0 | 0 |
| 3 | 0 | 0 | 43 | 0 | 2 | 83 | 0 | 0 | 123 | 0 | 2 | 163 | 0 | 1 |
| 4 | 5 | 1 | 44 | 0 | 0 | 84 | 0 | 1 | 124 | 0 | 0 | 164 | 3 | 1 |
| 5 | 0 | 1 | 45 | 0 | 0 | 85 | 0 | 0 | 125 | 0 | 0 | 165 | 0 | 0 |
| 6 | 1 | 0 | 46 | 0 | 0 | 86 | 5 | 1 | 126 | 0 | 0 | 166 | 0 | 0 |
| 7 | 1 | 2 | 47 | 0 | 2 | 87 | 1 | 2 | 127 | 1 | 2 | 167 | 1 | 3 |
| 8 | 1 | 1 | 48 | 10 | 2 | 88 | 0 | 0 | 128 | 1 | 1 | 168 | 0 | 0 |
| 9 | 0 | 1 | 49 | 4 | 6 | 89 | 1 | 0 | 129 | 0 | 0 | 169 | 3 | 1 |
| 10 | 15 | 4 | 50 | 1 | 1 | 90 | 2 | 1 | 130 | 1 | 1 | 170 | 0 | 1 |
| 11 | 6 | 3 | 51 | 0 | 0 | 91 | 0 | 0 | 131 | 1 | 1 | 171 | 0 | 1 |
| 12 | 3 | 4 | 52 | 0 | 1 | 92 | 4 | 2 | 132 | 1 | 2 | 172 | 0 | 1 |
| 13 | 0 | 1 | 53 | 0 | 2 | 93 | 7 | 1 | 133 | 2 | 1 | 173 | 3 | 3 |
| 14 | 14 | 3 | 54 | 2 | 0 | 94 | 2 | 2 | 134 | 1 | 2 | 174 | 0 | 1 |
| 15 | 8 | 4 | 55 | 3 | 1 | 95 | 10 | 3 | 135 | 1 | 1 | 175 | 7 | 2 |
| 16 | 16 | 3 | 56 | 15 | 4 | 96 | 0 | 2 | 136 | 1 | 1 | 176 | 1 | 1 |
| 17 | 3 | 2 | 57 | 1 | 0 | 97 | 0 | 0 | 137 | 1 | 2 | 177 | 0 | 0 |
| 18 | 0 | 1 | 58 | 2 | 4 | 98 | 2 | 3 | 138 | 9 | 1 | 178 | 0 | 1 |
| 19 | 15 | 5 | 59 | 9 | 4 | 99 | 3 | 2 | 139 | 0 | 3 | 179 | 0 | 0 |
| 20 | 7 | 5 | 60 | 26 | 3 | 100 | 1 | 3 | 140 | 0 | 3 | 180 | 4 | 1 |
| 21 | 4 | 2 | 61 | 5 | 2 | 101 | 5 | 3 | 141 | 12 | 8 | 181 | 0 | 0 |
| 22 | 10 | 4 | 62 | 0 | 0 | 102 | 0 | 2 | 142 | 1 | 2 | 182 | 3 | 2 |
| 23 | 12 | 3 | 63 | 6 | 4 | 103 | 0 | 2 | 143 | 0 | 0 | 183 | 5 | 4 |
| 24 | 0 | 0 | 64 | 5 | 2 | 104 | 0 | 0 | 144 | 0 | 4 | 184 | 10 | 2 |
| 25 | 0 | 2 | 65 | 19 | 4 | 105 | 0 | 1 | 145 | 0 | 1 | 185 | 4 | 1 |
| 26 | 7 | 1 | 66 | 0 | 1 | 106 | 2 | 0 | 146 | 5 | 1 | 186 | 0 | 0 |
| 27 | 2 | 4 | 67 | 0 | 0 | 107 | 0 | 0 | 147 | 0 | 1 | 187 | 2 | 3 |
| 28 | 5 | 2 | 68 | 1 | 1 | 108 | 0 | 0 | 148 | 0 | 0 | 188 | 0 | 0 |
| 29 | 0 | 0 | 69 | 0 | 1 | 109 | 2 | 1 | 149 | 0 | 1 | 189 | 3 | 4 |
| 30 | 0 | 1 | 70 | 0 | 1 | 110 | 0 | 0 | 150 | 1 | 1 | 190 | 4 | 4 |
| 31 | 0 | 0 | 71 | 0 | 0 | 111 | 0 | 0 | 151 | 4 | 1 | 191 | 0 | 0 |
| 32 | 3 | 1 | 72 | 0 | 0 | 112 | 0 | 0 | 152 | 0 | 0 | 192 | 8 | 2 |
| 33 | 0 | 0 | 73 | 0 | 0 | 113 | 0 | 0 | 153 | 0 | 0 | 193 | 0 | 1 |
| 34 | 0 | 0 | 74 | 4 | 3 | 114 | 0 | 0 | 154 | 1 | 1 | 194 | 0 | 1 |
| 35 | 0 | 0 | 75 | 0 | 0 | 115 | 0 | 0 | 155 | 0 | 0 | 195 | 0 | 2 |
| 36 | 4 | 0 | 76 | 0 | 0 | 116 | 0 | 0 | 156 | 2 | 1 | 196 | 0 | 0 |
| 37 | 0 | 0 | 77 | 0 | 1 | 117 | 0 | 1 | 157 | 0 | 1 | 197 | 0 | 0 |
| 38 | 0 | 0 | 78 | 0 | 0 | 118 | 0 | 2 | 158 | 0 | 0 | 198 | 0 | 2 |
| 39 | 0 | 0 | 79 | 0 | 1 | 119 | 2 | 0 | 159 | 5 | 2 | 199 | 2 | 1 |
| 40 | 0 | 3 | 80 | 3 | 1 | 120 | 0 | 1 | 160 | 0 | 0 | 200 | 0 | 0 |

B. Brentwood 6 August 1973

| Sample unit no. | No. larvae and pupae | No. plants |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 2 | 4 |
| 3 | 0 | 3 |
| 4 | 0 | 2 |
| 5 | 0 | 4 |
| 6 | 1 | 8 |
| 7 | 5 | 17 |
| 8 | 0 | 0 |
| 9 | 0 | 4 |
| 10 | 0 | 6 |
| 11 | 0 | 12 |
| 12 | 1 | 13 |
| 13 | 1 | 10 |
| 14 | 1 | 5 |
| 15 | 1 | 6 |
| 16 | 0 | 5 |
| 17 | 0 | 1 |
| 18 | 0 | 6 |
| 19 | 1 | 4 |
| 20 | 7 | 16 |
| 21 | 3 | 8 |
| 22 | 1 | 11 |
| 23 | 2 | 6 |
| 24 | 1 | 3 |
| 25 | 0 | 7 |
| 26 | 1 | 6 |
| 27 | 2 | 6 |
| 28 | 0 | 3 |
| 29 | 2 | 12 |
| 30 | 1 | 5 |
| 31 | 1 | 14 |
| 32 | 1 | 15 |
| 33 | 0 | 10 |
| 34 | 2 | 18 |
| 35 | 0 | 7 |
| 36 | 1 | 2 |
| 37 | 1 | 9 |
| 38 | 0 | 7 |
| 39 | 4 | 12 |
| 40 | 2 | 3 |
| 41 | 5 | 7 |
| 42 | 0 | 1 |
| 43 | 0 | 10 |
| 44 | 0 | 4 |
| 45 | 0 | 3 |
| 46 | 0 | 9 |
| 47 | 0 | 3 |
| 48 | 4 | 13 |
| 49 | 0 | 5 |
| 50 | 0 | 2 |
| 51 | 0 | 1 |
| 52 | 0 | 5 |
| 53 | 2 | 10 |
| 54 | 6 | 14 |
| 55 | 0 | 0 |
| 56 | 1 | 4 |
| 57 | 2 | 3 |
| 58 | 0 | 0 |
| 59 | 1 | 6 |
| 60 | 3 | 18 |
| 61 | 3 | 9 |
| 62 | 0 | 10 |
| 63 | 0 | 4 |
| 64 | 0 | 2 |
| 65 | 1 | 6 |
| 66 | 0 | 2 |
| 67 | 0 | 7 |
| 68 | 1 | 11 |
| 69 | 1 | 11 |
| 70 | 0 | 6 |
| 71 | 6 | 3 |
| 72 | 2 | 9 |
| 73 | 1 | 7 |
| 74 | 0 | 4 |
| 75 | 1 | 1 |
| 76 | 0 | 5 |
| 77 | 0 | 6 |
| 78 | 0 | 16 |
| 79 | 0 | 8 |
| 80 | 1 | 14 |
| 81 | 2 | 10 |
| 82 | 0 | 14 |
| 83 | 0 | 0 |
| 84 | 0 | 21 |
| 85 | 0 | 9 |
| 86 | 4 | 3 |
| 87 | 0 | 4 |
| 88 | 2 | 1 |
| 89 | 2 | 0 |
| 90 | 2 | 9 |
| 91 | 1 | 11 |
| 92 | 2 | 0 |
| 93 | 1 | 14 |
| 94 | 1 | 4 |
| 95 | 4 | 3 |
| 96 | 0 | 10 |
| 97 | 0 | 4 |
| 98 | 1 | 2 |
| 99 | 2 | 6 |
| 100 | 1 | 7 |
| 101 | 3 | 17 |
| 102 | 0 | 4 |
| 103 | 0 | 7 |
| 104 | 0 | 8 |
| 105 | 1 | 12 |
| 106 | 0 | 2 |
| 107 | 1 | 7 |
| 108 | 0 | 15 |
| 109 | 0 | 16 |
| 110 | 1 | 7 |
| 111 | 1 | 14 |
| 112 | 0 | 5 |
| 113 | 3 | 16 |
| 114 | 1 | 9 |
| 115 | 0 | 8 |
| 116 | 1 | 3 |
| 117 | 0 | 7 |
| 118 | 0 | 5 |
| 119 | 3 | 12 |
| 120 | 3 | 3 |
| 121 | 1 | 13 |
| 122 | 3 | 17 |
| 123 | 0 | 5 |
| 124 | 0 | 13 |
| 125 | 0 | 4 |
| 126 | 0 | 6 |
| 127 | 1 | 4 |
| 128 | 3 | 10 |
| 129 | 2 | 6 |
| 130 | 1 | 5 |
| 131 | 1 | 18 |
| 132 | 2 | 7 |
| 133 | 4 | 12 |
| 134 | 1 | 12 |
| 135 | 1 | 5 |
| 136 | 0 | 8 |
| 137 | 2 | 7 |
| 138 | 1 | 13 |
| 139 | 1 | 8 |
| 140 | 2 | 3 |
| 141 | 0 | 4 |
| 142 | 0 | 9 |
| 143 | 0 | 7 |
| 144 | 0 | 5 |
| 145 | 9 | 6 |
| 146 | 0 | 7 |
| 147 | 3 | 7 |
| 148 | 0 | 15 |
| 149 | 2 | 4 |
| 150 | 5 | 9 |
| 151 | 1 | 0 |
| 152 | 2 | 23 |
| 153 | 0 | 11 |
| 154 | 0 | 9 |
| 155 | 3 | 17 |
| 156 | 3 | 5 |
| 157 | 0 | 7 |
| 158 | 1 | 4 |
| 159 | 2 | 7 |
| 160 | 3 | 20 |
| 161 | 2 | 15 |
| 162 | 0 | 8 |
| 163 | 4 | 11 |
| 164 | 1 | 9 |
| 165 | 0 | 4 |
| 166 | 0 | 7 |
| 167 | 0 | 18 |
| 168 | 0 | 20 |
| 169 | 3 | 12 |
| 170 | 1 | 10 |
| 171 | 1 | 5 |
| 172 | 6 | 7 |
| 173 | 5 | 7 |
| 174 | 16 | 12 |
| 175 | 1 | 10 |
| 176 | 1 | 4 |
| 177 | 2 | 7 |
| 178 | 1 | 1 |
| 179 | 5 | 5 |
| 180 | 6 | 15 |
| 181 | 0 | 11 |
| 182 | 0 | 1 |
| 183 | 5 | 7 |
| 184 | 1 | 9 |
| 185 | 3 | 7 |
| 186 | 1 | 20 |
| 187 | 2 | 7 |
| 188 | 3 | 30 |
| 189 | 1 | 3 |
| 190 | 1 | 15 |
| 191 | 1 | 7 |
| 192 | 8 | 8 |
| 193 | 0 | 12 |
| 194 | 1 | 15 |
| 195 | 0 | 5 |
| 196 | 5 | 10 |
| 197 | 0 | 14 |
| 198 | 2 | 15 |
| 199 | 3 | 8 |
| 200 | 0 | 19 |
| 201 | 1 | 4 |
| 202 | 3 | 14 |
| 203 | 0 | 10 |
| 204 | 5 | 12 |
| 205 | 0 | 22 |
| 206 | 1 | 7 |
| 207 | 1 | 9 |
| 208 | 2 | 14 |
| 209 | 2 | 16 |
| 210 | 0 | 0 |
| 211 | 2 | 7 |
| 212 | 7 | 5 |
| 213 | 0 | 5 |
| 214 | 7 | 11 |
| 215 | 2 | 7 |
| 216 | 5 | 11 |
| 217 | 6 | 9 |
| 218 | 3 | 20 |
| 219 | 2 | 14 |
| 220 | 0 | 21 |
| 221 | 4 | 4 |
| 222 | 1 | 6 |
| 223 | 2 | 7 |
| 224 | 0 | 8 |
| 225 | 2 | 6 |
| 226 | 7 | 16 |
| 227 | 6 | 20 |
| 228 | 3 | 5 |
| 229 | 4 | 3 |
| 230 | 3 | 3 |
| 231 | 0 | 9 |
| 232 | 8 | 5 |
| 233 | 8 | 4 |
| 234 | 2 | 6 |
| 235 | 1 | 5 |
| 236 | 0 | 10 |
| 237 | 5 | 6 |
| 238 | 0 | 10 |
| 239 | 1 | 16 |
| 240 | 6 | 7 |
| 241 | 0 | 17 |
| 242 | 0 | 7 |
| 243 | 1 | 24 |
| 244 | 0 | 13 |
| 245 | 1 | 7 |
| 246 | 5 | 10 |
| 247 | 11 | 12 |
| 248 | 6 | 2 |
| 249 | 2 | 3 |
| 250 | 6 | 13 |
| 251 | 9 | 8 |
| 252 | 3 | 3 |
| 253 | 0 | 17 |
| 254 | 2 | 18 |
| 255 | 6 | 3 |
| 256 | 3 | 19 |
| 257 | 14 | 6 |
| 258 | 1 | 9 |
| 259 | 0 | 1 |
| 260 | 0 | 0 |

C. Brentwood 15 July 1974

| Sample unit no. | No. larvae | No. plants | Sample unit no. | No. larvae | No. plants | Sample unit no. | No. larvae | No. plants | Sample unit no. | no. larvae | No. plants | Sample unit no. | No. larvae | No. plants |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 41 | 0 | 0 | 81 | 0 | 0 | 121 | 0 | 0 | 161 | 0 | 0 |
| 2 | 4 | 4 | 42 | 10 | 4 | 82 | 0 | 0 | 122 | 58 | 22 | 162 | 16 | 3 |
| 3 | 0 | 0 | 43 | 1 | 2 | 83 | 3 | 2 | 123 | 76 | 10 | 163 | 56 | 13 |
| 4 | 1 | 1 | 44 | 21 | 12 | 84 | 0 | 0 | 124 | 17 | 12 | 164 | 0 | 0 |
| 5 | 22 | 10 | 45 | 21 | 11 | 85 | 12 | 4 | 125 | 7 | 6 | 165 | 1 | 5 |
| 6 | 2 | 9 | 46 | 7 | 3 | 86 | 0 | 0 | 126 | 5 | 9 | 166 | 2 | 7 |
| 7 | 1 | 11 | 47 | 0 | 0 | 87 | 15 | 4 | 127 | 2 | 3 | 167 | 8 | 8 |
| 8 | 4 | 6 | 48 | 1 | 2 | 88 | 0 | 1 | 128 | 12 | 9 | 168 | 4 | 9 |
| 9 | 15 | 6 | 49 | 0 | 7 | 89 | 3 | 6 | 129 | 8 | 12 | 169 | 2 | 2 |
| 10 | 5 | 17 | 50 | 8 | 9 | 90 | 0 | 7 | 130 | 15 | 7 | 170 | 0 | 7 |
| 11 | 40 | 21 | 51 | 3 | 3 | 91 | 2 | 6 | 131 | 1 | 1 | 171 | 0 | 1 |
| 12 | 19 | 11 | 52 | 9 | 2 | 92 | 13 | 18 | 132 | 4 | 2 | 172 | 0 | 9 |
| 13 | 1 | 3 | 53 | 2 | 6 | 93 | 2 | 2 | 133 | 13 | 14 | 173 | 6 | 8 |
| 14 | 4 | 3 | 54 | 9 | 6 | 94 | 25 | 24 | 134 | 0 | 2 | 174 | 2 | 2 |
| 15 | 6 | 6 | 55 | 4 | 6 | 95 | 0 | 10 | 135 | 1 | 0 | 175 | 0 | 3 |
| 16 | 9 | 6 | 56 | 15 | 17 | 96 | 3 | 7 | 136 | 0 | 0 | 176 | 8 | 4 |
| 17 | 3 | 3 | 57 | 9 | 6 | 97 | 1 | 9 | 137 | 11 | 5 | 177 | 0 | 2 |
| 18 | 18 | 15 | 58 | 16 | 28 | 98 | 2 | 11 | 138 | 0 | 0 | 178 | 21 | 12 |
| 19 | 4 | 9 | 59 | 11 | 9 | 99 | 0 | 1 | 139 | 0 | 12 | 179 | 19 | 11 |
| 20 | 0 | 2 | 60 | 0 | 6 | 100 | 6 | 4 | 140 | 0 | 2 | 180 | 13 | 11 |
| 21 | 4 | 9 | 61 | 6 | 16 | 101 | 9 | 6 | 141 | 52 | 13 | 181 | 26 | 14 |
| 22 | 4 | 5 | 62 | 0 | 4 | 102 | 0 | 4 | 142 | 8 | 4 | 182 | 32 | 20 |
| 23 | 1 | 5 | 63 | 7 | 13 | 103 | 2 | 3 | 143 | 4 | 3 | 183 | 20 | 17 |
| 24 | 5 | 6 | 64 | 5 | 12 | 104 | 0 | 6 | 144 | 0 | 2 | 184 | 26 | 4 |
| 25 | 24 | 24 | 65 | 2 | 7 | 105 | 8 | 3 | 145 | 12 | 9 | 185 | 8 | 6 |
| 26 | 35 | 21 | 66 | 2 | 1 | 106 | 12 | 16 | 146 | 9 | 5 | 186 | 7 | 3 |
| 27 | 7 | 4 | 67 | 0 | 2 | 107 | 0 | 1 | 147 | 0 | 2 | 187 | 1 | 1 |
| 28 | 4 | 6 | 68 | 3 | 1 | 108 | 39 | 13 | 148 | 8 | 6 | 188 | 2 | 1 |
| 29 | 8 | 13 | 69 | 9 | 7 | 109 | 3 | 10 | 149 | 3 | 6 | 189 | 0 | 1 |
| 30 | 14 | 9 | 70 | 2 | 7 | 110 | 0 | 4 | 150 | 1 | 7 | 190 | 9 | 0 |
| 31 | 20 | 12 | 71 | 11 | 9 | 111 | 1 | 12 | 151 | 2 | 7 | 191 | 0 | 2 |
| 32 | 9 | 10 | 72 | 2 | 5 | 112 | 12 | 4 | 152 | 2 | 5 | 192 | 1 | 2 |
| 33 | 4 | 7 | 73 | 0 | 1 | 113 | 34 | 11 | 153 | 10 | 3 | 193 | 13 | 2 |
| 34 | 8 | 7 | 74 | 0 | 0 | 114 | 5 | 0 | 154 | 5 | 2 | 194 | 1 | 0 |
| 35 | 8 | 8 | 75 | 0 | 0 | 115 | 1 | 3 | 155 | 10 | 6 | 195 | 1 | 0 |
| 36 | 13 | 6 | 76 | 1 | 2 | 116 | 44 | 17 | 156 | 0 | 3 | 196 | 8 | 8 |
| 37 | 9 | 10 | 77 | 15 | 6 | 117 | 0 | 0 | 157 | 5 | 0 | 197 | 40 | 22 |
| 38 | 0 | 1 | 78 | 1 | 1 | 118 | 3 | 5 | 158 | 4 | 9 | 198 | 9 | 9 |
| 39 | 0 | 0 | 79 | 1 | 0 | 119 | 0 | 0 | 159 | 8 | 7 | 199 | 0 | 0 |
| 40 | 0 | 0 | 80 | 0 | 0 | 120 | 0 | 0 | 160 | 1 | 0 | 200 | 0 | 2 |

D. Brentwood 27 August 1974

| Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 41 | 0 | 0 | 81 | 2 | 2 | 121 | 0 | 0 | 161 | 9 | 0 |
| 2 | 12 | 7 | 42 | 2 | 3 | 82 | 0 | 0 | 122 | 9 | 3 | 162 | 6 | 0 |
| 3 | 4 | 2 | 43 | 1 | 1 | 83 | 0 | 0 | 123 | 19 | 4 | 163 | 28 | 0 |
| 4 | 10 | 2 | 44 | 24 | 1 | 84 | 3 | 2 | 124 | 31 | 0 | 164 | 1 | 1 |
| 5 | 3 | 0 | 45 | 1 | 0 | 85 | 22 | 3 | 125 | 26 | 5 | 165 | 3 | 4 |
| 6 | 3 | 1 | 46 | 7 | 3 | 86 | 12 | 0 | 126 | 2 | 1 | 166 | 3 | 2 |
| 7 | 6 | 6 | 47 | 8 | 0 | 87 | 9 | 3 | 127 | 11 | 4 | 167 | | |
| 8 | 5 | 2 | 48 | 17 | 1 | 88 | 3 | 3 | 128 | 7 | 4 | 168 | 2 | 0 |
| 9 | 19 | 8 | 49 | 32 | 9 | 89 | 12 | 0 | 129 | 3 | 5 | 169 | 9 | 5 |
| 10 | 16 | 4 | 50 | 19 | 2 | 90 | 5 | 2 | 130 | 4 | 4 | 170 | 0 | 1 |
| 11 | 17 | 4 | 51 | 29 | 4 | 91 | 8 | 7 | 131 | 2 | 1 | 171 | 1 | 1 |
| 12 | 6 | 2 | 52 | 9 | 3 | 92 | 7 | 0 | 132 | 24 | 7 | 172 | 1 | 0 |
| 13 | 9 | 1 | 53 | 12 | 0 | 93 | 2 | 3 | 133 | 12 | 4 | 173 | 1 | 0 |
| 14 | 7 | 3 | 54 | 19 | 10 | 94 | 9 | 1 | 134 | 13 | 5 | 174 | 3 | 1 |
| 15 | 9 | 2 | 55 | 27 | 10 | 95 | 1 | 0 | 135 | 9 | 6 | 175 | 2 | 4 |
| 16 | 19 | 2 | 56 | 2 | 3 | 96 | 6 | 7 | 136 | 0 | 3 | 176 | 0 | 0 |
| 17 | 8 | 4 | 57 | 28 | 9 | 97 | 3 | 0 | 137 | | | 177 | 7 | 1 |
| 18 | 48 | 17 | 58 | 1 | 0 | 98 | 3 | 4 | 138 | 13 | 11 | 178 | 10 | 5 |
| 19 | 11 | 4 | 59 | 1 | 2 | 99 | 11 | 6 | 139 | 13 | 4 | 179 | 1 | 0 |
| 20 | 18 | 3 | 60 | 4 | 1 | 100 | 22 | 12 | 140 | 27 | 7 | 180 | 2 | 2 |
| 21 | 17 | 0 | 61 | 9 | 5 | 101 | 10 | 12 | 141 | 43 | 9 | 181 | 16 | 6 |
| 22 | 26 | 8 | 62 | 12 | 10 | 102 | 1 | 1 | 142 | 10 | 4 | 182 | 12 | 2 |
| 23 | 19 | 4 | 63 | 0 | 0 | 103 | 41 | 2 | 143 | 5 | 6 | 183 | 8 | 5 |
| 24 | 11 | 5 | 64 | 0 | 0 | 104 | 0 | 1 | 144 | 25 | 4 | 184 | 8 | 2 |
| 25 | 33 | 7 | 65 | 13 | 2 | 105 | 12 | 9 | 145 | 15 | 2 | 185 | 0 | 0 |
| 26 | 20 | 6 | 66 | 30 | 7 | 106 | 22 | 14 | 146 | 25 | 1 | 186 | 5 | 1 |
| 27 | 44 | 5 | 67 | 1 | 1 | 107 | 8 | 6 | 147 | 10 | 3 | 187 | 1 | 0 |
| 28 | 17 | 1 | 68 | 5 | 8 | 108 | 2 | 2 | 148 | 3 | 6 | 188 | 3 | 0 |
| 29 | 45 | 21 | 69 | 3 | 4 | 109 | 2 | 1 | 149 | 1 | 0 | 189 | 4 | 1 |
| 30 | 10 | 3 | 70 | 17 | 1 | 110 | 0 | 2 | 150 | 29 | 5 | 190 | 1 | 1 |
| 31 | 20 | 5 | 71 | 31 | 17 | 111 | 1 | 7 | 151 | 2 | 2 | 191 | 0 | 0 |
| 32 | 33 | 7 | 72 | 3 | 1 | 112 | 3 | 0 | 152 | 0 | 0 | 192 | 3 | 2 |
| 33 | 6 | 2 | 73 | 39 | 3 | 113 | 2 | 0 | 153 | 20 | 9 | 193 | 8 | 11 |
| 34 | 1 | 0 | 74 | 6 | 2 | 114 | 2 | 0 | 154 | | | 194 | 11 | 4 |
| 35 | 5 | 1 | 75 | 12 | 3 | 115 | 5 | 4 | 155 | 21 | 13 | 195 | 30 | 7 |
| 36 | 4 | 1 | 76 | 21 | 1 | 116 | 3 | 4 | 156 | 1 | 0 | 196 | 9 | 4 |
| 37 | 21 | 3 | 77 | 12 | 1 | 117 | 46 | 0 | 157 | 9 | 2 | 197 | 28 | 7 |
| 38 | 0 | 1 | 78 | 2 | 0 | 118 | 1 | 2 | 158 | 0 | 0 | 198 | 30 | 3 |
| 39 | 0 | 0 | 79 | 1 | 0 | 119 | 0 | 2 | 159 | 3 | 3 | 199 | 3 | 1 |
| 40 | 3 | 0 | 80 | 0 | 0 | 120 | 1 | 0 | 160 | 0 | 0 | 120 | 0 | 0 |

## E. Brentwood 24 September 1974

| Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants | Sample unit no. | No. larvae & pupae | No. plants |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 41 | 1 | 0 | 81 | 0 | 0 | 121 | 0 | 0 | 161 | 0 | 0 |
| 2 | 0 | 4 | 42 | 8 | 1 | 82 | 2 | 1 | 122 | 23 | 3 | 162 | 10 | 3 |
| 3 | 8 | 0 | 43 | 4 | 2 | 83 | 0 | 0 | 123 | 6 | 3 | 163 | 39 | 6 |
| 4 | 10 | 0 | 44 | 7 | 0 | 84 | 24 | 8 | 124 | 17 | 5 | 164 | 4 | 1 |
| 5 | 13 | 0 | 45 | 13 | 1 | 85 | 4 | 0 | 125 | 24 | 4 | 165 | 0 | 3 |
| 6 | 1 | 1 | 46 | 0 | 0 | 86 | 0 | 0 | 126 | 2 | 2 | 166 | 0 | 0 |
| 7 | 11 | 0 | 47 | 2 | 0 | 87 | 3 | 0 | 127 | 7 | 1 | 167 | 5 | 3 |
| 8 | 17 | 2 | 48 | 6 | 3 | 88 | 1 | 0 | 128 | 10 | 0 | 168 | 23 | 6 |
| 9 | 5 | 0 | 49 | 8 | 3 | 89 | 1 | 1 | 129 | 4 | 4 | 169 | 10 | 0 |
| 10 | 9 | 0 | 50 | 36 | 4 | 90 | 12 | 6 | 130 | 12 | 1 | 170 | 1 | 2 |
| 11 | 24 | 11 | 51 | 4 | 3 | 91 | 5 | 7 | 131 | 14 | 2 | 171 | 14 | 0 |
| 12 | 9 | 1 | 52 | 10 | 4 | 92 | 13 | 7 | 132 | 11 | 3 | 172 | 10 | 6 |
| 13 | 0 | 0 | 53 | 18 | 10 | 93 | 4 | 6 | 133 | 8 | 1 | 173 | 0 | 0 |
| 14 | 4 | 1 | 54 | 7 | 4 | 94 | 9 | 8 | 134 | 4 | 2 | 174 | 0 | 1 |
| 15 | 9 | 3 | 55 | 7 | 5 | 95 | 4 | 2 | 135 | 9 | 2 | 175 | 22 | 5 |
| 16 | 4 | 5 | 56 | 23 | 7 | 96 | 1 | 5 | 136 | 3 | 2 | 176 | 5 | 3 |
| 17 | 14 | 2 | 57 | 8 | 3 | 97 | 1 | 0 | 137 | 7 | 4 | 177 | 13 | 6 |
| 18 | 0 | 1 | 58 | 13 | 0 | 98 | 5 | 0 | 138 | 40 | 14 | 178 | 9 | 1 |
| 19 | 14 | 4 | 59 | 0 | 0 | 99 | 3 | 3 | 139 | 29 | 9 | 179 | 6 | 0 |
| 20 | 10 | 1 | 60 | 3 | 0 | 100 | 0 | 0 | 140 | 36 | 11 | 180 | 0 | 0 |
| 21 | 20 | 4 | 61 | 6 | 4 | 101 | 0 | 1 | 141 | 4 | 3 | 181 | 17 | 1 |
| 22 | 0 | 0 | 62 | 3 | 8 | 102 | 9 | 5 | 142 | 22 | 14 | 182 | 45 | 3 |
| 23 | 35 | 8 | 63 | 34 | 10 | 103 | 7 | 8 | 143 | 8 | 0 | 183 | 1 | 2 |
| 24 | 20 | 9 | 64 | 2 | 1 | 104 | 4 | 5 | 144 | 34 | 4 | 184 | 5 | 2 |
| 25 | 19 | 0 | 65 | 7 | 4 | 105 | 34 | 4 | 145 | 24 | 2 | 185 | 9 | 4 |
| 26 | 12 | 3 | 66 | 26 | 20 | 106 | 10 | 3 | 146 | 12 | 8 | 186 | 1 | 0 |
| 27 | 4 | 0 | 67 | 5 | 1 | 107 | 2 | 4 | 147 | 5 | 1 | 187 | 1 | 0 |
| 28 | 5 | 1 | 68 | 8 | 2 | 108 | 4 | 0 | 148 | 5 | 5 | 188 | 8 | 4 |
| 29 | 54 | 21 | 69 | 33 | 8 | 109 | 12 | 4 | 149 | 0 | 0 | 189 | 0 | 0 |
| 30 | 16 | 2 | 70 | 9 | 6 | 110 | 0 | 0 | 150 | 48 | 14 | 190 | 1 | 3 |
| 31 | 18 | 1 | 71 | 17 | 2 | 111 | 9 | 10 | 151 | 8 | 5 | 191 | 2 | 6 |
| 32 | 7 | 2 | 72 | 16 | 5 | 112 | 22 | 4 | 152 | 8 | 1 | 192 | 7 | 5 |
| 33 | 3 | 0 | 73 | 7 | 1 | 113 | 14 | 3 | 153 | 22 | 4 | 193 | 15 | 3 |
| 34 | 12 | 0 | 74 | 3 | 1 | 114 | 11 | 2 | 154 | 3 | 1 | 194 | 2 | 4 |
| 35 | 7 | 0 | 75 | 53 | 8 | 115 | 21 | 11 | 155 | 1 | 0 | 195 | 11 | 1 |
| 36 | 3 | 1 | 76 | 6 | 1 | 116 | 39 | 6 | 156 | 35 | 8 | 196 | 7 | 1 |
| 37 | 16 | 0 | 77 | 6 | 3 | 117 | 10 | 1 | 157 | 13 | 2 | 197 | 29 | 1 |
| 38 | 2 | 0 | 78 | 0 | 0 | 118 | 49 | 3 | 158 | 1 | 0 | 198 | 6 | 0 |
| 39 | 0 | 0 | 79 | 1 | 0 | 119 | 2 | 1 | 159 | 0 | 1 | 199 | 23 | 3 |
| 40 | 0 | 0 | 80 | 0 | 0 | 120 | 0 | 0 | 160 | 0 | 0 | 200 | 0 | 1 |

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| Sample unit no. | No. immature insects* | No. plants | Sample unit no. | No immature insects* | No. plants | Sample unit no. | No immature insects* | No. plants | Sample unit no. | No. immature insects* | No. plants | Sample unit no. | No. immature insects* | No. plants |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 41 | 0 | 0 | 81 | 0 | 0 | 121 | 0 | 0 | 161 | 0 | 0 |
| 2 | 8 | 7 | 42 | 1 | 1 | 82 | 0 | 0 | 122 | 0 | 0 | 162 | 0 | 0 |
| 3 | 1 | 0 | 43 | 25 | 1 | 83 | 11 | 5 | 123 | 12 | 1 | 163 | 0 | 0 |
| 4 | 9 | 0 | 44 | 0 | 0 | 84 | 4 | 0 | 124 | 2 | 1 | 164 | 20 | 3 |
| 5 | 1 | 2 | 45 | 0 | 0 | 85 | 6 | 3 | 125 | 16 | 1 | 165 | 3 | 4 |
| 6 | 17 | 0 | 46 | 0 | 0 | 86 | 18 | 6 | 126 | 16 | 0 | 166 | 0 | 0 |
| 7 | 1 | 0 | 47 | 2 | 1 | 87 | 0 | 0 | 127 | 1 | 1 | 167 | 4 | 0 |
| 8 | 10 | 1 | 48 | 9 | 0 | 88 | 0 | 0 | 128 | 11 | 3 | 168 | 6 | 1 |
| 9 | 0 | 1 | 49 | 0 | 0 | 89 | 3 | 1 | 129 | 0 | 0 | 169 | 6 | 5 |
| 10 | 14 | 2 | 50 | 9 | 4 | 90 | 7 | 1 | 130 | 4 | 0 | 170 | 1 | 1 |
| 11 | 0 | 0 | 51 | 41 | 10 | 91 | 2 | 1 | 131 | 7 | 4 | 171 | 0 | 2 |
| 12 | 23 | 6 | 52 | 6 | 1 | 92 | 4 | 2 | 132 | 2 | 3 | 172 | 3 | 4 |
| 13 | 16 | 6 | 53 | 11 | 3 | 93 | 12 | 5 | 133 | 5 | 0 | 173 | 8 | 7 |
| 14 | 2 | 3 | 54 | 2 | 0 | 94 | 8 | 10 | 134 | 0 | 0 | 174 | 6 | 2 |
| 15 | 1 | 0 | 55 | 9 | 6 | 95 | 2 | 9 | 135 | 0 | 0 | 175 | 0 | 0 |
| 16 | 8 | 3 | 56 | 33 | 2 | 96 | 2 | 3 | 136 | 3 | 0 | 176 | 3 | 0 |
| 17 | 8 | 1 | 57 | 44 | 10 | 97 | 0 | 1 | 137 | 3 | 4 | 177 | 2 | 1 |
| 18 | 15 | 1 | 58 | 4 | 4 | 98 | 0 | 0 | 138 | 1 | 1 | 178 | 4 | 3 |
| 19 | 21 | 7 | 59 | 20 | 4 | 99 | 1 | 3 | 139 | 2 | 0 | 179 | 0 | 0 |
| 20 | 17 | 2 | 60 | 3 | 1 | 100 | 2 | 0 | 140 | 4 | 0 | 180 | 8 | 2 |
| 21 | 10 | 7 | 61 | 0 | 0 | 101 | 8 | 7 | 141 | 12 | 2 | 181 | 41 | 9 |
| 22 | 10 | 1 | 62 | 1 | 1 | 102 | 2 | 0 | 142 | 4 | 0 | 182 | 38 | 8 |
| 23 | 4 | 2 | 63 | 10 | 3 | 103 | 4 | 1 | 143 | 0 | 0 | 183 | 20 | 5 |
| 24 | 10 | 1 | 64 | 7 | 2 | 104 | 3 | 6 | 144 | 7 | 2 | 184 | 9 | 2 |
| 25 | 8 | 6 | 65 | 0 | 3 | 105 | 1 | 5 | 145 | 1 | 0 | 185 | 7 | 3 |
| 26 | 18 | 3 | 66 | 4 | 3 | 106 | 9 | 3 | 146 | 6 | 3 | 186 | 2 | 0 |
| 27 | 5 | 0 | 67 | 7 | 2 | 107 | 16 | 2 | 147 | 13 | 2 | 187 | 4 | 3 |
| 28 | 37 | 3 | 68 | 3 | 7 | 108 | 4 | 10 | 148 | 0 | 0 | 188 | 3 | 2 |
| 29 | 6 | 0 | 69 | 10 | 1 | 109 | 0 | 0 | 149 | 1 | 1 | 189 | 1 | 0 |
| 30 | 16 | 2 | 70 | 3 | 0 | 110 | 1 | 2 | 150 | 1 | 2 | 190 | 12 | 0 |
| 31 | 23 | 1 | 71 | 13 | 1 | 111 | 3 | 3 | 151 | 2 | 2 | 191 | 7 | 5 |
| 32 | 10 | 2 | 72 | 0 | 0 | 112 | 0 | 1 | 152 | 15 | 7 | 192 | 1 | 0 |
| 33 | 3 | 1 | 73 | 0 | 0 | 113 | 7 | 3 | 153 | 0 | 0 | 193 | 6 | 0 |
| 34 | 2 | 1 | 74 | 1 | 0 | 114 | 4 | 2 | 154 | 4 | 3 | 194 | 5 | 2 |
| 35 | 1 | 0 | 75 | 16 | 0 | 115 | 17 | 6 | 155 | 9 | 2 | 195 | 0 | 0 |
| 36 | 28 | 4 | 76 | 25 | 0 | 116 | 1 | 0 | 156 | 5 | 7 | 196 | 6 | 2 |
| 37 | 4 | 3 | 77 | 0 | 0 | 117 | 0 | 0 | 157 | 25 | 2 | 197 | 2 | 0 |
| 38 | 24 | 1 | 78 | 0 | 0 | 118 | 2 | 0 | 158 | 6 | 0 | 198 | 1 | 2 |
| 39 | 0 | 1 | 79 | 0 | 0 | 119 | 6 | 2 | 159 | 0 | 0 | 199 | 3 | 1 |
| 40 | 0 | 0 | 80 | 0 | 0 | 120 | 0 | 0 | 160 | 0 | 0 | 200 | 0 | 0 |

* immature insects - total of larvae, pupae and teneral adults (not emerged from ground).

## Appendix 11 - Taylor's Power Law

Taylor (1961, 1965) showed that the following method can be used to obtain the appropriate transformation for normalizing data and stabilizing the variance.

1. Mean and variance calculated from raw data

2. The values of $\bar{x}$ and $s^2$ are ploted on log/log scale The value of b can be calculated from regression analysis of the equation $\log s^2 = \log a + b \log \bar{x}$

   The appropriate transformation is the form $z = x^p$ where x = original number, z = transformed value and $p = 1 - \frac{1}{2}b$.

The mean and variance values may be obtained from several sets of samples from different areas, from sets of samples of different sizes or by combining samples to form different sized sampling units.

Nine samples of adults were used for S. humeralis to obtain the appropriate transformation. Their means and variance are given in the table below:

Table A

Mean and Variance of samples of adult S. humeralis

| Date | Sample unit size $cm^2$ | Mean | Variance |
|---|---|---|---|
| 2.5.74 | 5000 | 44.05 | 987.39 |
| 2.5.74 | 2500 | 19.8 | 150.8 |
| 2.5.74 | 1000 | 6.85 | 47.19 |
| 2.5.74 | 100 | 0.95 | 0.89 |
| 13.5.74 | 2500 | 20.23 | 176.89 |
| 24.6.74 | 2500 | 15.89 | 133.63 |
| 30.7.74 | 2500 | 7.64 | 37.34 |
| 12.9.74 | 2500 | 2.58 | 8.51 |
| 2.10.74 | 2500 | 1.26 | 2.78 |

The log of variance and mean are plotted in Figure A.

The slope of the line (b) = 0.59 hence the appropriate transformation is $z = x^{0.7}$

Figure A. Log mean and variance to obtain b of Taylor's power law for S. humeralis adults.