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3.1.3.

THE MEASUREMENT OF ARTHROPOD NUMBERS AND ACTIVITY BY SAMPLING WITH SWEEP–NETS AND TRAPS

by

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A. SWEEP-NETS

Sweep-net sampling is a comparative method in which insect population density is usually recorded as number of insects collected per 100 sweeps; it is not converted to number per unit area. Comparison of samples is valid for the same operator, catching the same insect species, at the same time of day, in the same crop at the same stage of growth. All five factors have been shown to have significant, and sometimes large, effects on the resulting sample and each should therefore be standardized as far as practicable. In particular, attention should be given to the position of the insects on the plant at different times of day because some species, for example of Diptera and Hemiptera, have a diurnal rhythm of vertical movement on plants that greatly affects sweep samples.

In practice the number of sweeps taken varies with population density; sweeping is continued until a reasonably consistent sample is obtained and the number of insects collected is scaled, up or down, to numbers per 100 sweeps. Interpretation of 'a reasonably consistent sample' depends on the crop, the insect species, the population density and the purpose of sampling.

1. Field sampling

Field crops, from about 10 to 100 cm high, in which the plant cover is fairly continuous and the plants flexible, can be swept for larvae, or nymphs, and adults that are fairly easily dislodged but do not fly too freely. Larvae and some adults of Lepidoptera, Hemiptera at all stages, some Diptera, Orthoptera, Coleoptera and Thysanoptera are commonly sampled by sweeping.

It is impractical to take sweeps distributed at random through a crop; hence a regular pattern should be adopted, traversing as large an area as possible, representative of the whole field, without bias towards the edges of the crop. The net is made of tough material such as nylon with mesh suited to the size of insect sampled, and mounted on a 40 cm hoop on a 100 cm handle. It is swept in a 180° arc at crop height, with not more than half the net inside the crop, and one sweep is made with each step forward along the traverse. A few preliminary sweeps are made to assess the general level of population and the number of sweeps between each inspection of the net is then adjusted to catch as many of the required species as can easily be counted before they become active, For example, not more than about 10 active grasshoppers can be counted at a time. Furthermore, too many sweeps between inspections yield a mass of debris and insects that wastes time in sorting. Sweeping is continued if possible until a total of about 100 of the required insects is obtained. When insects, such as aphids, are very common, a single sweep may yield very large numbers and counting becomes difficult. However, the degree of error is proportional to population density and with dense populations, lower accuracy in counting is tolerable.

In contrast, sweeping to find the first few immigrants entering a crop may involve taking hundreds of strokes before any insects are caught and an arbitrary limit must be set on the number of sweeps before a zero record is accepted as indicating absence of insects.

2. Laboratory processing

Sweep-net samples are usually inspected, identified and counted in the net. Because counting may be inaccurate, some error in identification is often acceptable, and only small samples need to be taken to the laboratory for checking. If sweeping has been done carefully and systematically, the insects are usually dry and in good condition. Preparation for identification and storage therefore follows the usual procedure for the particular species or group being sampled.

3. Interpretation of results

Because counts are made at each inspection and from one to many inspections constitute a sample, the catch at each inspection can be treated as a sample unit for analysis, providing the number of sweeps per inspection is constant. However, this degree of refinement in analysis is rarely justified by the method and total counts per sample are usually expressed simply as number per 100 sweeps.

Transformation of the data depends on the degree of aggregation of the species on the crop, but if sweeping is intended only to provide evidence of first arrivals, or sudden changes in population density, the evidence will frequently be such that full statistical analysis is unnecessary. For example, the sample may simply be recorded as presence or absence per 100 sweeps in each of 100 fields in an area, and crop protection action initiated when the total score exceeds 50% fields infested. Sweep-net samples are, however, often correlated with plant damage and action may then be taken at a given catch per 100 sweeps.

Southwood (1) discusses some of the problems involved in sweeping but there is no comprehensive account of sweeping as a sampling method. Most sampling systems using sweeping are specific to the person concerned and two people rarely obtain the same results. The method is therefore best developed by common sense for a specific purpose in the prevailing conditions and great restraint should be exercised both in extrapolating findings to other conditions or in comparing results obtained by different workers.

4. Source of information

(1) Southwood, T. R. E. 1966. *Ecological methods.* Methuen, London, 391 pp.

B. IMPACTION TRAPS

The cheapest, and often the simplest traps for sampling flying insects, sample by impaction. A stationary surface is placed so as to intercept the insect in flight, or on landing. Various adhesive substances are used to prevent escape after impaction, and often the surface is coloured to attract insects and thereby increase the size, although not the reliability, of the sample.

The disadvantages of impaction traps and the resultant difficulties of their standardization arise mainly from this practice of using an attractant colour to increase the size of the sample. For example, it has been estimated that painting a tray yellow may multiply the catch of particular species of aphid a thousand times, relative to other species of aphids. This makes it difficult to assess the relative abundance of species and almost impossible to estimate absolute numbers flying and alighting naturally elsewhere. However, it allows qualitative surveys of the distribution of species that are strongly attracted, and the very sparse populations of first immigrants into an area or a crop can be detected, and early warning of pest levels obtained.

Both the adhesive surface and the attractant colouring deteriorate in the open air. Rain and dust produce a surface film over the adhesive and rain and sunshine may flood or evaporate water trays. Adhesive properties may be damaged in a day and continued exposure for more than one week should be avoided. Paints used as attractants fade rapidly and deposits discolour them. Coloured surfaces should be repainted each season.

Impaction traps have been used mainly for small Coleoptera, Homoptera and small Diptera and are suitable, in some forms, for many day-flying insects in field and forest crops. They are not usually suitable for large nocturnal insects.

1. Field sampling

Sites for impaction traps should be exposed to wind. Cylindrical sticky traps are commonly placed at 1–2 m above ground. All water trays in a survey should be exposed against the same uniform background, preferably bare earth or grass; the sample size may be increased by raising the tray 0·5 m above ground.

When sampling for immigrant species, it is important to sample away from crops producing emigrants, otherwise a large local population may obscure a smaller sample immigrant from a population further away.

Various surfaces, especially flat vertical boards, are used for sampling insects. The simplest impaction surface is a vertical sheet of glass against which beetles impinge and fall into a trough of oil or water and drown. This 'window trap' was developed especially for timber beetles by Chapman and Kinghorn (2). Aerodynamically the most efficient surface is a cylinder and an upright cylinder also has the great practical advantage of sampling multidirectionally. Flat vertical surfaces either sample undirectionally or need to be pivoted and directed into the wind by a vane. The upright cylinder has long been used to sample flying aphids and is usually painted yellow to attract them (Fig. 1). The cylindrical surface is covered by a

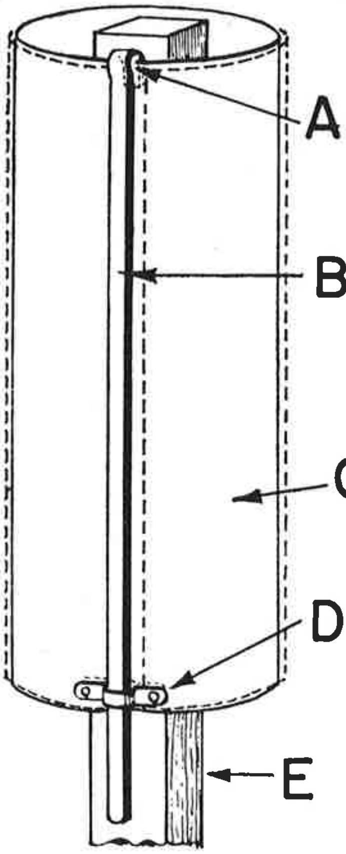

Figure 1. Cylindrical sticky trap (after Broadbent *et al.*, 1948). (A) Brass strip hooked over top of cylinder. (B) Brass strip holding acrylic sheet. (C) Metal cylinder. (D) Socket for brass strip. (E) Post.

removable transparent acrylic sheet, which is coated with tree-banding grease 1–2 mm thick: it is taken into the laboratory to remove adhering insects. Sampling by attraction in still air and increasingly by impact as the wind increases, a white upright sticky cylinder has a surprisingly consistent efficiency.

Horizontal surfaces are used for insects supposed to be alighting on the ground or crop, but in practice insects are also impacted on to horizontal surfaces by wind, and therefore deliberate alighting need not be inferred from capture. With such horizontal impaction surfaces the inconvenience of using adhesives to retain the insects after impaction can be avoided by using traps filled with water to which detergent and a killing agent have been added. The bottom of the tray is usually painted yellow to increase the catch; 'yellow trays' are widely used for aphid sampling. For chloropids and thrips, impaction surfaces are more usually painted white; 'white trays' would probably sample most small day-flying insects.

2. Laboratory processing

Insects recovered from water trays can be processed in the usual way. Those from sticky impaction traps must first be cleaned of grease, usually by soaking in ethyl acetate or xylol.

3. Interpretation of results

For recording first arrivals in crops, the untransformed daily catch suffices because it is the date of capture that is of prime importance and an estimate of population density is secondary. Catch, however, is the product of wind speed and relative density and when detailed records of daily or weekly changes in population density are required, the catch must be corrected for wind speed.

Logarithmic transformations are especially appropriate for catches from impaction traps in which an attractant acts as a specific multiplying factor on the catch.

4. Sources of information

(1) Broadbent, L., Doncaster, J. P., Hull, R., and Watson, M. A. 1948. Equipment used for trapping and identifying aphids. *Proc. Roy. Ent. Soc.* (London), A, 23:57–58.

(2) Chapman, J. A., and Kinghorn, J. M. 1955. Window flight traps for insects. *Can. Entomol.* 87:46–47.

(3) Southwood, T. R. E. 1966. *Ecological methods*. Methuen, London, 301 pp.

(4) Taylor, L. R. 1960. The distribution of insects at low levels in the air. *J. Anim. Ecol.* 29:45–53.

(5) Taylor, L. R. 1962. The efficiency of cylindrical sticky insect traps and suspended nets. *Ann. appl. Biol.* 5:681–685.

(6) Taylor, L. R., and Palmer, J. M. P. 1970. Aerial sampling. *In*, *Aphid Technology*. (ed. van Emden). Academic Press, London and New York.

C. SUCTION TRAPS

Suction traps are designed to give an absolute sample of the numbers of insects flying per unit volume of air, usually called aerial density. The sampling principle is to collect air continuously by an extractor fan working at a known rate, and to filter the insects from it. Electricity is necessary to drive the fan and, because the sample is collected randomly from the moving aerial insect community, it may contain much that is not required and so take more time to handle than a catch obtained with an attractant. The sample is, however, entirely reliable for any particular species, is consistent for comparisons between species and can be related quantitatively to field populations as only a truly random sample can. Suction traps have been rigorously standardized and variability between samples obtained by pairs of traps is almost entirely attributable to variability in the population sampled; this is not so with any other aerial insect sampling method.

The suction trap measures aerial density accurately at a point in space, the centre of the inlet plane of the trap. By making several such measurements at different points, the total number of insects in a given mass of air can be estimated. This does not directly record movement, except by tracing the path of the air mass itself, i.e. the wind direction and speed. If insects are drifting down-wind, the population, or numbers crossing a front, is the product of wind speed and aerial density. The number of insects settling out of the air on to a crop depends, not on population drift, but on aerial density.

Large non-segregating suction traps are therefore recommended as constant survey samplers giving an absolute measure of the numbers of insects against which to standardize the strongly biased samples, or non-dimensional catches, of attractant traps such as coloured impaction traps and light traps. The small segregating suction trap is a sensitive experimental instrument for defining temporal and spatial changes in aerial density over short intervals. It is not usually robust enough for a survey instrument.

Suction traps can be used to sample any crop and any insect whose population is dense enough to provide a sample at reasonable cost. All kinds of insects are caught, and a sampling correction which increases with insect size has to be made; correction tables were published in 1962 (5). These traps have been developed particularly for sampling Homoptera, small

Diptera, Hymenoptera and Coleoptera, but even large Lepidoptera are caught regularly in larger traps. Lewis and Taylor (3) give the range of insects caught.

1. Field sampling

For survey purposes, suction traps are operated at heights from 2 to 10 m and different traps collect from $0{\cdot}5$ to $1{\cdot}5 \times 10^5$ m^3 air per day. Since insect population is approximately halved with a doubling of sampling height, volume size of sample should in that event be doubled. Increasing the sampling height increases the randomness of the distribution from which the sample is taken and decreases the local component of the catch. A sample of $0{\cdot}5 \times 10^5$ m^3 of air, 10–20 m above ground in temperate climates, yields up to 10^5 insects per day in summer. The Rothamsted Insect Survey relies for its aerial aphid density reports on suction trap samples of $2{\cdot}3 \times 10^6$ ft^3 ($0{\cdot}65 \times 10^5$ m^3) air per day, collected at 40 ft (12·2 m) above ground (Fig. 2).

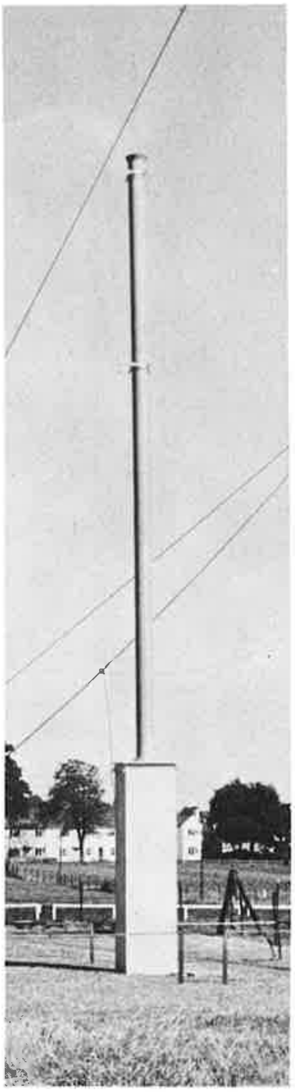

Figure 2. The 40-ft (12·2 m) survey suction trap used in the Rothamsted Insect Survey collecting 96,000 ft^3 (2,700 m^3) of air/hour.

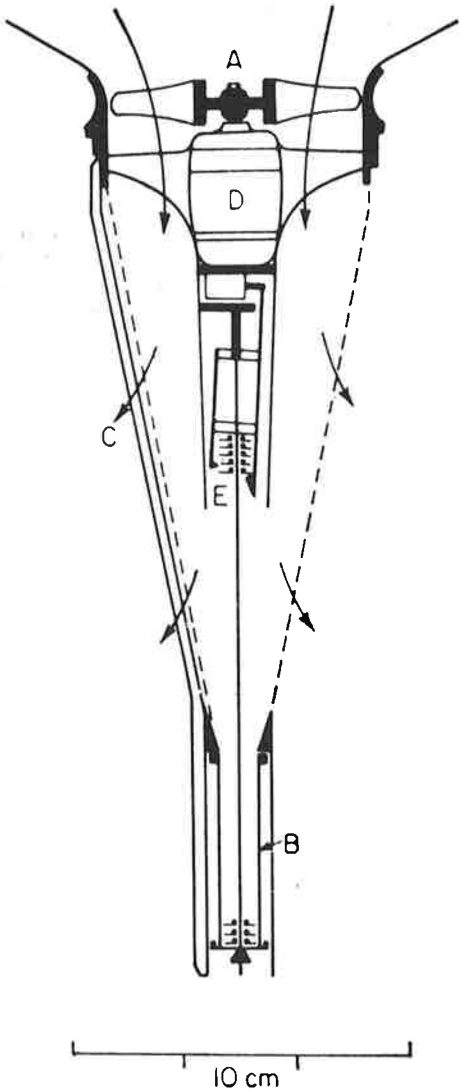

Figure 3. The 9-inch (22·4 cm) Vent-Axia suction trap with segregating mechanism. (A) Fan inlet. (B) Collecting tube. (C) Filter net inside iron framework. (D) Fan motor. (E) Disk-dropping device.

For experiments involving the assessment of aerial insect density below the crop canopy, small suction traps, collecting 0·5 to $2{\cdot}0 \times 10^3$ m^3 air per hour are used with time of flight being recorded by a time segregating mechanism incorporated into the traps. In these traps the insects are collected on to cloth-covered, brass plates impregnated with pyrethrum and contained in a brass cylinder (Fig. 3). Catches over periods of 24 hours or more are collected into jars of alcohol. Suction traps are occasionally used to collect live samples by filtering out the insects into a large, fine terylene net without a killing agent. Collected in this way the insects are in excellent condition.

Traps should match their backgrounds; it is implicit in the definition of a random sample that, as the insect approaches a trap, it should be neither attracted nor repelled by it. To sample the insects entering and leaving the crop, a suction trap is best set in the crop and hidden by it, with the inlet at crop canopy level.

To obtain a sample close to the ground surface, the trap is set in a trench with the air outlet 1 m or more from the inlet so that air does not recirculate back into the trap. Traps can be suspended in trees or mounted on stands to sample from within the canopy.

Suction traps should be serviced each season, cleaned, greased and nets examined. They should not be left in the field when not in action or the motors may be damaged by damp and dust.

2. Laboratory processing

Suction trap catches are usually collected into alcohol and subsequently processed in the usual manner for the group.

3. Interpretation of results

The spatial distribution of the insects sampled by survey traps may sometimes be almost random, suggesting a square root transformation. However, analysis is usually concerned more with temporal than with spatial changes. Such changes, from day to day or week to week, are largely geometrical; they derive from population changes that are multiplicative, and from effects of climate on behaviour that tend to be proportional to the population density or otherwise to be thresholds (i.e. all-or-none functions). The log $(n+1)$ transformation is therefore more appropriate and seasonal means are given as the $\{\text{antilog}[\log(n+1)]-1\}$, known as the 'Williams mean', which approaches the square root mean at small, and the geometric mean at large, catches.

Survey sampling with suction traps can yield more precise information of vector movements than other methods, as emphasized by Heathcote, Palmer and Taylor (1).

Threshold and regression analysis were discussed by Taylor (6) and the appropriate means and transformations by Southwood (4). Suction trap sampling is reviewed in Taylor and Palmer (7).

4. Sources of information

(1) Heathcote, G. D., Palmer, J. M. P., and Taylor, L. R. 1969. Sampling for aphids by suction trap, sticky trap and by crop inspection. *Ann. appl. Biol.* 63:155–166.
(2) Johnson, C. G. 1950. A suction trap for small airborne insects which automatically segregates the catch into successive hourly samples. *Ann. appl. Biol.* 37:80–91.
(3) Lewis, T., and Taylor, L. R. 1965. Diurnal periodicity of flight by insects. *Trans. Roy. Entomol. Soc.* (London) 116:393–479.
(4) Southwood, T. R. E. 1966. *Ecological methods.* Methuen, London, 391 pp.
(5) Taylor, L. R. 1962. The absolute efficiency of insect suction traps. *Ann. appl. Biol.* 50:405–421.
(6) Taylor, L. R. 1963. Analysis of the effect of temperature on insects in flight. *J. Anim. Ecol.* 32:99–117.
(7) Taylor, L. R., and Palmer, J. M. P. 1970. Aerial sampling. *In*, *Aphid Technology*. (ed. van Emden). Academic Press, London and New York.

D. LIGHT TRAPS

Light traps have probably been used more, and for longer, than any other insect-sampling instrument. They are especially suited to sampling large nocturnal flying insects. Their form and structure differ almost as much as the purposes for which they were developed. At an early stage attempts were made to use light traps to kill and thus to control insect pests. This has left an unfortunate impression in the literature, that the value of a trap depends on the size of the catch, and catch size has often been referred to as 'efficiency'.

It is difficult, or impossible, to define the efficiency of an attractant trap because the area from which the insects are collected depends on both the physical environment and the insect. For example, a light trap catches almost nothing by day because, against the bright background illumination, the trap is visible from within only a small area. Because the size of this area is neither known nor constant, the efficiency with which insects are extracted from it cannot be measured. The change in background illumination from the waxing and waning moon produces a spurious lunar cycle in light-trap catches for which allowance must be made in analysis. Allowance should also be made for loss of efficiency caused by increasing windspeed, although this can be decreased by windbreaks (Hollingsworth *et al.* (3)).

Frost (2) illustrates most of the basic patterns of light trap and lists the following as being the most frequently caught:

Collembola	Cercopidae
Gryllidae	Homoptera—Hemiptera, Misc.
Tipulidae	Scarabeidae
Tabanidae	Coleoptera, Misc.
Simulidae	Pyralidae
Chironomidae	Noctuidae
Tsetse flies	Tortricidae
Culicidae	Gelechiidae
Cicadellidae	Lepidoptera, Misc.

However, recent extensive use of 'black light', which is ultra-violet light with a small visible blue element, has considerably widened the range of insects caught. The development of fluorescent tubes has also made possible battery-operated, portable traps which produce a useful catch at powers as low as 6 or 8 watts. Hollingsworth *et al.* (4) give constructional details for a very practical 6 watt omnidirectional trap that is suitable for mains electricity or battery operation, and list the insect species of economic importance attracted to black light in North America. Some day-flying insects, such as aphids, have been listed in light-trap catches, but such samples are probably fortuitous and light traps cannot be used systematically for sampling these insects.

1 Field sampling.

Light traps are usually placed near, or slightly above, crop level. Background lighting which will affect the sample should be avoided if possible and the trap should be at least 5 m away from upstanding objects because the effect of reflected light on the catch is not understood. Insects are usually killed by toxic vapour; they should be kept dry in the collecting chamber, and removed dry into the laboratory. Traps should be cleaned at regular intervals since, particularly where spiders are common, glasses and inlets may become fouled.

2. Laboratory processing

Initial sorting of the catch can be done dry; the Lepidoptera especially should not be wetted or their scales will make subsequent sorting difficult. It is very easy to obtain samples by light trap that are excessively large and partially ruined in the collecting chamber. Such catches often need to be sub-sampled for counting. Sub-sampling is usually done by volume, but is not entirely satisfactory.

Catches in different traps differ greatly in quantity and quality. The opentopped Robinson trap with a 150 watt mercury vapour lamp catches about 10 times as many Lepidoptera as the covered Rothamsted trap with a 200 watt tungsten lamp. Also, the range of species differs but not consistently because of the complex interaction between the differential attraction of different species, time of flight and visibility.

Most traps now use electricity as the source of light and the characteristics of the wide range of available lamps have only partly been investigated.

3. Interpretation of results

Light-trap catches often fluctuate over 4 or 5 orders of magnitude; logarithmic transformation is then the only practicable method of handling data. There will always be zero catches, so log $(n+1)$ is customarily used. For smaller catches, with many zeros and ones, weekly totals are more easily handled and year to year comparisons are then facilitated by eliminating data for February 29th and December 31st so that each year has the same 52 numbered weeks.

There is no comprehensive review of light trapping. Frost (2) gives the most useful list of reference to traps; Brown, Betts and Rainey (1) illustrate the value of large-scale light-trap surveys.

4. Sources of information

(1) Brown, E. S., Betts, E., and Rainey, R. C. 1969. Seasonal changes in distribution of the

African Armyworm, Spodoptera exempta Walk. with particular reference to Eastern Africa. *Bull. Entomol. Res.* 58:661–728.
(2) Frost, S. W. 1952. Light traps for insect collection survey and control. *Penn. Agr. Exp. Sta. Bull.* 550:1–32.
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