ROTHAMSTED RESEARCH

Report for 1939-45

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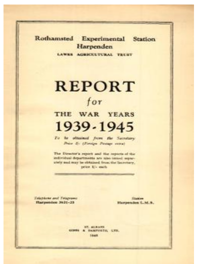
Rothamsted Experimental Station
Harpenden

REPORT
for
THE WAR YEARS
1939-1945

Entomology Department

C. B. Williams

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DEPARTMENT OF ENTOMOLOGY
1937 - 1945

By C. B. Williams

A summary of the work of the Department of Entomology from its commencement in 1915 to the end of the year 1936 was published in the Annual Report of the Experimental Station for 1936, pp. 99-120. This present Report is, therefore, extended to include the two pre-war years 1937-38 so that it will join on to the previous one and the two will give a complete outline of the work of the Department since its inception.

Since the last Report there has been no change in the senior staff, which consists of C. B. Williams (Head of Department), H. F. Barnes and A. C. Evans.

Temporary workers at the Laboratory during the period include the following ;

W. R. S. Ladell	Soil Insects	1935-38
K. D. Baweja	Soil Insects	1935-37
K. J. Grant	Insect Migration	1935-38
B. Lovibond	Leatherjackets	1935-39
D. C. Thomas	Hemiptera	1937-38
K. N. Trehan	Aleurodidae	1936-38
A. G. Robertson	Tipulidae in Light Trap and Chemotropic responses of Insects	1936-37
J. Deal	Preferred Temperatures of Insects	1936-40
G. F. Cockbill	Insect Migration	1938-41
S. R. Nutman	Collembola and Flea-beetles	1941-43

The Degree of Ph.D. at the London University for work done at Rothamsted was obtained by Baweja, Trehan, Deal and Cockbill.

Miss Lovibond after the first year was appointed to the staff of St. Ives Golf Green Research Station and seconded here to continue her work.

G. F. Cockbill was appointed for two years under a grant obtained from the Leverhulme Foundation for the study of insect migration.

C. B. Williams represented the Department at the Seventh International Congress of Entomology at Berlin in 1938. He also made an extended tour of South America at the invitation of the British Council from September, 1943 to April, 1944 for lecturing and liaison work on entomology and agricultural science. Nearly all the countries of South America were visited, and a number of lectures given including several on the history of Rothamsted. Since his return a steady flow of correspondence has developed putting workers in South America in touch with workers in this country.

Soil insects

An intensive study on the rate of recolonisation of sterilised soil was carried out on an area of allotment soil (36). The soil was sterilised by baking at a temperature of 212° F., for 6 hours. Sterilisation was carried out at two dates, in February and in May, and control plots of unsterilised soil were included. One half of the total number of plots were enclosed by iron sheets fixed 1 ft. below the ground and extending 6 inches above the surface. Grass was sown on all the plots. The observations on recolonisation were carried out for a period of just over one year; soil samples 3 inches by 4 inches in area and 9 inches deep were taken and the fauna extracted by the Ladell flotation process, previously developed in the department. The populations were recorded in millions per acre and calculated from the numbers of soil organisms in the sample by the formula (35)

$$\frac{x}{2} + \frac{x - 20}{20}$$

The total population in all the control plots was low during the winter, increased slowly with the advent of warmer weather until the middle of September when there was a rapid increase, the maximum population being reached by about the middle of November. This rapid increase was chiefly due to the increase in the population of Collembola whose activity seems to reach a maximum during a falling range of soil temperature of 55-45° F.

Recolonisation in both cases of sterilisation was very rapid and was rather more rapid in the enclosed plots. By the end of September the populations of the sterilised plots were equal to those of the control plots and at the end of the observations were three to five times as great. The fact that recolonisation averaged five months in the enclosed plots and seven months in the unenclosed plots suggests that there was but little lateral movement in the soil of the soil fauna and recolonisation was mainly effected by surface or aerial movement.

The results of this investigation show that sterilised soil is particularly favourable for the rapid increase of certain insects and that some of these are common glasshouse pests.

Wireworms

Soil insecticides.—One of the major activities of the department has been the study of wireworms, a pest which assumed great importance on the ploughing up of much grassland just before and during the first few years of the war. The first problem studied was the distribution of wireworms in the field and development of an adequate experimental field technique to test chemical control measures (54). Preliminary sampling showed that the distribution of wireworms was very uneven and that the experimental design used, a Latin square, nearly doubled the accuracy of the results. The sampling errors in the three experiments carried out were high, 20-50 per cent. of the mean, and accounted for a high proportion of the experimental error, 20-60 per cent. Several of the soil insecticides used caused a significant decrease in the wireworm population but some unfortunately also had an adverse effect on the crop. Naphthalene at 10 cwt. per acre produced a kill of 60 per cent. No differential action of the insecticides on wireworms of different sizes was found.

A further experiment (49) was carried out to see whether an increased rate of application of naphthalene, 15 cwt. per acre, would produce a complete kill of wireworms but unfortunately the treated plots did not show any reduction in numbers compared with the control plots. The only reason suggested for the failure of the naphthalene in this experiment is that the application was made in February at a time when wireworms are not usually considered active, whereas in the previous experiment the insecticide was applied in April.

In view of the low return of information relative to the amount of time and labour spent on large-field trials, it was decided to develop a laboratory technique to test new and more promising soil insecticides. Further, the interpretation of the results of the field trials was rendered more difficult by quite large changes in the populations on the control plots, the reasons for which were unknown. Work on the biology of wireworms was therefore begun.

A suitable laboratory technique for testing soil insecticides was developed and a wide range of substances tested. Even in these rigorously controlled experiments there was great variation between replicates carried out at the same time and at different times, pointing to necessity of further reasearch on the wireworm itself. Experiments were carried out on the placing of soil insecticides and fertilisers near the seed.

Biology.—In an oviposition preference experiment it was found that *Agriotes obscurus* L. females laid significantly more eggs in grass and significantly fewer eggs in fallow than in clover, wheat and kale. Marked beetles of *A. sputator* L. were trapped up to 30 yards away from their point of liberation. The ratios of adult *A. obscurus* to *A. sputator* were found to vary greatly from field to field (50).

Owing to the long life of the wireworm it has not yet been possible to study the effect of various factors on growth and mortality over the whole life-cycle but sufficient work has been carried out to provide an adequate basis for such a study (45), (46), (47). It has been found that the number of moults per annum varies inversely with the age of the wireworm and that during the moulting process the wireworm undergoes a considerable increase in weight followed by a decrease in weight. The magnitudes of these changes (in water content only) are such as to vitiate the results of growth experiments unless the experiments are planned so as to take account of them. The type of plant on which the wireworm feeds has a considerable effect on its rate of growth, some plants being very suitable, others less suitable, while flax proved to be very unsuitable for growth. Thus it might be expected that the type of crop grown in any one year might influence the behaviour of wireworms towards the succeeding crop. This conclusion was borne out by the results of an experiment on the cropping of newly ploughed grassland in which eight crops were sown during the first year followed by spring oats. A fairly uniform distribution of wireworms was present during both years, except in the case of one crop mentioned below, but the yields of the cereal crop following the various previous crops differed greatly. In the laboratory experiments, beans proved to be a rather unsuitable food and consequently rather heavy damage was expected to the following oat crops. Contrary to expectations an excellent crop was obtained. The reason for this exceptional result was found to lie in a great reduction of the wireworm population in the plots which previously carried beans, a reduction amounting to 75 per cent. of the original population. A toxic effect by the roots of the bean plant may be the explanation of this reduction.

The seasonal activity of wireworms is governed by soil temperature and moisture and also their moulting frequency, so that the amount of damage to be expected can depend on several factors, namely, soil conditions both physical and chemical, previous cropping and the frequency of the different size groups in the wireworm population.

The cuticle of wireworms is permeable to water and it has been found that in its relations to soil moisture the wireworm may be regarded as an osmotic system. The pF scale of soil moisture was shown to be a better expression of soil moisture in relation to wireworms than the percentage moisture present.

Leatherjackets

Miss B. J. Lovibond, appointed as Entomologist to the Board of Greenkeeping Research, St. Ives Research Station, Bingley, was seconded to work at Rothamsted following some preliminary investigations carried out by a member of this department. During her stay here (1936-39) she investigated the most important craneflies and their larvae (56) and conducted breeding and sampling experiments (57).

The orthodichlorobenzene emulsion method has also been investigated as a possible means of conducting a long-term study of fluctuations in the abundance of the common leatherjacket (19).

Slugs

This is a case where an immediate problem has developed of necessity into a fundamental one. At the outbreak of the war it was realised that if possible a substitute should be found for bran, a feeding stuff of value, in the metaldehyde-bran method of baiting slugs. Experiments quickly showed, however, that slugs, under the conditions of the experiments which were carried out in gardens, definitely preferred attractant substances of food value. In fact, the better the feeding value of the attractant the more slugs were attracted to and killed by the poison bait (16, 21, 22).

Lack of detailed knowledge concerning the bionomics of slugs leading to difficulties in the complete interpretation of the results of the baiting experiments revealed the necessity of an intensive ecological study.

It was decided to study the slugs in gardens since more species were to be found in gardens than in fields, and eventually about 50 gardens were involved in the investigation. A sampling method is used which consists of picking up all the slugs seen during 30 minutes, during which period the different ecological sites in the garden are visited. This method has shown that enormous numbers are often present, up to 570 slugs being gathered in half-an-hour, followed on one occasion by a further 517 half-an-hour later.

Each species has its own season of abundance during the year. Thus *Arion ater* is most abundant in January, *A. subfuscus* about June, *Agriolimax reticulatus* about July-September, *Milax sowerbyi*

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in September and October, *M. gracilis* about October, and *A. hortensis* slightly later in the year.

The study has already shown by observation of the slugs' food habits that slugs are practically omnivorous and that usually in gardens they are scavengers more than pests. It is estimated that 90 per cent. of their food is what the grower does not want either for its aesthetic value or its importance as food.

The distribution of the various species of slugs in neighbouring gardens is most interesting. In the case of two species *A. hortensis* and *M. gracilis* the numbers increase regularly from garden to garden up one side of an old river-bed whereas those of *M. sowerbyi* show a definite ridge of abundance a little way up the slope. The distribution of *A. ater* seems to be associated with the age of the gardens whereas that of *A. reticulatus* seems to be uniformly high whatever the garden. The distribution of *A. subfuscus* is peculiar, this species being abundant almost everywhere on the west side of the old river-bed and almost absent on the other.

The mating season of the two species which mate in the open has been studied, as well as the seasonal weights of the samples of the slugs collected.

Water-colour paintings of the various species have most generously been made by Miss Evelyn Tuke and they are being used, as three plates in the account of this ecological study of slugs in gardens (**1**, **2**, **29**, **33**, **34**).

A further development of this study has been the weighing of the specimens individually. The weights of two species, *A. subfuscus* and *A. reticulatus*, have been thus recorded since July, 1944 and those of one other species, *M. gracilis*, since October, 1944 and those of three other species since the summer of 1945. By this means it is possible to follow the changes in the weight distributions of the active slugs throughout the season and on occasion the growth rate and death rate. This is being linked up with the seasonal weights of populations in neighbouring gardens as well as the weights at which breeding takes place.

The determination of the numerical abundance of active slugs has now continued for four years and gives every promise as a method of investigating the year-to-year abundance of the various species.

Earthworms

Although earthworms are very common in many parts of the world and numerous statements have been made as to the part they play in maintaining soil fertility and soil structure very little indeed is known of their biology, and the results of the little experimental work which has been carried out on their relation to soil fertility are largely valueless owing to this lack of knowledge. In August, 1944 research was begun on earthworms as part of a wider programme on the relationships between the soil fauna and the soil with particular reference to soil fertility.

The relative abundance of the different species on various parts of the Rothamsted Farm and certain other soil types was first studied to decide which species should be used for experimental work. It was found that the proportions of the different species varied greatly according to the previous history of the fields and on the different soil types. Only the most general statements are available as to the length of the life-cycle of the various species, so cultures of twelve species have been set up to obtain material for a study of this problem. These cultures have also yielded valuable data as to the relative metabolic activity of the different species. On a basis of the weight of cocoons produced during a given time, the larger species have a much lower rate of metabolic activity than the smaller species with one exception *Lumbricus rubellus* Hoffm. a fairly large worm with a high rate of metabolism.

Methods have been developed to study the seasonal activity of worms under laboratory and field conditions, namely;

(*a*) The rate of deposition of cocoons (i.e., eggs) under known conditions of temperature and moisture.
(*b*) The collection of worm casts at four-day intervals throughout the year.
(*c*) The numbers of earthworms brought to the surface of grassland by watering with a worm irritant.

Weekly estimations, at least, of the soil moisture at three different depths are being made and continuous records of soil temperature at five different depths are available to study the effect of these factors on activity.

The preliminary results of the survey on the relative abundance of the different species shows that *Allolobophora caligniosa* Sav., a large earthworm, was one of the commonest species present on the farm, so it was chosen for the first pot experiment on the effect of earthworms on soil fertility. No data existed on the amount of organic matter which earthworms consume in a given time so a 3 by 3 factorial experiment was set up; 3 levels of organic matter (bullock droppings) 0, 25 and 50 grams: and 3 worm treatments, 0, 12-13 grams of living worms and 12-13 grams of dead worms. This weight of worms per pot is approximately equal to the amount present in a good pasture. After the worms had acted on the organic matter for 3½ months they were removed and any pots in which more than one worm had died were rejected. Finally five replicates of each treatment were set up and spinach beet sown. The results of the experiments showed that dead worms had a highly significant effect in increasing the yield of spinach but that living worms had no significant effects.

During the course of the above experiment, the biological studies showed that *A. caliginosa* was a worm with a low rate of metabolic activity. In a subsequent experiment, *L. rubellus* a fairly large worm but with a higher rate of metabolism was used as the test subject and the results of the experiment show clearly that it has had a highly significant effect in increasing the yield of the test crop grown, i.e., mustard. Further work along these lines is planned.

Insect Physiology

A study of the temperature preferendum of a wide range of insects was carried out (37). The results show that in general a range of temperatures rather than one particular temperature is preferred. The only preference which some insects may be said to show is an avoidance of both extremes of temperature, while some others merely avoid high temperature. Another rather peculiar preference is presented in the bi-modal curve with a peak near each end of the gradient. In general the preferences of the immature forms tended to coincide with those of the adults of the same species.

A study of the distribution of nitrogen in the castes of the wasp, *Vespula germanica* (Fab.) showed that in the adults most of the nitrogen is present in the cuticular and water-soluble protein fractions, in prepupae, little is found in the cuticle, but over 60 per cent. is in the form of soluble protein. Just emerged wasps probably contain a reserve protein, insoluble in water, which is utilised to complete the hardening of the skeleton. About 60 per cent. by weight of the cuticle and 55-70 per cent. of the total nitrogen is lost when adult cuticle is boiled in 1 per cent. KOH, a method used by previous workers to estimate the weight of cuticle present in an insect (38).

Further examination showed that the cuticle of the mealworm *Tenebrio molitor* L. contains about 60 per cent. of a protein which is easily soluble in water, dilute acids and alkalis. Previous to moulting about 80-85 per cent. of the cuticle is absorbed. The hypothesis is put forward that, in this insect, the material absorbed from the cuticle at the last larval moult may eventually be utilised to form the major part of the adult cuticle (40).

Very little indeed is known how the varying chemical composition of plants at different times of the year, under different manurial conditions, etc., can affect the growth and reproduction of insects, or whether the feeding processes of sucking insects can affect the chemical composition of plants. The cabbage aphis *Brevicoryne brassicae* L. fed on cabbages grown under different environmental conditions proved a very useful subject for this type of work. It was found in a series of cabbages grown under normal conditions of light that the rate of reproduction was positively correlated with the nitrogen content of the host plants and, in particular, with the protein content. In a series of plants grown under subnormal conditions of light the rate of reproduction was positively correlated with the soluble-sugar content and the total water-soluble carbohydrate content of the plant. Thus from November to February, the rate of reproduction is probably dependent on the carbohydrate content of the plant and for the rest of the year on the protein content. A low carbohydrate content in the food of the caterpillar of *Pieris brassicae* L. brings about a slower rate of growth and smaller pupae. It is generally agreed that overcrowding brings about the formation of winged forms in aphids, and there are about as many suggestions as to the cause of this as there have been workers. In the case of *B. brassicae* it has been found that once the protein content of the host plant falls below a critical level there is a highly significant negative correlation between the protein content and the percentage of winged forms present (39).

In addition to the direct reduction of crop yields, insects may also be the cause of changes in chemical composition, a factor likely to be of particular importance in crops, such as sugar beet, grown as a source of special substances. It was found that increasingly high populations of *B. brassicae* brought about a gradual diminution in the fresh-weight yield of cabbages, but that on a dry-weight basis a low population density caused a rapid diminution in yield. This diminution of yield was principally brought about by

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a very great decrease in the amounts of reducing sugars, sucrose, starch and acid-hydrolysable substances. Data were also obtained on the effect of the bean aphis *Aphis fabae* Scop. on the composition of field beans, but in this case no significant differences were found between beans obtained from clean or heavily infested plants (44).

Since aphids normally feed on the contents of the phloem tubes it is not possible to study the chemical composition of their food. In the case of lepidopterous larvae this is possible and detailed studies of the utilisation of food have been carried out on four lepidopterous larvae and on one coleopterous larva (41, 42, 43). A technique was developed to determine accurately the amount of food consumed and the weight of excreta derived from it, and chemical analysis was carried out on both food and excreta. In the case of nearly full-grown larvae of the Buff-tip, *Phalera bucephala* L. it was found that 60 per cent. of the water, 60 per cent. of the protein, 80 per cent. of the soluble sugars, 60 per cent. of the fat and 35 per cent. of the ash present in the food were utilised. Polysaccharides were not utilised. Nitrogen was excreted as ammonia and uric acid.

During the period of growth of the larvae, the coefficient of utilisation of dry matter remained approximately constant, but the coefficient of utilisation of water was very high during the first instar, approximately 0.95, and fell to approximately 0.6-0.7 during the second-fifth instars.

$$\text{Coefficient of utilisation} = \frac{\text{Weight utilised}}{\text{Weight consumed}}$$

The amounts of the various chemical substances present in the food are utilised in very different proportions by larvae of different species. Thus the larvae of *Malacosoma neustria* L. utilise starch but hardly any fat, while those of *Aglais urticae* L., *Pieris brassicae* L. and *Phalera bucephala* L. do not utilise starch but do utilise considerable amounts of fat. The amounts of protein utilised by these species also differ. The nutritive ratios of the four species vary from 0.32 to 1.18, and these in turn differ greatly from those of herbivores, 4.7-7.0.

The larvae of *Tenebrio molitor* L. feeding on bran utilise a wide variety of carbohydrates and maintain their water content above that of the food by the retention of metabolic water derived from the oxidation of these carbohydrates. Gliadin, glutenin and K_2SO_4-soluble proteins are utilised.

Relations of insects to climate and weather conditions

In the previous summary of work up to 1936 it was shown how the result of several years continuous trapping with a light trap was being used as a basis for a statistical study of the relation of weather conditions to insect numbers and insect activity.

The trapping was carried on for four years, and the analysis of the figures continued and published in two papers: the first (71) contains a general account of the different groups of insects obtained in the trap and the different species in the case of Lepidoptera; also an account of the sex ratios in different groups and the factors affecting it; a discussion of the variability in dates of appearance (phenology) in different years; and further data on the time of flight of different insects during the night.

The second paper (75) is a statistical analysis of the numbers caught in relation to weather conditions. In the first place it was shown that much more consistent results could be obtained in statistical analyses by using the logarithm of the number of insects caught instead of the actual number. This means that comparison is most profitable between geometric, rather than arithmetic, changes. Regressions were calculated between the log. number of insects and the various weather factors, such as minimum and maximum temperature, wind, humidity, rainfall, cloud and moonlight. Of these, the minimum temperature was found to be the most important. A rise in the minimum temperature of about 5° F. doubled the catch, and a fall of a similar amount halved it. This effect was approximately the same in summer and in winter, and with different groups of insects. Simultaneous regressions with several factors were also calculated and it was found possible to account for about 60 per cent. of the total variation in insect numbers by known climatic factors.

Finally, an attempt was made to forecast the average level of abundance of all insects during each month, from the rainfall and minimum temperature of the three previous months. Multiple regressions were calculated between the average monthly catch, corrected for activity, and the rainfall and temperature of the three previous months, for each of the forty-eight months in which the trap was working. The results showed that, under the conditions of the locality, in the summer the limiting factor in insect numbers was moisture, and in the winter temperature. Thus, a wet June results in more insects in July, August and September, but a warm June does not increase the number of insects in the following months.

Owing to the war, it was impossible to continue the light trap on which most of this work has been based. It is most important the work should be resumed with several traps, so as to study the climatic effects on single species of insects. Also the work should be repeated elsewhere in England or abroad, to see if the effects obtained here are general or only local in application.

Population studies

These studies during the period under review have been confined to the one dealing with the button-top midge at Syston, Leicestershire (17) which was discontinued owing to the difficulty of travel during war time, one on the carrot fly in north Lincolnshire and east Nottinghamshire (23) which was also discontinued owing to war-time difficulties, an incidental study of an unusual outbreak of vapourer moth caterpillars in Caernarvonshire in 1942 (24, 25) and the continuation of the original Rothamsted population study of the wheat-blossom midges on Broadbalk which was initiated in 1927 (20).

The last-mentioned study has reached a stage at which it is attracting world-wide attention as what promises to be a Rothamsted classical study. Already it is being used in courses on ecology both at Oxford and Cambridge in this country and at universities overseas.

Two gall midges are involved, *Contarinia tritici* which is the lemon-coloured wheat-blossom midge and whose larvae are the same colour and gregarious, and *Sitodiplosis mosellana* which is the orange-coloured wheat-blossom midge and whose larvae are the same colour and almost solitary. Their larvae in the first species present grain formation and in the second cause shrunken grain.

Since 1927 *C. tritici* has had three or four, more or less well defined peaks of abundance, the first in 1929-31 with about 19,000 larvae per 500 ears, the second in 1935 with about 4,000 larvae, the third about 1941 with about 2,000 larvae, and the fourth in 1945 with nearly 25,000 larvae, per 500 ears. The trough years have been 1927, 1933, 1938 and 1944. *S. mosellana* similarly has occurred in peak numbers in 1931, 1935, 1941 and 1945 with troughs in 1927-29, 1933, 1938 and 1944. The grain infestation of both these midges also indicates that there have been four peaks in the last nineteen years, namely in 1931, 1935, 1941 and 1945.

The inter-relationship of the midges and their host plant has been shown to be so close that a reasonable estimate of the forwardness of the year's crop can be obtained by observing the emergence dates of the wheat-blossom midges in an insectary, and also that the percentage grain attacked gives a useful first estimate of the crop yield (30).

It has also been shown that the larvae of the midges do not invariably emerge as midges the year following their presence on the wheat (26). Thus in the case of *C. tritici* it is known that besides sometimes emerging as midges the same year as the larvae attacked the wheat, the larvae sometimes remain two winters in the soil. Its parasites also can remain dormant for the same period. This delay of emergence is even more pronounced in the case of *S. mosellana*. Specimens of this species emerged in 1945 from larvae that were on the wheat in 1939, and so it is now known that they can spend at least six winters in the soil. The observations are continuing, but it is already clear that 1944 was a trough year for incidence of these midges on the wheat at least partly because 1944 was a bad year for emergence, whereas 1945 when the present peak of abundance was first manifest was a much better year for emergence.

Population studies: mathematical analysis of mixed populations

Arising out of the light-trap studies on the relation of insect numbers to climatic and weather conditions, a statistical study of the data obtained was made and it was found that there was a mathematical order in the relative abundance of different species of insects in a random sample from a mixed population as given, for example, by the light trap. Professor R. A. Fisher co-operated in the work (84) and found that the frequency of species in the sample could be best expressed by a logarithmic series. The results were applied to insects in the light trap (236) and it was found that in a random sample the number of species with 1, 2, 3 or more individuals, closely followed the series ;

$$n_1 : \frac{n_1 x}{2} : \frac{n_1 x^2}{3} : \frac{n_1 x^3}{4}$$

where n_1 is the number of species represented by one individual and x a constant, for the sample, less than unity. The sum of both individuals and of species in the series is finite, so that if in any random sample the numbers of individuals and of species is known, then n_1 and x can be calculated.

If a larger or smaller sample is taken by the same method from the same population, there will be different values of n_1 and x; the larger the sample, the closer x is to unity. It has been shown, however, both theoretically and practically by the light-trap results, that for all samples of whatever size from the same population taken by the same method, the ratio of $n_1 \div x$ is constant. This ratio has been designated "Index of Diversity" and is a property of the population sampled. If the population is rich in species, it is high: if poor in species, low. This has proved to be a very valuable new ecological weapon for distinguishing populations of different structure and composition.

The application of the general properties of the logarithmic series has been extended to light-trap catches of insects in the United States (93): the number of species of plants in different areas (87) and 85): the number of lice on the heads of infested men (87): the number of British nesting birds: of mosquitos caught in a light trap and of butterflies caught in Malaya (87). It has also been found to apply closely to the number of species in genera of both plants and animals (87): and even to the number of publications published by entomologists in one year (86).

Work is continuing on this, as it is thought that it may lead to a fundamental understanding of the relative abundance of species in an insect population, and hence of the balance of species numbers and the causes of displacement and outbreaks of insect pests.

Studies on Cecidomyidae

The underlying policy with regard to this work has always been two-fold; the provision of information to the advisory services and research workers throughout the world, and in the second place, the increase of the knowledge concerning this group of flies. The latter has involved what might be termed neo-systematic or bio-systematic studies.

The demands for information have been very widespread. Thus since 1937 two check lists of Cecidomyidae have been published, one relating to New Zealand (5), the other with Oceania (3).

Requests for identifications involving the describing of new species have included: midges from beech buds in Germany (6), from sesame or simsim in Tanganyika Territory (7), from coffee in Tanganyika Territory and the Belgian Congo (10), from a grass *Stenotaphrum dimidiatum* and from citrus blossom in Mauritius (31), from apple and black-currant blossom from Japan and Finland respectively (13, 18) and from the leaves of *Hydrangea* in Cornwall (28).

Advice has been sought regarding the identity of gall midges reared on a variety of plants including tomato, hibiscus, egg-plant, etc. in the Hawaiian Islands.

The increase in seed production has resulted in inquiries concerning midges found in grass seed (9, 15) and stored seeds (27). In New Zealand, likewise, trouble has been caused to cocksfoot grass-seed production, and this restarted an investigation into the status of the gall midges affecting the seeding of this grass in Great Britain (14). It was this which led to the interesting fact that one of the well-known meadow-foxtail grass gall midges is now breeding successfully on cocksfoot in England, Ireland and New Zealand. The individuals reared from both these grasses in the first two named countries are apparently identical on morphological evidence whereas those in New Zealand exhibit differences. From this it has been inferred that the change-over in New Zealand took place some years ago but that in Great Britain the change-over is more recent. Considerable help has been given to a survey of the gall midges of cocksfoot grass in Devon that was initiated by Seale-Hayne Agricultural College, half the samples collected being studied at Rothamsted.

The increase of the chrysanthemum midge in England has led to an intensive study being made of this species both from the biological (11, 12) and from the host-plant-range (8) points of view.

Other host-plant-range studies have included the arabis midge and the black-currant leaf midge as well as the hawthorn-stem midge (8).

The recent outbreaks of the raspberry-cane midge in the raspberry trials at Wisley led to an investigation as to whether this midge can oviposit successfully on undamaged canes, the position of healthy and parasitised larvae and the host-plant range (32).

During the war years, when inquiries from abroad fell cinsiderably in numbers, advantage was taken to get the work on *Gall Midges of Economic Importance* throughout the world nearer completion. As a result arrangements have now been completed for its publication in eight volumes. The first two, *Gall Midges of Vegetable and Root Crops* and *Gall Midges of Fodder Crops*, are due for publication in the spring of 1946.

Insect migration

The work described in the previous report has been continued and was considerably helped between 1938 and 1940 by a grant from the Leverhulme Foundation, which enabled extra clerical and scientific assistance to be employed. Progress has been made in the collection of information on a large number of British insects, particularly through the co-operation of the Insect Immigration Committee of the South-Eastern Union of Scientific Societies, who collect records of immigrant insects from amateurs throughout the country, and forward them to Rothamsted for filing and study.

From an examination of these, and from other information, reports have been published on the migrations of the Cabbage White Butterfly (*Pieris brassicae*) (53, 69 and 78), the Silver Y Moth (*Plusia gamma*) (52, 48 and 90), and the Silver Striped Hawk Moth (*Celerio lineata* (5). The two former of these are pests in Britain and the latter a pest of vines in the south of France and only a rarity in this country. A race of the Silver Striped Hawk Moth occurs in North America, and by a comparison of the dates of outbreaks of the two races it has been shown (51) that there is a statistically significant tendency for the outbreaks to occur simultaneously on both sides of the Atlantic. After this had been established, a similar investigation was made in the case of the Painted Lady Butterfly (*Vanessa cardui*), and a similar result was obtained (78).

Records continue to come in from all over the world, and these have been summarised in a series of papers for India (68), Africa (70), America (67, 64 and 70) and Australia and Asia (73). Observations on migration made and collected during C. B. Williams's visit to South America have also been published separately (91 and in the Press).

In co-operation with Miss M. E. Gibbs and Mr. J. A. Downes, a series of " Studies in the Migration of Lepidoptera " was published in 1942 (78) summarising most of the work of the last ten years and including several new types of investigation, including a statistical study of the years of occurrence of 35 species of British migrating Lepidoptera in Great Britain in the last sixty years. It was found that there was a distinct tendency for the species to be associated in groups. The species within one group tend to occur in numbers in the same years together, but species in other groups tend to be rare in those years.

There was also included in the report a discussion on the sense of orientation of insects during migration : the evolutionary aspect of the question of the return flight : the possibility of marking insects to trace their movements : and a very full account of the occurrence in England of the Monarch Butterfly (*Danaus plexippus*).

Recently a short investigation was made on the food reserve of migrant insects in the form of stored fat (90). A large number of Silver Y Moths was caught in a searchlight, apparently during a migration, and a number of these were dried and weighed individually before and after extracting with ether. The results show the amount of fat stored in the body, and also the variation from one individual to another.

Aleurodidea (white flies)

An investigation was made during the years 1936-38 on the British species of Aleurodidea, some of which, especially the greenhouse white-fly and the cabbage white-fly, are of considerable economic importance. Two papers (62 and 63) give the results of this work.

In the former, two new species found in greenhouses at Kew are described, and the second deals particularly with certain British native species which are closely related to each other and difficult to distinguish. In some cases distinguishing features were found, but in others they were believed to be only one species on several food plants.

A list of seventeen British species is given, of which thirteen were studied. Keys for the identification of these last were given, and observations on parasitism, in the field and experimentally in the laboratory, were also discussed.

Miscellaneous

The life history of the oil or blister beetle, *Meloe proscarabaeus L.*, has been studied (58) following its appearance in sufficient numbers to annoy lady golfers.

A bulletin was prepared for the Imperial Bureau of Pastures and Forage Crops, Aberystwyth, entitled " Insect and other pests injurious to the production of seed in herbage and forage crops " (4).

PUBLICATIONS

1. ANON. 1943. *Slugs*. Mon. Sci. News, June.

2. ANON. 1944. *Do you know your slugs ?* The Countryman, **30**, 58-59. Popular account of slug investigations going on at Rothamsted.

3. BARNES, H. F. 1937. *Check list of Cecidomyidae of Oceania*. Occasional Papers of Bernice P. Bishop Museum, Honolulu, **13**, 61-66.

The gall midges recorded from the area bounded by Hawaii on the north, by the Bonin, Bismark and Trobriand Islands on the west, by New Caledonia and Rapa on the south, and by Easter Island and Galapagos on the east.

4. BARNES, H. F. 1937. *Insects and other pests injurious to the production of seed in herbage and forage crops*. Imp. Bur. Past. For. Crops, Bull., **20**.

Summary of the available information in the light of the most recent research. The lack of control measures in so many instances is disturbing.

5. BARNES, H. F. 1937. *Check list of the Cecidomyidae of New Zealand*. Proc. Roy. Soc. New Zealand, **67**, 115-121.

Thirty-four species have so far been recorded, of these five have undoubtedly been introduced, namely *Dasyneura alopecuri* (Reuter) and *Stenodiplosis geniculati* (Reuter), two of the meadow foxtail grass midges ; *Dasyneura pyri* (Bouché), the leaf-curling pear midge ; *Mayetiola destructor* (Say), the Hessian fly ; and *Contarinia tritici* (Kirby), one of the wheat-blossom midges.

6. BARNES, H. F. 1939. *A new gall midge attacking beech buds*. Arb. phys. angew. Ent. Berlin-Dahlem, **6** (**1**), 41-43.

Description of *Dasyneura fagicola* found in Germany attacking beech buds.

7. BARNES, H. F. 1939. *Two new gall midges from* Sesamum angustifolium. Ann. and Mag. Nat. Hist., **3**, 453-456.

Descriptions of two new gall midges attacking the blossoms of cultivated *Sesamum angustifolium* in Tanganyika Territory.

8. BARNES, H. F. 1939. *Some gall midge species and their host plant range*. Ann. App. Biol., **26**, 318-347.

Emphasis is laid on the need for using biological in addition to morphological characters, in the separation of closely allied species of gall midges. An analysis is given of the recorded host plant range of species of the genus *Asphondylia*, showing that the great majority of species, 103 out of 133, are recorded from only one species of plant.

Four studies concerning gall midges of economic importance are presented in support of the plea for more intensive biological studies. The first deals with three supposed species which make terminal leaf galls on various species of Arabis. As a result of study it is concluded that only one true species causes the damage. The species is *Dasyneura alpestris* (Kieffer) de Meijere, while *D. schneideri* Rübsaamen and *D. arabis* Barnes are synonyms. The midge involved attacks certain species of the subgenus *Euarabis* and one other species which may belong to the subgenus *Lomaspora*.

The second study deals with the chrysanthemum gall midge, *Diarthronomyia* sp. Its distribution on commercial chrysanthemums is traced from its initial record as a pest in the United States of America and Canada in 1915. It appeared in England in 1927 and again in 1936, on both occasions the infestation being traceable to chrysanthemum varieties imported from the U.S.A. More recently it has appeared in Denmark (1934), in Sweden (1935), in Finland (1936) and in Northern Ireland (1937). Experiments on the host plant range are described. Oviposition only took place on nearly all the *Chrysanthemum* spp. subjected to trial. Galls were formed on *C. Parthenium*, but no adults developed. The midge was bred successfully only on commercial varieties of autumn chrysanthemums, *C. indicum* L., *C. rubellum* Sealy, *C. indicum* var. *azaleoides* (*C. azaleanum* Hort.) and *C.* Korean Apollo. In addition, eggs were laid on such plants as *Matricaria inodora*, *Anthemis nobilis*, *A. Cotula*, *Achillea Millefolium* and *Senecio vulgaris* : in these cases no galls were formed. The conclusion is reached that the midge of commercial chrysanthemums should be regarded as distinct and separate from *Diarthrinomyia hypogaea* F.Lw. of wild *Chrysanthemum* spp. recorded from Central Europe.

The third study involves three species of the genus Dasyneura whose larvae cause the leaves of *Rubus* spp., *Ribes nigrum* and *R. Grossularia* to become twisted and crinkled. Attempts to induce *Dasyneura tetensi* Rübsaamen of black currant to attack gooseberry always failed. *D. tetensi* would not mate with *D. plicatrix* H.Lw. of blackberry. In spite of two records in the literature of *D. tetensi* attacking gooseberry, the conclusion is reached that the three species are genuine species—*D. tetensi* Rübsaamen confining its attention to black currant, *D. ribicola* Kieffer limiting itself to gooseberry, and *D. plicatrix* H.Lw. only attacking species of Rubus.

The fourth study describes the biology of the newly discovered hawthorn stem midge and compares its bionomics with those of the red bud borer (*Thomasiniana oculiperda* Rübsaamen) and the raspberry cane midge (*T. theobaldi* Barnes). It is concluded that the three midges are distinct species and a description is added of the hawthorn stem midge to which the name *Thomasiniana crataegi* sp. n. is given.

9. Barnes, H. F. 1939. *Grass-seed* Dasyneura *gall midges together with the descriptions of two new species.* Arb. phys. angew. Ent. Berlin-Dahlem, **6** (**2**), 171-175.

Including descriptions of two new gall midges, *Dasyneura festucae* whose larvae prevent seed formation in creeping red fescue in England, and *Dasyneura triseti* whose larvae prevent seed formation in golden oat-grass in the Austrian Alps.

10. Barnes, H. F. 1939. *Gall midges (Cecidomyidae) associated with coffee.* Rev. Zool. Bot. Afr. **32,** 324-336.

A résumé of what is known concerning gall midges associated with coffee in Tanganyika Territory, the Belgian Congo, Uganda, Madagascar and the Seychelles. The paper includes descriptions of two new species whose larvae live in the flowers, one new species whose larvae feed on coffee rust, and two new species whose larvae are predacious on coccids attacking coffee.

11. Barnes, H. F. 1939. *The chrysanthemum midge.* J. Royal Hort. Soc. **64,** 503-506.

A popular account of the host plant range and life history of the chrysanthemum midge in England.

12. Barnes, H. F. 1940. *The biology of the chrysanthemum midge in England.* Ann. App. Biol., **27,** 71-91.

The life history of the chrysanthemum midge has been worked out at Harpenden, England both under laboratory and unheated glass-house conditions. Important points have been emphasised in §7.

The midge breeds continuously throughout the year, the generations following each other more rapidly as the hottest weather approaches. Under unheated glasshouse conditions five generations occurred between March, 1938 and March, 1939. Considerable overlapping takes place. There was no evidence of hibernation or aestivation. Emergence has been observed when there was frost on the plants, but the threshold temperature for mating and egg-laying appears to be slightly above freezing-point. No ceiling temperature or upper limit for breeding was encountered. Field notes have shown that the midge behaves in commercial nurseries in much the same way as in the experiments conducted in the unheated glasshouse throughout the year.

For total eradication it is shown that fumigation and spraying are not economical. Dipping the cuttings in nicotine-soft soap solution greatly reduces the numbers of developing midges. The most hopeful method of eradicating the pest seems to be cutting down the entire plant, then isolating the cut down stools and, subsequently using the new growth for cuttings.

13. Barnes, H. F. 1940. *Two new pests of apple and black currant.* Bull. Ent. Res. **31,** 85-87.

Includes a description of *Dasyneura ribis*, sp. n. whose larvae attack black-currant flowers in Finland.

14. BARNES, H. F. 1940. *The gall midges attacking the seed-heads of cocksfoot,* Dactylis glomerata, *L.* Bull. Ent. Res., **31**, 111-119.

An account is given of four gall midges whose larvae damage the seed of cocksfoot, viz., *Contarinia dactylidis* (H. Lw.), *Dasyneura dactylidis,* Metcalfe, *Sitodiplosis dactylidis* which is described from England and Ireland in the present paper, and *Stenodiplosis geniculati* (Reuter). The occurrence of predacious midges of the genus *Lestodiplosis* is also noted. A short section is devoted to characters by which these midges can be distinguished.

Stenodiplosis geniculati is recorded from one English and two Irish localities on cocksfoot grass for the first time, hitherto it has always been recorded from foxtail. These midges, together with some experimentally bred on cocksfoot from foxtail parents, exhibit the typical characters of this species.

A new variety, *Stenodiplosis geniculati* var, *dactylidis,* is described from cocksfoot in New Zealand.

In a discussion of the host-plant specificity of gall midges attacking grass seeds, it is suggested that the present discovery of *S. geniculati* on cocksfoot in England and Ireland and the occurrence in New Zealand of this new variety exhibiting distinct morphological characters are two steps in the evolution of a new species.

15. BARNES, H. F. 1940. *Gall midges and grass seed production.* J. Board Greenkeep. Res. **6**, 118.

A popular résumé of gall midges preventing grass seed production.

16. BARNES, H. F. and WEIL, J. W. 1940. *Meta slug control : experiments on possible substitutes for bran.* Gardeners' Chron., **108**, 20.

Experiments to discover a wartime substitute for bran for the control of slugs by the metaldehyde-bran method, show that with one exception, all the substances which have been shown to be as good or better than bran, are foodstuffs. The exception is tea leaves. Another fact which is apparent is that the metaldehyde is not the main attractant and the success of the treatment does depend on the choice of substances used with it.

17. BARNES, H. F. 1940. *Studies in fluctuations in insect populations.* VII. *The buttontop midge* (Rhabdophaga heterobia) *at Syston,* 1934-39. J. Anim. Ecol., **9**, 202-214.

This study of the gall midge *Rhabdophaga heterobia* H.Lw. is a continuation of the third study in the series, which covered the years 1928-33, and the data for the years 1934-9 are given. In addition, the results of the whole twelve years 1928-39 are reviewed.

The changes in the total insect population (midge and parasites) have been discussed. Birds are shown to play an important role in reducing the total population during the winter months. The drop in 1930 was probably caused by a drought in the late summer of 1929. The hot summers of 1933 and 1934, acting through the plant growth, caused similar reductions in 1934 and 1935. Since 1936 the population has steadily fallen because the willows have been allowed to go out of cultivation and become exterminated as a result of grazing.

A positive correlation has been found to exist between the numbers of midges and parasites, but there is no correlation between the size of the total population (midges and parasites) and the percentage parasitism. The changes from year to year in the numbers of the total population and in those of the parasites are almost identical. It is concluded that relative parasitism as high as 64 per cent. exerts no control on the number of midges and also that the parasites do not become more efficient at high population levels than at low ones and so cannot have any balancing effect.

The readiness of the midge and its parasites to emerge in response to extra warmth given in March has been demonstrated. Under normal conditions dates of first emergence have varied from 13 April to 16 May in the case of the midge, but the variation is less when the weeks of maximum emergences are considered. The emergence of the parasites usually follows closely that of the midge, but in some years the weather appears to act differentially on the midge and its parasites as regards the dates of emergence.

18. BARNES, H. F. 1939. Contarinia mali *sp. n. the apple blossom midge, with notes on the more common gall midges attacking apple and pear.* Kontyu **7, 13** (June, 1939), Ent. Soc. of Nippon, 126-132.

Includes description of a new gall midge attacking apple blossom in Japan. The larvae prevent the flower buds from opening.

19. BARNES, H. F. 1941. *Sampling for leatherjackets with orthodichlorobenzene emulsion.* Ann. Appl. Biol., **28**, 23-28.

The orthodichlorobenzene method is satisfactory for estimating rapidly the numbers of leatherjackets present early in the year, providing it is used on suitable days, i.e., damp rather than dry ones, warm rather than frosty ones. About 80 per cent. of the leatherjacket population is obtained. It is unreliable later in the season when the leatherjackets are approaching their fully fed stage. For one reason the leatherjackets appear to become immune to orthodichlorobenzene, and, secondly, at this period a definite movement away from the original feeding site appears to take place. The dates when the treatment becomes ineffective vary from year to year. Generally speaking it is effective till the end of March, but it may be used some years throughout April with good results.

20. BARNES, H. F. 1941. *Studies of fluctuations in insect populations. VIII. The wheat blossom midges on Broadbalk, 1932-40, with a discussion of the results obtained, 1927-40.* J. Anim. Ecol., **10**, 94-120.

This is the continuation of the investigation started in 1927 of the wheat blossom midges, *Contarinia tritici* Kirby and *Sitodiplosis mosellana* Gehin, as they occur in the field of permanent wheat (Broadbalk) at Rothamsted Experimental Station.

Data are given for the years 1932-40 relating to their biology, viz., emergence, number of larvae per infested grain, larvae overwintering more than one winter and alternative host plants, as well as to the degree of infestation of the wheat and the relative parasitism of the midges.

The results of the whole fourteen years' continuous study are considered. The date of emergence is correlated with the wheat-ear emergence, and it appears that both are correlated with the harvesting dates. Thus knowing the dates of either the midge's emergence or the wheat-ear emergence, one can apparently predict in June the date of harvest.

There seem to be cycles (about five years) of abundance of *C. tritici* and *S. mosellana*, either considered separately or together. Years in which there are high numbers of wheat midge larvae are followed by years of high relative parasitism, and years of low larval number are followed by years of low relative parasitism in both species of midge. High relative parasitism accompanies low winter survival of midges and parasites, low relative parasitism accompanies high winter survival.

The percentage grain attack is negatively correlated with the yield of wheat. If there is no adequate compensation in the wheat ear that has been attacked between the time of the attack and harvest, then the midges must be considered as pests. If on the other hand there is compensation, the numbers of midge larvae can only be regarded as an indication of the size of the yield, or in other words a measure of those climatic conditions during the previous months which influence the yield of wheat.

Manuring does not affect the intensity of midge attack.

The effect of one year's fallowing is to reduce the infestation by the midges, although this is somewhat masked on Broadbalk field by positional differences in infestation. One part of the field is always comparatively more heavily infested than the rest. This effect of fallowing seems to have disappeared by the third successive crop, i.e., non-rotation increases the infestation by both midges.

The effect of one year's fallowing on the number of grains of wheat is a marked increase in the first crop after the fallow. The number of grains in the second crop after fallow, while considerably less, is appreciably greater than that of the third and fourth crops.

In the years when the number of blind spikelets of wheat is high, the number of possible grains and the actual number of grains formed are low. Thus by estimating the number of blind spikelets between 5 and 16 July one can obtain an early estimate of the number of grains per ear at harvest. But unfortunately the number of grains formed per ear does not necessarily indicate the yield, since the yield would be measured by the number of ears or grains per acre and the weight per grain.

21. BARNES, H. F., and WEIL, J. W. 1941. *Slug control with metaldehyde.* Gardeners' Chron., **110**, 144.

Foodstuffs attract the slugs to the baits. Metaldehyde alone, metaldehyde with non-foodstuffs, and bran without metaldehyde are not such efficient baits as foodstuffs with metaldehyde.

Foodstuffs with metaldehyde form the most efficient slug killers, the more nutritive foodstuffs being more efficient than bran.

22. BARNES, H. F. and WEIL, J. W. 1942. *Baiting slugs using metaldehyde mixed with various substances.* Ann. Appl. Biol., **29**, 56-68.

The literature concerning mixtures of other substances with metaldehyde for use as slug baits has been briefly reviewed. An account has been given of the comparison of the numbers caught by forty-four substances and by bran in metaldehyde baits. It is shown that baits containing feeding stuffs are undoubtedly better than baits of metaldehyde alone or metaldehyde mixed with non-feeding stuffs, such as soil, sand, etc. Nutritive feeding stuffs, such as cakes and meals, are better as a group than roughage feeding stuffs, such as bran. The efficiency of metaldehyde baits is discussed. The range of effectiveness of the baits, the proportion of slugs visiting the baits dying, the speed of annihilation of a slug population, the most economical strength of metaldehyde to use, as well as the mixing of the baits and their distribution, are points which need further investigation. Meanwhile, it is suggested that it is worth while using small quantities of a feeding stuff in order to save much larger quantities of crops which are themselves feeding stuffs. A large slug population can be greatly reduced by a single application of metaldehyde plus a feeding stuff and can be subsequently prevented, by the use of metaldehyde and an inert or non-feeding stuff diluent, from reaching undue proportions again.

23. BARNES, H. F. 1942. *Studies of fluctuations in insect populations : IX. the carrot-fly* (Psila rosae) *in 1936-41.* J. Anim. Ecol., **2**, 69-81.

This is the ninth paper dealing with fluctuations in insect populations collected in the field and studied in an out-door unheated insectary. The previous eight papers have dealt with various species of gall midges.

A satisfactory method of assessing the yearly abundance of the carrot-fly and its parasites is described. Data are given for the years 1936-41.

The dates of emergence of the adult flies for the same period are also given.

The preparation of standard tables for the dates of hatching, emergence, etc., of insect pests is discussed briefly. For this purpose the setting up of an insect phenological station is suggested. The function of such a station would be to provide local growers, through their advisers, with information as to the earliness or lateness of the season.

24. BARNES, H. F. 1942. *Unusual abundance of* Notolophus (Orgyia) antiqua *L.* (*Lep., Lymantriidae*). Ent. Mon. Mag., **78**, 240.

An estimate showed that there was a quarter of a million larvae of the Vapourer moth on the eastern half of the perimeter of a circular patch roughly fifty yards in diameter of Bilberry on the mountains behind Penmaenmawr, North Wales.

25. BARNES, H. F. 1942. *A further note on the unusual abundance of Orgyia antiqua L.* (*Lep. Lymantriidae*). Ent. Mon. Mag., **79**, 47.

A Braconid parasite *Rhogas geniculator* Nees and two species of parasitic Tachinid flies were emerged from the larvae of the Vapourer moth. The final figures of the emergence were 95 per cent. Vapourer moth, 4 per cent. Tachinidae, and 1 per cent. Braconidae.

26. BARNES, H. F. 1943. *Studies of fluctuations in insect populations.* X. *Prolonged larval life and delayed subsequent emergence of the adult gall midge.* J. Anim. Ecol., **12**, 137-8.

The emergence of *Contarinia tritici* adults can occur in the autumn of the same year as the larvae attack the wheat, during the next spring and after a lapse of two winters. Its parasites generally emerge after the first winter but have been known not to emerge until after the second.

The emergence of *Sitodiplosis mosellana* takes place up to four years after the larvae have attacked the wheat, but not later in the same year. Its parasites can survive two winters in the soil.

The effect of this variability in the duration of the larval stage in preserving the race and as a cause of sudden increases in numbers is pointed out.

27. BARNES, H. F. 1944. *Gall midge larvae among stored seeds.* J. Roy. Hort. Soc., **69**, 242-243.

A note pointing out that gall midge larvae found among stored seeds are usually non-injurious. The injurious gall midges leave the seed heads of plants, usually before the seed is harvested. Those found in stored seeds are inquilines or else are predacious feeding on mites.

28. BARNES, H. F. 1944. Clinodiplosis hydrangeae *sp. n.* (*Cecidomyidae*) *causing a leaf blister gall on* Hydrangea hortensis. Entom., **77**, 129-130.

Description of a new gall midge *Clinodiplosis hydrangeae* whose larvae cause blister galls on the leaves of *Hydrangea hortensis* in Cornwall.

29. BARNES, H. F. 1944. *Discussion on slugs.* I. *Introduction. Seasonal activity of slugs.* Ann. Appl. Biol., **31**, 160-163.

A description of a sampling method involving the collection of slugs at night with an electric torch by means of which the seasonal activity of slugs can be accurately determined.

30. BARNES, H. F. and WEIL, J. W. 1944. *Studies of fluctuations in insect populations.* XI. *The interrelationship of the wheat blossom midges and their host plant.* Ann. Appl. Biol., **31**, 231-234.

The date of wheat blossom midge emergence in an insectary some distance away from the growing wheat can give as reliable an estimate of the forwardness of the crop as field observation of the date of ear emergence. The percentage grain attacked by the wheat blossom midges, which can be assessed by routine workers without any special experience of wheat, can give in early July a useful first estimate of the crop yield.

31. BARNES, H. F. 1944. *Two new gall midges from Mauritius.* Bull. Ent. Res., **35**, 211-213.

Descriptions of two new gall midges, *Stenodiplosis stenotaphri* and *Contarinia citri*, whose larvae respectively prevent seed formation in the grass *Stenotaphrum dimidiatum*, and the normal opening of *Citrus* blossoms in Mauritius.

32. BARNES, H. F. 1944. *Investigations on the raspberry cane midge 1943-44.* Journ. Roy. Hort. Scc., **69**, 370-375.

The raspberry cane midge prefers to lay its eggs on undamaged raspberry canes. Those larvae which are found on raspberry canes during the winter are parasitised, whereas the healthy larvae spend the winter on the soil. Experiments on the host plant range of this midge showed that it would breed successfully on raspberry, giant himalayan blackberry and loganberry. On one occasion, two individuals were bred successfully on wild rose. On the other hand, oviposition took place on wild and American cut leaf blackberry, cultivated rose, apple, hawthorn, plum and quince, but on these plants no G_1 adults were reared. Oviposition did not take place on cherry, black and red currant, gooseberry or worcesterberry. It is considered wisest for the present to regard the raspberry cane midge as distinct from the hawthorn stem midge and the red bud borer, because outbreaks of these three midges do not occur simultaneously. For example, the latest outbreak of the raspberry cane midge was at Wisley in 1943, on raspberries, but neither the hawthorn nor the roses in the area suffered any attack from this group of midges.

33. BARNES, H. F. and WEIL, J. W. 1944. *Slugs in gardens: their numbers, activities and distribution, Part I.* J. Anim. Ecol., **13**, 140-175.

The paper gives the results of an ecological study, extending over three years in certain gardens at Harpenden, Herts, of about 100,000 slugs. It is pointed out that the straw-coloured young of *Arion ater* are quite different in appearance from the more mature individuals and may easily be thought to be a distinct species. An attempt has been made to clear up the confusion that has existed regarding the separation of the three species of *Milax*, viz., *gagates*, *gracilis* and *sowerbyi*.

The present investigations concern nine species—*Arion ater*, *A. circumscriptus*, *A. hortensis*, *A. subfuscus*, *Milax gracilis*, *M. sowerbyi*, *Agriolimax reticulatus*, *Limax maximus* and *L. flavus*. Notes are given on the characters used by the authors in distinguishing these species. A key is appended for the separation of fifteen out of the twenty or more species which have been recorded in the British Isles.

The areas used have been about fifty gardens chiefly in the Moreton End district of Harpenden. While one garden has been the main scene of the investigations, six others have been visited throughout the year and others at less frequent intervals.

The method employed has been the collection of slugs seen with the aid of an electric torch chiefly on what have been thought to be favourable nights for slug activity, warm, moist, still nights being considered the ideal. The unit sample has been the slugs able to be picked up without searching during a thirty minute walk round the area under immediate consideration. The method and its applications are fully described.

Some idea of the abundance of the slugs that are active after dark in quite ordinary suburban gardens may be gathered from the fact that 30,626 have been collected in 170 half-hour periods during 1942 and 38,416 in 181 half-hours in 1943 without the use of any baits, just by walking round the gardens with an electric torch. This gives an average for the two years of nearly 200 per half-hour. It should be remembered that the fifty or so gardens have not been chosen because they have been suspected of harbouring an unusual number of these animals. When considering the average number per half-hour one must also recall that the collecting has been done on what were judged to be favourable nights for activity and throughout the year. In the garden, roughly one-fifth of an acre in area, that has been sampled most frequently (100 times) the average per half-hour is nearly 276 ; in another garden, one about half this size, that has been sampled twenty-three times at all times of the year, the average is 296. The largest number ever picked up in any garden during half an hour has been 570 and another half-hour's collection made in the same garden over the same route after an interval of only half an hour yielded an additional 517.

Three species—*Arion hortensis, Agriolimax reticulatus* and *Milax gracilis*—have been virtually in every garden, although some of them have been visited only once. The average numbers of these picked up per half-hour during the two years are respectively about 60, 50 and 40, the 1942 and 1943 totals being roughly 10,000, 11,000 ; 9,000, 9,000 ; and 5,000, 9,000. The largest numbers of these three species collected in a single half-hour are 315, 165 and 371.

Three other species—*Arion subfuscus, Milax sowerbyi* and *Arion ater*—have occurred sufficiently abundantly to enable 100 or more of them to be picked up in a single half-hour. The yearly totals of these species have been roughly 3,000, 4,000 ; 1,000, 2,000 ; and 1,000, 1,000. The remaining three species—*Arion circumscriptus, Limax maximus* and *L. flavus*—have been much less common, the totals for the two years being only 245, 222 and 10.

The section ends with a short discussion on the use of the word " abundance " and the possibility of assessing changes in population by this collecting method of sampling active slugs.

The total number of slugs active after dark on nights suitable for activity has not varied greatly throughout the year and large numbers have been found at all times of the year whenever the weather conditions have been favourable. But it is shown that each species has its own well-defined rhythm in numbers to be found active. These pulsations occur annually and in every garden with remarkable regularity whether there be large or small numbers of the species present. There have been slight variations in date according to the " earliness " or " lateness " of the year and the " aspect " of the particular garden.

The species do not reach their peak numbers at the same time of the year. Most *Arion ater* have been found active in January ; most *A. subfuscus* in June; *Agriolimax reticulatus* has reached its maximum numbers in June (during 1943 an " early " year) and August-September which is probably more normal ; *Milax sowerbyi* between August and October ; *M. gracilis* in October chiefly, but equally large numbers have been collected even as late in the year as December ; and *Arion hortensis* between October and December, closely associated with *gracilis* but, on the whole, inclined to reach its peak numbers later in the year.

In the discussion various points are briefly mentioned, including the night-to-night fluctuations in numbers of the various species, the fact that the peaks of numbers active coincide with the peaks of the largest sized individuals, except in the case of *Arion ater*, and the relation between the numbers found active and the basic populations.

34. BARNES, H. F. and WEIL, J. W. 1945. *Slugs in gardens; their numbers, activities and distribution, Part II.* J. Anim. Ecol., **14**, 71-105, three coloured plates.

Observations of slugs feeding in gardens indicate that very little of their food consists of plant material grown for human consumption or pleasure. In places where one crop only is grown, e.g., potato patches in the autumn, the damage would be higher owing to the absence of alternative food.

Mating of *Agriolimax reticulatus* and *Arion subfuscus* takes place out in the open on the surface of the ground after dark, the peaks being soon after the peaks of seasonal activity; the former species also mates to some extent throughout the year, whereas in the latter species mating is restricted to July-October. *A. hortensis* and *ater* usually require some shelter, e.g., dead leaves, under which to mate, while it is presumed the *Milax* species usually mate underground or under cover.

By weighing the slugs, species by species en masse as collected and then calculating the weight per 100 individuals, regular changes in weight throughout the year have been found. This method has been found to be as satisfactory for assessing seasonal changes in weight as the half-hour method of collecting slugs is for measuring seasonal changes in activity numbers. The slugs are heaviest soon after the greatest numbers are found active and at the time when the peak of mating occurs.

The distribution of the species varies from garden to garden. *A. hortensis* and *M. gracilis* are most abundant in the gardens at the bottom of an old river bed slope and decrease steadily until their lowest numbers occur half-way up it. *M. sowerbyi* has a ridge of abundance across the slope. *A. subfuscus* is almost completely absent on the east side of the valley. Two particular gardens form foci of abundance of *L. maximus* and *A. ater* is more abundant in gardens of recent origin in close proximity to coarse grass areas than in old well-established gardens. These distributions have persisted month by month throughout two years.

There is some evidence that each species has its own regular curve of nightly activity, providing of course weather conditions are suitable. In the summer, activity appears to be more closely adjusted to the time of sunset than in the winter. Immature specimens of *A. hortensis* preponderated in steadily decreasing numbers in twilight collections made from May to December.

All species are fully active at about 40°F., but some activity continues until almost freezing point; below this there is no activity. Some species, e.g., *Milax gracilis*, resume activity after cold spells later than others, e.g., *Agriolimax reticulatus*, perhaps owing to their deeper penetration of the soil.

Lack of surface moisture seems to be one of the factors limiting activity. Slug activity in rainless periods is reduced more at some periods of the year than at others. Rainless periods in the spring have less effect on limiting activity than summer droughts. This is probably due to the different water contents of the soil at these seasons. Activity is reduced while heavy rain is actually falling and also in heavy wind.

The optimum conditions for slug activity may be summarised thus: a warm still night with plenty of surface moisture either in the shape of recent rain or dew.

35. BAWEJA, K. D. 1937. *The calculation of soil population figures.* J. Anim. Ecol., **6**, 366-367.

By using a sample 3 in. by 4 in. surface dimensions, the population in millions per acre can be calculated from the formula:

$$\frac{x}{2} + \frac{(x-20)}{40}$$

where x = number of organisms per sample.

36. BAWEJA, K. D. 1939. *Studies of the soil fauna, with special reference to the recolonisation of sterilised soil.* J. Anim. Ecol., **8**, 120-161.

The prominent components of the soil fauna were (of insects) Collembola, Diptera, Coleoptera, Hemiptera and to some extent Hymenoptera and (of other invertebrates) Myriopoda, Arachnida and Oligochaeta. The mean population during an experiment in the control plots varied from 61·2 to 67·6 million and in the sterilised plots from 98·3 to 111·8 million per acre. An analysis of the individual orders and immature forms is included.

The relative proportion of the insects to other invertebrates was considerably affected in the area, viz., from 2 : 1 in the controls to 20 : 1 in one of the sterilised plots. Some of the predominating forms like Onychiuridae, *Anommatus 12-striatus*, *Harpalus* sp., etc., failed to maintain their dominance in the sterilised plots, while some rare ones such as Hypogastruridae, Aphididae, *Amischa analis*, *Agriotes* sp., etc., increased enormously, a striking instance being that of Aphididae which increased 43·6 times over the control.

Distinct fluctuations were another feature of the populations. The peak period in the density of their population occurred in late autumn or early winter in the controls and the first set of the sterilised plots. This was caused by the sudden increase of Collembola which was soon followed by an equally sharp decline.

The economic aspects of sterilisation inside glasshouses and of the baked soils in the tropics are discussed from an entomological point of view. Since both are subjected to heavy infestation of soil organisms, the desirability of further investigation is suggested.

A study of the subsoil population showed that a few organisms existed down to a depth of 33 in. Their percentage density varied between 80 and 91 in the top 9 in., being higher in spring than in winter. The reverse phenomenon occurred in deeper layers.

37. Deal, J. 1941. *The temperature preferendum of certain insects.* J. Anim. Ecol., **10**, 323-356.

A description is given of three different types of apparatus experimented with before selecting a linear brass gradient which gave a range of temperature from 10°C. to 35°C. in a straight line gradient. This allowed the insects a choice of about 1°C. in every 4 cm. The relative humidity in such an apparatus varied inversely with the temperature except where food was used, when it remained practically uniform.

The temperature preferendum was tested of twenty-three species of insects from six orders. Insects were chosen to represent different environments or habitats, such as the following : stored product insects, leaf-feeding insects, plant-sucking insects, human parasites, insect parasites and soil insects.

At the cold end of the gradient the metabolic activities of the insects were slowed down to such an extent that many of the species were trapped there, thus giving an apparent preference for the colder end. As a result when insects went to a warmer zone it was considered more significant than when they went to a cold zone.

Insects that were given food in the gradient had a narrower preference zone than when not given food.

In general the preferences of the immature forms tended to coincide with those of the adults of the same species.

With saw-flies (*Pteronides melanaspis*) the males tended to have a wider temperature range than did the females.

The Braconid parasites (*Apanteles congestus*) went to a lower temperature on each successive day they were in the gradient and at the end of three days were alive and quite active. At the same time a surplus stock kept at room temperature were all dead at the end of 1½ days.

38. Evans, A. C. 1938. *Studies in the distribution of nitrogen in insects*, I. Proc. Roy. Ent. Soc. A., **13**, 25-29.

The distribution of nitrogen in the castes of the wasp at various stages of development is discussed. In the adult most of the nitrogen is present in the skeletal and soluble protein fractions, in prepupae little is found in the skeleton, but over 60 per cent. is in the form of soluble protein. Just-emerged wasps probably contain a reserve protein, insoluble in water, which is utilised to complete the hardening of the skeleton.

39. Evans, A. C. 1938. *The effect of the chemical composition of the plant on reproduction and production of winged forms in* Brevicoryne brassicae *L. (Aphididae).* Ann. Appl. Biol., **25**, 558-572.

It is shown that under late summer conditions of light the rate of reproduction of the aphis, *Brevicoryne brassicae*, is positively correlated with the nitrogen content of the host plant and, in particular, with the protein content. The formation of winged forms is negatively correlated with the same factors.

The chemical composition of the plant affects the rate of growth, length of larval period and final pupal weights of *Pieris brassicae*. It also influences the amount of food eaten.

40. Evans, A. C. 1938. *A note on the estimation and some properties of insect cuticle.* Proc. Roy. Ent. Soc. A., **13**, 107-110.

It is shown that the cuticle of the mealworm *Tenebrio molitor L.* contains about 60 per cent. protein, which is easily soluble in water, dilute acids and alkalis. The hypothesis is put forward that, in this insect, the material absorbed from the cuticle at the last moult may eventually be utilised to form the major part of the adult cuticle.

41. Evans, A. C. 1939. *The utilisation of food by the larvae of the Buff-tip,* Phalera bucephala (*Linn.*) (*Lepidopt.*) Proc. Roy. Ent. Soc. A., **14**, 25-30.

An accurate method is described for determining in a caterpillar the amount of excreta derived from a given amount of food. Analysis of food and excreta show that about 60 per cent. of the protein, 80 per cent. of the soluble sugars, 60 per cent. of the fat and 35 per cent. of the ash are utilised. Polysaccharides are not utilised. Nitrogen is excreted as ammonia and uric acid.

42. Evans, A. C. 1939. *The utilisation of food by certain Lepidopterous larvae.* Trans. Roy. Ent. Soc. A., **89**, 13-22.

The food relationships of the larvae of *Phalera bucephala, Aglais urticae, Smerinthus populi, Malacosoma neustria* and *Pieris brassicae* have been studied.

The co-efficient of utilisation of food falls steadily during the first and second instars of *P. bucephala;* during the third, fourth and fifth instars it fluctuates irregularly. The consumption, utilisation and metabolism of food per gramme of larva per day follows a similar course. The co-efficient of growth increases until the middle of the third instar and then fluctuates irregularly. About 90 per cent. of the water contained in the food is extracted during the first four days of larval life.

The larvae of the species studied utilise and consume food at very different rates. The amounts of carbohydrate, fat and ash utilised per gramme of larva, per day differ very much in the four species.

The nutritive ratio of the larvae is very much lower than that of certain growing mammals, i.e., cattle, sheep and pigs, and the difference seems to be correlated with the chemical composition of the tissues.

43. Evans, A. C. and Goodliffe, E. R. 1939. *The utilisation of food by the larva of the mealworm* Tenebrio molitor *L.* (*Coleopt.*) Proc. Roy. Ent. Soc. A., **14**, 57-62.

The larva of *T. molitor* utilises nearly half of the food which it consumes. Gliadin, glutenin and K_2SO_4 soluble proteins are utilised. About 60 per cent. of the total protein consumed is utilised and about one half of this retained. Mono, di- and poly-saccharides are utilised to different extents. Fatty acids are utilised to a greater extent than unsaponifiable matter. Only a small proportion of the ash is used. About 93 per cent. of the substances utilised have been accounted for.

The larva does not utilise as much of the bran as do ruminants. The nutritive ratio of bran for *T. molitor* is similar to that for ruminants, but is very different from that determined for various lepidopterous caterpillars fed on leaves.

The water content of the larva is maintained above that of its food since the larva retains metabolic water produced from the oxidation of carbohydrates utilised from the food.

44. Evans, A. C. 1941. *A preliminary study of the effects of aphides on the chemical composition of cabbage and field beans.* Ann. Appl. Biol., **28**, 368-371.

Infestation of cabbage by the aphis *Brevicoryne brassicae*, caused a marked decrease in the amount of carbohydrate synthesised but smaller decreases in fat, crude protein and other constituents. Infestation of field beans by the aphis *Aphis fabae* did not have any great effect on the chemical composition of the crop.

45. EVANS, A. C. and GOUGH, H. C. 1942. *Observations on some factors influencing growth in wireworms of the genus* Agriotes *Esch.* Ann. Appl. Biol., **29**, 168-175.

A technique has been worked out for rearing wireworms which permits detailed studies of individuals in relation to food, soil moisture, and other factors. As the wireworm increases in size the moulting process becomes more elaborate. A large portion of the life of the wireworm is spent in non-feeding phases. Newly hatched and half-grown wireworms do not utilise decaying organic matter in the soil. The type of vegetable food on which the wireworm feeds influences its rate of growth.

46. EVANS, A. C. 1943. *Value of the pF scale of soil moisture for expressing the soil moisture relations of wireworms.* Nature, **152**, 21-22.

The pF scale of soil moisture suitably expresses the dryness or wetness of a soil in relation to wireworms.

47. EVANS, A. C. 1944. *Observations on the biology and physiology of wireworms of the genus* Agriotes *Esch.* Ann. Appl. Biol., **31**, 235-250.

Detailed studies of the growth of wireworms kept at a constant temperature of 15°C. for three years and at natural soil temperatures for two years are presented. It is shown that small wireworms grow rapidly and moult frequently, but large wireworms grow slowly or remain constant in weight and moult infrequently. A basic pattern to account for the decreasing frequency of moulting during the life cycle is presented.

The feeding activity and moulting frequency of a population of wireworms has been studied in detail throughout the season. Definite peaks in feeding activity and moulting frequency occur during the season. A suitable method for the analysis of such activity in a population has been found by dividing the population into groups on a basis of the number of annual moults.

It is shown that increase in dry weight is a more valid estimate of growth than increase in fresh weight.

The cuticle of wireworms is permeable to water, and it is shown that in its relations to soil moisture the wireworm may be regarded as an osmotic system. The pF scale of moisture is shown to be of value in expressing the soil-moisture relations of wireworms. Wireworms feed more actively in moist soil than in dry or wet soil.

48. FISHER, Katherine (Mrs. K. Grant). 1938. *Migrations of the silver Y moth* (Plusia Gamma) *in Great Britain.* J. Anim. Ecol., **7**, 230-247.

Records of the presence and movements in Great Britain of the Moth *Plusia gamma* L. from 1932 to 1937 have been collected from amateur lepidopterists and others by the Insect Immigration Committee of the South Eastern Union of Scientific Societies. The moths have been seen in varying numbers in each of these years, and an account of their distribution in each year is given. Only two winter records have been received, although such records were specially asked for. Both these concerned pupae.

About fifty records give the direction of flight of the moths. From these it is shown that there is a general tendency for northward movements to preponderate in spring, and southward movements in autumn. Westward immigration from across the North Sea seems to occur regularly in mid-August.

A study of records in which direction and strength of wind are given show that wind direction has little or no effect on the direction of migratory flights, and that migrations can take place in adverse winds of Force 4 (13-18 m.p.h.) or in cross winds of Force 5 (19-24 m.p.h.).

Possible starting points of migration have been chosen by prolonging the line of flight backwards from the point of observation to the nearest point on the Continent, and weather conditions for the period immediately preceding the flights have been studied. There appears to be a tendency for migrations to begin in periods of rising barometer, rising or steady temperature, and light or moderate winds. Wind direction at presumed starting points seems to have no influence on the direction of migration.

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49. GOUGH, H. C. 1942. *Laboratory and field experiments on the control of wireworms.* Ann. Appl. Biol., **29**, 280-289.

In a large-scale field experiment, neither naphthalene at 15 cwt. per acre nor calcium sulphide at 350 lb. per acre applied broadcast in February and ploughed in, caused any decrease in the wireworm population. A technique for testing soil insecticides in the laboratory is described and brief notes given on results. In preliminary glasshouse experiments both naphthalene and superphosphate applied near the seed effectively reduced wireworm attack on wheat. A more elaborate experiment on barley did not give such good results.

50. GOUGH, H. C. and EVANS, A. C. 1942. *Some notes on the biology of the click beetles* Agriotes obscurus *L. and* A. sputator *L.* Ann. Appl. Biol., **29**, 275-279.

In a laboratory experiment *Agriotes obscurus* L. females laid significantly more eggs in grass, and significantly fewer eggs in a bare fallow, than in clover, wheat and kale which did not differ significantly from one another. Marked adults of *Agriotes sputator* L. were caught up to 30 yards away from their liberation point, the maximum distance that traps were placed. The ratio of *A. obscurus* to *A. sputator* adults was shown to vary from 1 to 62 to nearly 3 to 1 in nearby fields.

51. GRANT, K. J. 1937. *An historical study of the migrations of* Celerio lineata lineata *Fab. and* Celerio lineata livornica *Esp. (Lepidoptera).* Trans. Roy. Ent. Soc., **86**, 345-357.

The distribution and outbreaks of the sub-species *Celerio lineata lineata* Fab. in America, and *Celerio lineata livornica* Esp. in the Old World as far as they are known are described. It is suggested that both sub-species originate in semi-desert areas, and this idea is supported in the case of the American sub-species by showing that a correlation exists between outbreaks of moths and a certain sequence of desert rainfall. No correlation is found between European outbreaks and the rainfall of those North African meteorological stations for which records are available, but this may be due to the paucity of suitable figures. A full account is given of the occurrence of *C.l. livornica* in Great Britain, and the main European outbreaks are listed. A correlation is given to show that both years of unusual abundance and absence tend to occur simultaneously in Europe and America, and that the cause of the outbreaks must therefore be sought in some factor common to the two continents. There seems to be some correlation between outbreaks and the sunspot cycle, but the figures are barely significant. The outbreaks tend to occur away from the sunspot minima.

52. GRANT, K. J. 1937. *Some recent migrations of the silver Y moth.* J. S.E. Un. Sci. Soc., 1-8.

This is a short account of the immigration into England of *Plusia gamma*, the silver Y moth in the years 1932-36. In 1932-35 there were only small immigrations, but 1936 was one of the largest that has ever been properly recorded and details are given of the dates of arrival of the swarms and the areas in Great Britain covered by the outbreaks.

53. GRANT, K. J. 1938. *A migration of cabbage white butterflies in Hertfordshire in May,* 1937. Entomologist, **31**, 103-107.

An account of the migration of cabbage white butterflies which passed through the Harpenden district in May, 1937. It was first noticed on the 17th May, was well marked on the 24th to the 29th May, but diminished rapidly on the 30th and came to an end on the 31st. The flight was almost entirely to the north. Later in the summer, on the 29th July, there was another flight of the same species, this time chiefly to the south-west and west.

54. LADELL, W. R. S. 1938. *Field experiments on the control of wireworms.* Ann. Appl. Biol., **25**, 341-389.

This paper describes an attempt to find out whether it is possible to test chemical measures against wireworms by a field technique similar to that used in fertiliser and varietal experimentation. A full account is given of three field experiments using old grassland on a heavy " clay-with-flints " soil.

Wireworm populations were ascertained in every case by sampling the soil before and after treatment. The Ladell flotation machine was found rather too small and a modification of the technique using oil drums was adopted. Later, a larger and improved form of the machine was used.

In the first experiment six samples (9 by 9 by 5 inches) were taken in each plot, making a total of 150 soil samples on each occasion. In the second, four samples (9 by 9 by 5 inches) per plot were taken, making a total of 120 before treatment, but after treatment the size of the samples was reduced to 6 by 6 by 5 inches, the number of samples remaining as before. In the third experiment two samples (6 by 6 by 6 inches) per plot were taken, totalling 96 on each occasion.

Local control was introduced in the first two experiments. In addition preliminary experiments were carried out using potatoes and cabbage leaf as baits as a means of estimating wireworm populations. No relationship was found between the number of wireworms obtained in the baits and the actual number in the soil.

The mean density of the original wireworm population was 65, 335 and 277 per square yard respectively in the three experiments. The uneven distribution of the wireworms in the soil resulted in high sampling errors accounting for most of the experimental error. This aspect of the work is discussed fully by W. G. Cochran in the Appendix. No relation was found between the pH of the soil and the density of the wireworm population.

The untreated controls showed changes of -23, +1 and -9 per cent. between the first and second sampling respectively. The biggest drop was obtained when the second sampling was done in July and the smallest difference when the second sampling was done in May. It is suggested that the big drop in July might be due to a downward movement of the wireworms to escape the heat, but the evidence is insufficient to prove this point.

Fumigants " K " and " S " (mixtures of o- and p-dichlorbenzene) reduced the population by 69 and 62 per cent. but had an adverse effect on the crop (sugar beet) in both cases, due to insufficient interval between its application and the drilling of the seed. There was also a residual effect the following year, a reduction in the number of the wireworms and an increase in the plant stand (barley) although there was no significant increase in the final crop yield.

Chlorpicrin reduced the population by 46 and 33 per cent. but there was no harmful effect on the crops (sugar beet and barley). No residual effect was detected.

Fumigant " M " (sodium cyanide) reduced the population by 45 per cent. and increased the yield of the crop (sugar beet). The residual effect was negligible.

Crude naphthalene (" creosote salts ") reduced the population by 60 per cent. tar plus lime by 29 per cent. and ammonium carbonate by 20 per cent. on a summer fallow. Other treatments which all proved ineffective were chlordinitrobenzene, lime alone and superphosphate.

55. LYSAGHT, A. M. 1937. *An ecological study of a thrips* (Aptinothrips rufus) *and its nematode parasite* (Anguillulina aptini). J. Anim. Ecol., **6**, 169-192.

Aptinothrips rufus Gmelin is abundant on the grass plots of the classical field park grass at Rothamsted Experimental Station. Sampling has been carried out for two years on a number of plots and population counts have been made.

A. rufus is parasitised by *Anguillulina aptini* (Sharga). Some experimental work on the biology of the nematode has been carried out.

The nematode is rarely found on two of the plots and this difference in distribution was found to be constant during 1933 and 1934. There is a very rank growth of *Holcus lanatus* on these two plots and the coarseness of this growth appears to exert an unfavourable effect on the nematodes. Infected insects have been bred on a less sturdy growth of *H. lanatus* under greenhouse conditions.

An account is given of other factors which might affect the distribution of the nematode.

56. Lovibond, B. 1937. *Investigations on the control of leatherjackets : (2) Notes on craneflies and their larvae.* J. Board of Greenkeeping Research, **5**, 12-17.

Notes on the economic species, length of life of adults, egg-laying and early grub stages, as well as the frequency of number of eggs found in *T. paludosa* females caught in the light trap at Rothamsted in 1934.

57. Lovibond, B. 1937. *Investigations on the control of leatherjackets : (3) Some results of breeding and sampling experiments during the current season.* J. Board of Greenkeeping Research, **5**, 107-112.

Notes on the technique of rearing craneflies from the larval stage. Flies were reared from 47 out of 69 localities sampled. Photographs are given of the eggs of three *Tipula* species.

58. Lovibond, B. 1939. Meloe proscarabaeus *L.* J. Board of Greenkeeping Research, **6**, 42-45.

A popular account of what is known concerning the oil or blister beetle (*Meloe proscarabaeus* L.). Photographs are given showing adult bees infested with triangulin larvae, as well as photo-micrographs of the triangulin larvae.

59. Robertson, A. G. 1939. *The nocturnal activity of craneflies (Tipulinae) as indicated by captures in a light trap at Rothamsted.* J. Anim. Ecol., **8**, 300-322.

Seventeen species of craneflies of the sub-family Tipulinae were captured in a light trap in the four years 1933-36. *Tipula paludosa* accounted for about 57 per cent. of the total of nearly 3,400 individuals. Males predominated in *T. paludosa* and three other species, females predominated in *T. oleracea* and three other species. *T. paludosa* is most abundant in September, *Pales flavescens* in June. *T. oleracea* is definitely double-brooded. They are most active just after sunset, and activity is favoured by high minimum temperature and a low daily range. At the time of greatest activity of the group, a rise of about 4° F. in the minimum temperature will effect a doubling of the catch. The same result is produced by a reduction in the daily range of temperature by about 6° F. Cloud and moonlight have a distinct effect, and the optimum conditions are absence of moon and complete cloud. The converse conditions of full moon and no cloud are least favourable, and the catch is eight or nine times as large in the former as in the latter conditions.

60. Thomas, D. C. 1938. *Report on the Hemiptera-Heteroptera taken in the light trap at Rothamsted Experimental Station during the four years 1933-36.* Proc. Roy. Ent. Soc., A, **13**, 19-24.

Nearly 1,500 Hemiptera-Heteroptera were captured in the light trap and identified to species. This gives a short account of these species, their distribution throughout the night, and the sex ratios in the different species. There is also a discussion of the feeding habits of the different species according to whether they are arboreal, ground living or aquatic.

61. Thomas, D. C. 1938. *An annotated list of species of Hemiptera-heteroptera not hitherto recorded for Middlesex.* Entomologist, **31**, 148-153.

The contents of this paper are well covered by the title. Eighty-eight new species are added, bringing the county total to 242.

62. Trehan, K. N. 1938. *Two new species of Aleurodidae found on ferns in greenhouses in Britain (Hemiptera).* Proc. Roy. Ent. Soc., B **7**, Pt. 9.

The scope of this paper is covered by the title. The two new species are *Aleuroplatus kewensis* and *Trialeurodes williamsi*.

63. Trehan, K. N. 1940. *Studies on the British white-flies (Homoptera, Aleyrodidae).* Trans. Roy. Ent. Soc., **90**, 575-625.

An account of the systematics and biology of thirteen species of *Aleurodidae* (white flies) found in Great Britain, with keys for the separation of species in both pupal cases and adults. Notes are also given on parasites.

64. Williams, C. B. 1937. *The migrations of day-flying moths of the genus* Urania *in tropical America*. Proc. Roy. Ent. Soc., **12**, 141-147.

In parts of Central and the northern half of South America conspicuous day-flying moths of the genus *Urania* make very definite migrations and are frequently recorded, particularly in the neighbourhood of the Canal zone where observers frequently pass them on board ships. This paper is a summary of the information available for two species, one found chiefly in the east, Brazil, the Guianas and Trinidad, and the other ranging from southern Mexico, through Central America to Columbia and Ecuador. Maps and diagrams are given showing the geographic and seasonal distribution of the flights. There is some evidence of a return flight in parts of Central America, but the records are rather confused.

65. Williams, C. B. 1935. *British immigrant butterflies and moths*. Booklet E.57, British Museum (Natural History).

A popular account of the immigration of butterflies and moths into Great Britain, published by the Natural History Museum in London at a low price (ninepence) with five coloured plates, in order to interest the general public in the problem and to get them to send in records of migration to us for study. The first edition of 1,000 copies were printed in October, 1935 and sold out in six months, and a second edition, now out of print, was published in April, 1936. It is hoped that a third edition will be printed now that the war is over.

66. Williams, C. B. 1937. *Butterfly migrations in the tropics*. Booklet E. 58, British Museum (Natural History).

A popular account of the migration of butterflies in the tropics, published by the Natural History Museum in London with five coloured plates, with the object of interesting the general public in the subject and obtaining records from different parts of the world.

67. Williams, C. B. 1938. *Recent progress in the study of some North American migrant butterflies*. Ann. Ent. Soc. of America, **31**, 211-239.

An account of the increase in our knowledge of ten of the most important North American migrant butterflies since the summary published in C. B. Williams's "Migration of Butterflies" in 1930. Considerable information is given about the migrations of the Monarch butterfly and particularly its spring flight to the north and hibernation in Florida and California. In the case of the Painted-Lady butterfly (*Vanessa cardui*) maps are given showing the distribution of recorded abundance in four years 1924, 1926, 1931 and 1935. In the intervening years, the insect was extremely rare throughout the whole country. In the case of the Great Southern White (*Ascia monuste*) which moves on a very large scale along the Atlantic coast of Florida, there is a suggestion of a change in the direction of the movement from north to south. For fuller information on this, see publication 78.

68. Williams, C. B. 1938. *The migration of butterflies in India*. J. Bombay Nat. Hist. Soc., **40**, 439-457.

An account of what is known of the migration of butterflies in India with a map showing the distribution of the records, and a list of all the known migrant species with the records of their flights classified according to the month of the year and the duration of the flight. The majority of the records are from Southern India, Madras and Bombay, and then in the extreme north along the Himalayas. In the latter area there appears to be some evidence of a flight up the mountains in the spring, and possibly a return flight in the autumn. Just over fifty species have been recorded migrating.

69. Williams, C. B. 1938. *The migrations of the cabbage white butterfly* (Pieris brassicae). Proc. VII. Internat. Congr. Entom., **482-.493**.

A summary of the movements of cabbage white butterflies with particular reference to Central and Western Europe, but not dealing in detail with Great Britain. Maps and documents show that the recorded flights are chiefly at the end of July and the beginning of August, and throughout Germany, Austria and Western Czechoslovakia and chiefly in a southerly direction, from which it would appear that they originate somewhere in Scandinavia or the Baltic area. In an Addendum there is a record of a southerly movement in Sweden which confirms this conclusion.

70. WILLIAMS, C. B. 1939. *Records of butterfly migration in Africa (Lepidoptera)*. Proc. Roy. Ent. Soc., A. **14**, 69-74.

Twenty records of insect migration in different parts of Africa, sent in by correspondents and published to provide information on the movements of butterflies of this continent.

71. WILLIAMS, C. B. 1939. *An analysis of four years captures of insects in a light trap*. Part 1: *General survey; sex proportion; phenology; and time of flight*. Trans. Roy. Ent. Soc., **89**, 79-132.

A light trap of approximately 300 c.p. was exposed in the fields at Rothamsted Experimental Station, almost every night from March, 1933 to February, 1937. The light was about 3 feet 6 inches from the ground.

The total number of insects captured in each of the four years were: 109,344; 103,362; 399,006; and 242,822. The arithmetic mean catches per night were 310, 287, 1,102 and 728 respectively, but the geometric means, which are believed to give a better indication of comparative abundance, were 37, 53, 54, and 64. The highest catch in a single night was 73,100 on the 30th June, 1935.

On the geometric mean basis the highest average catch was in July (723 insects) and the lowest in February (4.2 insects) on an average of all four years.

Diptera constituted 86.7 per cent. of the catch. Lepidoptera 10.3 per cent. while all other insects only constituted 3 per cent. The distribution of all orders in the different months is discussed more fully.

Among the Lepidoptera 256 species of Macrolepidoptera were captured, which is just over one-third of the known British species. Several species were new to the local fauna. There was practically no evidence that the trap markedly reduced the population except possibly in one *Geometrid* moth.

A light trap on a roof at a height of 35 feet (10.6 metres) caught several species of Noctuidae which were absent or rare in the lower trap.

Seventy-four species of Heteroptera were captured, of which 57 were Capsidae. This is almost one-third of the known British species of Capsidae.

The majority of Lepidoptera come to the trap with a considerable excess of males over females, but this is not an absolute rule, and some species give an excess of females. The sex proportion in a number of species is listed

In the Tipulidae (Diptera) the sex ratio varied from species to species and even the closely related species *Tipula paludosa* and *T. oleracea* give opposite results.

In Chrysopidae and Hemerobiidae there is an excess of females and in the Heteroptera an excess of males.

Certain species of Lepidoptera are shown to vary considerably in the sex ratio from year to year and there is also slight evidence of different sex ratios in the individuals captured from different broods.

The proportion of females caught increases in many species during the course of the brood.

In the Lepidoptera there is evidence in many species that a higher proportion of females are caught before midnight than after. The same appears to be true of the Neuroptera, but in the Diptera some species show a higher and some a lower proportion before midnight.

In a trap placed on a roof at a height of 35 feet from the ground more species and individuals of Noctuidae were captured than near the ground, and the individuals included a considerably higher percentage of females. The difference was more marked in some species than in others.

When the trap was removed from the roof and placed on a tripod immediately above the ground trap, but at the same height as the roof, the numbers of individuals of Noctuidae fell very considerably, but the relatively high percentage of females in the captures remained.

It was found that in certain Noctuidae females were in a higher percentage on nights when the moths were rare and relatively much fewer when the moths were common. Also in all the species of this family there was on an average a lower proportion of females caught in the common species than in the rarer ones.

The sequence of broods in a number of species of Lepidoptera is discussed and it is shown that in general first dates were early in 1933 and late in 1935 and 1936.

There is slight evidence that the Noctuidae have a lower variability of date than the other families and also slight evidence of a seasonal change in variability.

The date of first appearances, usually taken for phenological purposes, has the advantage of convenience but is more variable than other points later in the brood, such as, for example, the date on which 25 or 50 per cent. of the total captures have appeared.

Work on the time of flight of insects at night, on which two years' data had previously been published, is reviewed in the light of two more years' work. Nearly all previous conclusions are found to hold. For all four years on a log. basis the highest catch is in period 1 and the lowest in period 7. Evidence is, however, brought forward to indicate a seasonal change of distribution.

The time of flight of a number of species of Lepidoptera is discussed and it is found that there is a tendency for the peak flights to occur in periods 2, 5 and 8 of the 8 equal periods into which the flight was divided.

In the Neuroptera, the Hemerobidae tend to fly into the trap early in the night and the Chrysopidae later.

72. WILLIAMS, C. B. 1939. *Some records of butterfly migration in America.* Proc. Roy. Ent. Soc., A, **14,** 139-144.

Details of thirteen records of the migration of Lepidoptera sent in from correspondents in North, South and Central America.

73. WILLIAMS, C. B. 1939. *Some butterfly migrations in Europe, Asia and Australia.* Proc. Roy. Ent. Soc., A, **14,** 131-137.

Details of fifteen records of migration of Lepidoptera sent in by correspondents from Europe, Asia, and one from Australia. Included in these are records of the cabbage white butterfly and silver Y moth (*Plusia gamma*).

74. WILLIAMS, C. B. 1940. *A note on the statistical analysis of sentence length as a criterion of literary style.* Biometrika, **31,** 356-361.

A resemblance is pointed out between the form of frequency distribution of the number of insects caught on different nights in a light trap and the number of words in successive sentences as written by different authors. In both cases the curve as represented by actual numbers of insects or of words is extremely skew, but when the log. of the number of words or of insects is used instead, the curve becomes normal and symmetrical. This transformation greatly facilitates comparison between different samples, and examples are given from the works of three different authors to illustrate this point. This form of curve has recently been designated the Lognormal curve.

75. WILLIAMS, C. B. 1940. *An analysis of four years captures on insects in a light trap.* Part 2: *The effect of weather conditions on insect activity, and the estimation and forecasting of changes in the insect population.* Trans. Roy. Ent. Soc., **90,** 227-306.

The analysis is based on four years captures in a light trap at Rothamsted Experimental Station. The trap was working on 1,407 nights between March, 1933 and February, 1937 and caught altogether about 850,000 insects. An account is given of the normal weather conditions of the district and also of the weather during the four trap years.

The sources of error were reduced as far as possible, and it was found necessary to deal with changes in the catch in geometrical or logarithmic proportion.

The catch is dependent chiefly on the two factors of activity and population, and, of course, only measures the positively phototropic nocturnal insects.

The analysis of the individual effect of each weather factor is made more difficult by the close correlation which exists between many of the weather factors themselves.

The first analysis was a simple comparison of the weather conditions on nights of high and low catch. On the good nights the minimum and the grass minimum temperatures of that night and the maximum temperatures of the previous day were all higher than on poor nights ; the wind was also calmer ; the moon closer to new moon than to full, and the barometer high. Rain during the previous day time is associated with low catch, but rain during the night occurs with equal frequency with high as with low catch. Relative humidity also appears to be more or less similar in both series.

A short account is then given of the statistical method of regressions and it is shown that activity is most likely to be correctly estimated by using as a basis of calculation the difference between successive days in both catch and weather conditions. The effect of minimum temperatures, considered alone, is that a change of 1° F. is associated with a change of log. catch of about 0.060 or, in other words, the catch is doubled by an increase in minimum temperature of 5°F. (or just under 3°C.). There is no evidence from the data available that this figure alters with the season, the differences found from month to month are irregular and not outside the limits of non-significant variation. Res ılts for Lepidoptera only and Hemiptera only give values which do not differ significantly from the value for total insects.

The effect of maximum temperature alone is smaller than that of minimum temperature and the average effect (over the four years) is that 1° F. change is associated with 0.042 change in log. catch, or the catch is doubled with a rise of about 7° F.

The grass minimum alone (calculated from six months results) shows a regression of 0.030. The regression on daily range of temperature (from three months) is only 0.004 which has no significance.

Relative humidity at 9 p.m. shows a small but probably significant regression of about 0.008 change in catch produced by 1 per cent. change in humidity.

Insects fly later on cloudy nights, probably owing to the slow fall in temperature. The effect of fog is uncertain ; usually it occurs on cold nights with very poor catch, but one very foggy night in September, 1933 gave high catches in the family *Noctuidae*.

The catch is lower at full moon than at new moon and there are asymmetries in the effect that can be explained by similar asymmetries in the times of rising and setting on the moon.

Wind force was divided into six artificial groups, the lowest being " dead calm " and the highest "wind over 20 m.p.h. " The effect is complicated by the fact that the windy nights are warmer than the still nights, particularly in the winter. When the method of difference between successive days is used the effect of a change of one group was to alter the log. catch by 0.095 (other factors being neglected).

The effect of barometric pressure is complicated and difficult to understand. Catch is low with low barometer, and high with high barometer unless pressure is falling ; in this latter case the catch is distinctly lower. If the direction of movement is neglected, the average effect of a rise of 1 inch in the barometer is to add 0.668 to the log. catch. The catch is therefore doubled by a rise of 0.48 inches (1.14 centimetres.)

There is no evidence of the effect of thunderstorms on the total catch of all insects, but slight indication that moths of the family *Noctuidae* are more abundant during thundery weather.

The simultaneous analysis of several factors acting together show differences from some of the above results owing to correlation between the weather conditions themselves. Analysis of 9 p.m. temperature and humidity, expressed as Relative Humidity, Absolute Humidity and Saturation Deficiency, shows no advantage to be gained by using one method rather than another.

With partial regressions of catch on the minimum temperature of several nights preceding the catch, it was found that the previous night has about one-fifth of the effect of the current night, but the night before that had on an average no effect.

When the maximum and minimum temperatures and wind were taken simultaneously the regressions of each were 0.023, 0.070 and 0.144 respectively.

For the year 1933 the simultaneous effect of the above three factors plus 9 p.m. relative humidity was calculated and the regressions were 0.016, 0.065, 0.121 and 0.006.

It is possible to correct the mean catch for each month for the effect of its departures from the normal in temperatures, wind, etc., thus getting a value for what the catch would probably have been if all conditions had been normal for the month. The differences then remaining are due to population effects. These values have been calculated for the 48 months in which the trap was running.

The relation of these values to the rainfall and minimum temperature of the three previous months has been caculated and two regression formulae obtained, one for winter and one for summer, from which the population changes can be estimated from a knowledge of previous weather conditions only. Rainfall is most important in summer and temperature in winter.

Thus a beginning has been made in the problem of measuring the variations in abundance of insects and in forecasting this from a knowledge of the weather conditions. So far it has only been described for the total population of all insects but it will later be extended to single species.

76. WILLIAMS, C. B. 1940. *The numbers of insects caught in a light trap at Rothamsted during four years, 1933-37.* Proc. Roy. Ent. Soc., A, **15**, 78-80.

As the insects caught in the light trap at Rothamsted during the four years, 1933-37 have been used in a series of discussions on the effect of weather conditions on insect activity, it was decided to publish the complete data of the numbers caught each night in the four years, so as to make it available for other workers. The trap was working on 1,407 nights and captured a total of just over 853,000 insects. The insects were approximately 87 per cent. Diptera, 10 per cent. Lepidoptera, and 3 per cent. of the remaining orders.

77. WILLIAMS, C. B. 1940. *On "type" specimens.* Ann. Ent. Soc. America, **33**, 621-624.

A discussion on the value of the designation of "type" specimens in Entomology for the prevention of difficulties of nomenclature. It is argued that one type individual only is necessary, as the object of the "type" specimen is to eliminate doubt in naming, and if two or more "type" specimens are allowed doubt is again introduced.

78. WILLIAMS, C. B., COCKBILL, G. F., GIBBS, M. E. and DOWNES, J.A. 1942. *Studies in the migration of Lepidoptera.* Trans. Roy Ent. Soc., **92**, 102-283.

The report gives a general account of progress along various lines in the study of the migration of Lepidoptera particularly in the last ten years since the publication of Williams' "Migration of Butterflies" in 1930. Among interesting early records of butterfly migration in an account of one seen in the year 1508 near Calais in France.

A detailed history of the abundance each year for over 100 years is given for about forty of the principal British immigrant butterflies and months. A geometric scale is adopted and all species are graded each year in one of six levels of abundance, the scale for each species being proportional to its maximum occurrence. As much as possible of the early literature has been examined and the records are believed to be sufficiently complete to justify discussion. The monthly distribution of most species has been worked out and in one or two it has been possible to show a relation between early appearance and abundance during the summer.

An analysis of nearly 400 records of insects from ten lightships off the east and south-east coasts of Britain gave a list of 140 species of Lepidoptera on which 35 occurred on several occasions or in numbers which make it unlikely that their presence was accidental. Thirteen of these were known or suspected migrants. Others high up in the list were *P. meticulosa*, *A. monoglypha*, *E. similis* and *A. c-nigrum*. The flights were predominantly to the north and north-west from May to mid-August and to the east or south-south-east after mid-August.

Mr. and Mrs. Hodges of Florida made an almost continuous daily watch on the movement of butterflies for nearly two years. Their results are analysed. They show: (1) a regular migration of *A. monuste* each year, at first to the south and then a sudden reversal of direction during May or June; (2) an almost continous southerly movement of *P. eubule* and *T. lisa* at all times of the year; (3) regular movements to the north in spring, and/or autumn movements to the south in several other species including *Danaus plexippus* and *D. berenice*, *Dione vanillae*, *Papilio cresphontes* and *Eudamus protemus*.

The migrations of *D. plexippus* are discussed from several points of view. A study of geographical variations in America indicates a northerly migratory race in North America; a southerly migratory race in South America, south of the Amazon; and a non-migratory race between these two in the northern portion of South America and many of the West Indian islands.

Downes observed the overwintering of *D. plexippus* in California and considers that most hibernating areas are very close to the sea and nearly all suitable spots are occupied to some extent. The males are sexually mature on emerging from the chrysalis in the autumn, pairing taking place throughout autumn, winter and spring ; but the females do not normally mature eggs till the spring.

A large number of new records of migration for North and South America are discussed. A full list of the British and European records of appearance of *D. plexippus* is given, and a number have been examined, all except one of which are of the Northern American race.

Summaries are given of the present information on the migration of several other butterflies from America, Europe, Africa and Australia. A full account is given of recent extensive migrations of *Pieris brassicae* in England, including a flight at Harpenden that continued to the south for over three weeks. New records of *V. cardui* in West Africa indicate a definite migrating season south of the desert belt in September and October. New records are summarised for *Glycestha aurota*, *G. creona*, *G. java*, *C. florella* and several others.

An account is given of some recent experiments in marking butterflies. Practically no recoveries have been made at a distance but much can be learnt from the rate of disappearance of the marked individuals from the locality of marking. A satisfactory technique is described. It is important to be able to distinguish individuals of the same species marked on the same date.

Orientation might possibly be by wind, sight or perception of the earth's magnetic field. These three are discussed. It is shown that an individual insect might determine the direction of the wind without the use of sight, but there is no evidence that the direction of the wind determines the direction of migration. Recent work on orientation by sight is discussed in relation to migration. Experiments on young locusts showed no evidence of appreciation of a powerful magnetic field.

Evidence for the occurrence of a return flight in migrant Lepidoptera is shown to be increasing. The question of the fundamental difference between migrations with and without a return flight is reviewed, and the evolutionary difficulty of the persistence of migration without a return flight is emphasised.

A significant positive correlation between the occurrence in unusual numbers of *V. cardui* in Europe and North America is shown to exist. This supports the similar results previously obtained from *C. lineata*.

Intercorrelations between 35 British immigrant Lepidoptera have been calculated and discussed. The average correlation is slightly positive (+0.12). By sorting the species it has been possible to find several groups the members of which are positively correlated within their own groups, but usually negatively correlated with other groups (Table 34). The first of these is quite definite and contains fifteen closely associated species. The second is less definite. Group 7 contains five species and Group 8 the three *Pieris* species. To a certain extent the grouping follows the geographical range of the species. The average frequency of the principal groups each year for 78 years shows no evidence of periodicity.

A classification is suggested of the density of any flight as measured by the number of insects crossing a definite front in a definite time. This is a series of seven grades in which the numbers are in geometric proportion.

The bibliography includes all references to the migration of butterflies that have been traced in the past ten years and which are not included in the previous bibliography given in Williams's "Migration of Butterflies," 1930.

79. Williams, C. B. 1943. *Studies in wild populations*. Nature, **151**, 71.

A short account of the discussions of problems relating to the wild populations at a joint meeting of the Royal Entomological Society and the Genetical Society.

80. Williams, C. B. 1943. *Birds and butterflies*. Nature, **151**, 173-175.

A review of the recent work by Professor G. D. H. Carpenter and Mr. C. F. M. Swinnerton on the extent to which birds eat butterflies, and on the selection which they make between supposedly distasteful and palatable species.

81. Williams, C. B. 1943. *A method of collecting and storing without pressure insects and galls attached to leaves*. Proc. Roy. Ent. Soc., A. **18**, 1-2.

The paper gives a short illustrated account of a method of storing leaves to which insects are attached in a special form of pill-box to protect them from pressure.

82. WILLIAMS, C. B. 1943. *A safe method of measuring the wings of se butterflies.* Proc. Roy. Ent. Soc., A, **18,** 3-5.

A simple optical device is described by which measurement of the length of wing of pinned insects can be made without removing the glass from the box in which they are contained. The method consists essentially of two similar glass scales mounted about an inch apart, by means of which the error of parallax can be avoided.

83. WILLIAMS, C. B. 1943. *Notes on some Monarch butterflies captured in Great Britain.* Entomologist, **76,** No. 956.

A list of nine records of the monarch butterfly in Great Britain, additional to the complete list of occurrences given in paper No. 78.

84. WILLIAMS, C. B., FISHER, R. A. and CORBET, A. S. 1943. *The relation between the number of species and the number of individuals in a random sample of an animal population.* J. Anim. Ecol., **12,** 42-58. Summary of Part 2, by C.B. Williams.

Extensive data on the capture of about 1,5000 Macrolepidoptera of about 240 species in a light trap at Harpenden is analysed in relation to Fisher's mathematical theory and is shown to fit extremely closely to the calculations. The calculations are applied first to the frequency of occurrence of species represented by different numbers of individuals—and secondly to the number of species in samples of different sizes from the same population. The parameter " α " which it is suggested should be called the " index of diversity," is shown to have a regular seasonal change in the case of the Macrolepidoptera in the trap. In addition, samples from two traps which overlooked somewhat different vegetation are shown to have " α " values which are significantly different.

It is shown that, provided the samples are not small, " α " is the increase in the number of species obtained by increasing the size of a sample by e (2.718). A diagram is given (Fig. 8) from which any one of the values, total number of species, total number of individuals and index of diversity (α), can be obtained approximately if the other two are known. The standard error of α is also indicated on the same diagram.

85. WILLIAMS, C. B. 1943. *Area and number of species.* Nature, **152,** 264.

A large number of records of species of plants in certain areas of known size were collected and studied in particular reference to the number of species and the area of the locality. The areas ranged from two square inches up to the total land surface of the globe, and the number of species from two up to approximately 200,000. By means of a double Logarithmic scale, the information for about 200 localities is given diagramatically and it is suggested that the relation between area and number of species is governed largely by Logarithmic series when the area is small (up to about three or four acres). within which area there is a chance of uniform ecological conditions. From the limits of this area to the limits of the continental areas of two or three million square miles, the rate of increase in number of species with area is more rapid, and this is probably due to the increasing ecological diversity of the area as it gets bigger. When continents are added together, to produce a flora of the whole world, there is a still more rapid increase in the number of species with area, due to the fact that we are now putting together areas of different geological and evolutionary history.

86. WILLIAMS, C. B. 1944. *The numbers of publications written by biologists.* Ann. Eugen., **12,** 143-146.

In investigations on the relative numbers of species of insects with different numbers of individuals, it was found that the mathematical series so obtained closely fitted a Logarithmic series. The present paper shows that the number of publications by biologists in one year as exemplified by the contents of the Review of Applied Entomology and the Review of Applied Mycology also fit to the same Logarithmic series.

87. Williams, C. B. 1944. *Some applications of the Logarithmic series and the index of diversity to ecological problems.* J. Ecol., **32**, 1-44.

The paper describes the application of Logarithmic series to a number of problems of the division of individuals into species and of species into genera. The series, first suggested by R. A. Fisher in this connection is:

$$n_1 \quad ; \quad \frac{n_1}{2}x \quad ; \quad \frac{n_1}{3}x^2 \quad ; \quad \frac{n_1}{4}x^4$$

where n_1 is the number of groups with one unit and x is a constant less than unity. Unlike the hyperbolic series, which has previously been considered to apply to some of the cases discussed, the Logarithmic series is convergent; both the number of groups (e.g., species) and the number of units (e.g., individuals) can be summed. When several samples are taken from a population containing a number of species it is found that the ratio n_1/x is constant and, as it is therefore a characteristic of the population, it has been called the Index of Diversity.

The Logarithmic series is found to fit extremely well to a large number of frequency series drawn from insects, birds, butterflies and plants, except that there is a slight tendency for the calculated n_1 to be below the observed. It also fits well, sometimes extremely well, to the number of genera with different numbers of species in standard classifications of groups of both animals and plants. The conception of the index of diversity is applied to problems of the number of species of plants on different areas, and to the comparison of floras of different areas with interesting results. A classification is given of the 171 families of dicotyledons according to their index of diversity to stimulate a discussion as to which may be the factors which bring about differences and resemblances in this index. In general, the families with large numbers of species and genera have large index of diversity, but there may be a very big range of index in families of approximately the same size.

88. Williams, C. B. 1945. *Occurrence of* Vanessa cardui (*Lepidoptera*) *at sea off the West African coast.* Proc. Roy. Ent. Soc., **20**, A, 4-5.

An account of observations made during a sea voyage down the west coast of Africa in September, 1943, when painted lady butterflies were observed at sea, more than a hundred miles from land, over a period of nearly a week and over a distance of nearly 1,500 miles from the first one seen off Morocco to the last one seen just north of Sierra Leone. Previous records of the abundance of painted lady along this coast are nearly all in the months of September and October.

89. Williams, C. B. 1945. *Index of diversity as applied to ecological problems.* Nature, **155**, 390-392.

A short reply to a letter by Mr. E. W. Jones in "Nature" criticising certain results obtained in the number of plants on different areas of land in relation to the Logarithmic series. It is shown from the data available that in all probability on the area studied the plants were strongly aggregated and therefore the areas used for sampling were not large enough to give a fair sample of the population.

90. Williams, C. B. 1945. *Notes on the fat content of two British migrant moths* (*Lepidoptera*). Proc. Roy. Ent. Soc., A., **20**, 6-13.

Recent work in the United States on a migrant leaf-hopper shows that the amount of fat food reserve in the body is related to the distance flown on migration. A very large number of Silver-Y moths and some other species were captured at a searchlight on the south coast of England in August, 1944, and the opportunity was taken to extract the fat from the dried bodies of a number of specimens, to get figures for the fat content and particularly the variation from individual to individual which had not been possible in the case of the small leaf-hoppers in America. Diagrams are included showing the frequency distributions of the weights of the abdomen and the weights of fat. This reached about 45 per cent. of the total weight of the abdomen in 48 males and 50 females, and about 33 per cent. of the total weight of the body excluding wings, but there was very considerable variation, some specimens containing 70 per cent. of the abdomen weight, and 60 per cent. of the total weight of the body. Results are also given for another moth, *Phlogophora meticulosa*, for comparison.

91. WILLIAMS, C. B. 1945. *Evidence for the migration of Lepidoptera in South America*. Rev. Ent., **16**, 113-131.

Information is given on 84 directional flights of Lepidoptera in South America, some observed by the writer and others reported from published and unpublished sources. The whole is given as evidence of extensive migration of Lepidoptera in South America.

92. WILLIAMS, C. B. and BEALL, G. 1945. *Geographical variations in the wing length of* Danaus plexippus (*Lep. Rhopalocera*). Proc. Roy. Ent. Soc., A., **20**, 65-76.

In association with Dr. G. Beall of Canada, a study was made of the variability in wing length of the migrant butterfly *Danaus plexippus*. The wing lengths of over 2,000 specimens were measured, and the paper gives an account of the variability in wing length according to the geographical distribution of the different races in North and South America and of different localities in North America. The object was to see if it would be possible to identify populations of similar origin by average wing length and variability. It was found that approximately 50 individuals must be examined in order to be able to compare differences of 1 mm. In general, there was some evidence that the species was smaller near the Equator than either in the extreme north or south, and smaller in the west than in the east.

93. WILLIAMS, C. B. 1945. *Recent light trap catches of Lepidoptera in U.S.A., analysed in relation to the Logarithmic series and the index of diversity*. Ann. Ent. Soc. America, **38**, 357-364.

Walkden and Whelan in 1942 published data on the catching of about 500,000 moths on 300 species in light traps in six localities of Kansas and Nebraska. The data provided by this publication has been analysed in relation to the Logarithmic series and has been found to fit closely, with the exception that the observed number of rare species with one two or three specimens only is in general above that collected. The fit is not so good as for similar data obtained in Great Britain. In one or two cases the catch was dominated by very large numbers of one or two species. In one locality two species made up over 90 per cent. of the total captured. It is possible that this may account for the generally poorer fit.

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