THE PRACTICAL USE OF THE INSECT ENEMIES OF INJURIOUS INSECTS.

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INTRODUCTORY.

AMONG the many things which the Department of Agriculture has done for agriculture and horticulture in the United States, very few have been as spectacular and as immediately beneficial as the introduction of the Australian ladybird, or lady-beetle, from Australia in the eighties to destroy the white, fluted, or cottony-cushion scale, which at that time threatened the absolute extinction of the orange and lemon growing industry in California. The immediate and extraordinary success of this experiment attracted attention all over the civilized world, and, although it was followed by very many impractical and unsuccessful experiments of a similar nature, remains as the initial success in much beneficial work which since then has been carried on both in this country and in others.

The whole story of this work, and of later efforts of the same kind, has been told at length in Bulletin 91 of the Bureau of Entomology, published in 1911, but a competent résumé has never appeared in the Yearbook, and the retelling of it in more summary form will possibly prove of general interest.

THE AUSTRALIAN LADYBIRD AND THE FLUTED SCALE.

In the early seventies of the past century there appeared upon certain acacia trees at Menlo Park, Cal., a scale insect, which rapidly increased and spread from tree to tree, attacking apples, figs, quinces, pomegranates, roses, and many other trees and plants, but seeming to prefer orange and lemon trees. This insect, which came to be known as the white scale, or fluted scale, or the Icerya (from its scientific name), was an insignificant creature in itself, resembling a small bit of fluted white wax a little more than a fourth of

an inch in length. But when the scales had once taken possession of a tree they swarmed over it until the bark was hidden; they sucked its sap through their minute beaks until the plant became so feeble that the leaves and young fruit dropped off, a black smut fungus crept over the young twigs, and the weakened tree gradually died.

THREATENED EXTINCTION OF THE CALIFORNIA CITRUS INDUSTRY.

In this way orchard after orchard of oranges, worth a thousand dollars or more an acre, was utterly destroyed, the best fruit-growing sections of the State were invaded, and ruin stared the fruit growers in the face. This spread was rather gradual, extending through a series of years, and it was not until 1886 that it was so serious as to attract national attention.

In this year (1886) an investigation was begun by the Department of Agriculture. Two agents of the Division of Entomology, Messrs. D. W. Coquillett and Albert Koebele, were sent to California to study the problem of remedies. In the course of a year the complete life history of the insect had been worked out and a number of washes had been discovered that, applied to the trees in the form of a spray, would kill a large proportion of the pests at comparatively slight expense (say from one-half to one-third of a cent per gallon). It was soon found, however, that the average fruit grower would not take the trouble to spray his trees, largely from the fact that he had experimented for some years with inferior washes and quack mixtures and from his lack of success had become disgusted with the idea of using liquid compounds; something easier, something more radical, was necessary in his disheartened condition.

IMPORTATION OF THE AUSTRALIAN LADYBIRD AND ITS SPECTACULAR SUCCESS.

Meantime, after much sifting of evidence and much correspondence with naturalists in many parts of the world, it was decided by Prof. C. V. Riley, at that time Chief of the Division of Entomology of the Department of Agriculture, that the white scale was a native of Australia and had been brought over to California accidentally upon Australian

plants. In the same way it was found to have reached South Africa and New Zealand, in both of which countries it had gradually increased and had become almost as great a pest as in California. In Australia, however, it did not seem to be abundant and was not known as a pest, which was assumed to be evidence of the fact that Australia was the native home of the species, and that there must exist there some natural check to its increase. It therefore became important to send a trained man to Australia to investigate this promising feature.

It happened at that time that the appropriation bill for the Department of Agriculture prohibited foreign travel, but it also happened that some appropriations had been made to the Department of State to provide for an exhibit from the United States which was to be held at an international exposition at Melbourne. So by arrangements with the Department of State and the United States commissioner to the Melbourne Exposition, Mr. Frank McCoppin of San Francisco, it was planned to send an expert assistant from the Division of Entomology to Australia to study the conditions of the fluted scale in regard to parasites and other natural enemies, his expenses being paid from exposition funds. Mr. Albert Koebele was chosen for this work. In order to justify this expenditure from exposition funds, the Department of Agriculture sent another agent, the late Prof. F. M. Webster, to prepare a report for the commission on the agricultural features of the international exposition.

Koebele proved to be an excellent choice. He was a skilled collector and the best man who could have been selected for this work. He at once found that Prof. Riley's supposition was correct—there existed in Australia small flies which laid their eggs in the fluted scales, and these eggs hatched into grubs which devoured the pests. He also found a remarkable little ladybird, a small, reddish-brown, convex beetle which breeds with marvelous rapidity and which, with voracious appetite and at the same time with discriminating taste, devours scale after scale, but eats fluted scales only and does not destroy other insects. This beneficial creature, now known as the Australian ladybird, or the Vedalia (fig. 8), was at once collected in large numbers, together with several other insects found doing the

same work. Many hundreds of living specimens, with plenty of food, were packed in tin boxes and placed on ice in the ice box of the steamer at Sydney. They were carried carefully to California, where they were liberated upon orange trees already inclosed in gauze by Mr. Coquillett at Los Angeles.

The results more than justified the most sanguine expectations. The ladybirds reached Los Angeles alive, and, with appetites sharpened by the long ocean voyage, immediately fell upon the scales and devoured them one after another without rest. Their hunger temporarily satisfied, they began to lay eggs. These eggs hatched in a few days into active grublike creatures—the larvæ of the beetles—and these grubs proved as voracious as their parents; they devoured the scales right and left, and in less than a month transformed into beetles. And so the work of extermination went on. Each female beetle laid on an average 300 eggs, and each of these eggs hatched into a hungry larva. Suppose that one-half of these larvæ produced female beetles, a simple calculation will show that in 5 months a single ladybird became the ancestor of 75 billions of other ladybirds, each capable of destroying very many scale insects.

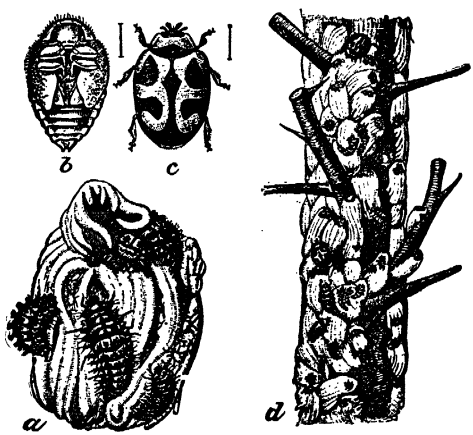

FIG. 8.—The Australian ladybird (*Novius cardinalis*), an imported enemy of the fluted scale: *a*, Ladybird larvæ feeding on adult female scale and its egg sac; *b*, pupa of ladybird; *c*, adult ladybird; *d*, orange twig, showing scales and ladybirds. *a–c*, Enlarged; *d*, natural size. (Marlatt.)

Is it any wonder, then, that the fluted scale soon began to disappear? Is it any wonder that orchard after orchard was entirely freed from the pest, until in the course of less than 5 years hardly an Icerya was to be found in California? In fact, in less than a year from the time when the first of

these hungry Australians was liberated from its box in Los Angeles the orange trees were once more in bloom and were resuming their old-time verdure. The Icerya had practically become a thing of the past.

The general effect of this extraordinary California success on the horticultural world at large was striking, but not wholly beneficial. Many enthusiasts, headed by certain Californians, concluded that it was no longer necessary to use insecticidal mixtures and that all that was necessary in order to eradicate any insect pest of horticulture or of agriculture was to send to Australia for its natural enemy. In fact, it is safe to say in a general way that, by blinding people to other and immediate measures of control, this success retarded the general warfare against injurious insects in the State of California.

The fact that the Vedalia preys only upon the fluted scale, and perhaps upon some very closely allied forms, was disregarded, and it was supposed by many fruit growers that it would destroy any scale insect. Therefore the people in Florida, whose orange groves were suffering from the long scale and the purple scale, sent to California for specimens of the Vedalia to rid their trees of these other scale pests. Their correspondents in California sent them specimens of the beetle in a box with a supply of the fluted scale for food. When they arrived in Florida the entire contents of the box were placed in an orange grove. The result was that the beneficial insects died and the fluted scale gained a foothold in Florida, a State in which it had never before been seen. It bred rapidly and spread to a considerable extent for some years and did an appreciable amount of damage before it was finally subdued.

On the other hand, the work of this predatory beetle in other parts of the world has been of the same successful character as that in California, wherever it has been introduced for the purpose of destroying the fluted scale or another species of the same genus. It was introduced into New Zealand, into South Africa, into Portugal, into the Hawaiian Islands, Italy, Syria, Egypt, and recently into the south of France, everywhere reducing the fluted scale from alarming numbers to practically none. In no case does it appear absolutely to have exterminated the fluted scale;

always a few are left, which sometimes multiply so as to necessitate a reintroduction of the Vedalia.

WHY THE AUSTRALIAN LADYBIRD WAS SUCCESSFUL.

It thus appears that in this ladybird beetle we have an almost perfect remedy against the fluted scale. There have been no failures in its introduction to any one of the different countries to which it has been carried. Its success has been more perfect than that of any other beneficial insect which has so far been tried in this international work, that which comes nearest to it being the introduction of the parasites of the cane leafhoppers into Hawaii, which will be referred to later. There are good reasons for this—reasons which do not hold in the relations of many other beneficial insects to their hosts. In the first place, the Vedalia is active, crawls rapidly about in the larval state, and flies rapidly as an adult beetle, whereas the fluted scale is fixed to the plant, does not fly, and crawls very slowly when first hatched and later not at all. In the second place, the Vedalia is a rapid breeder and has at least two generations during the time in which a single generation of the scale insect is being developed. In the third place, it feeds upon the eggs of the scale insect; and in the fourth place, it seems to have no enemies of its own; and this is a very strange fact, since other ladybird beetles are destroyed by several species of parasites.

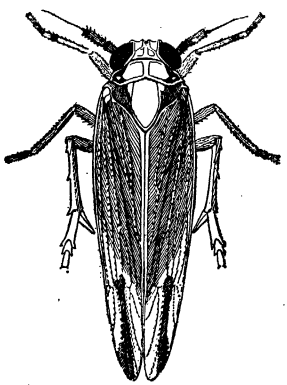

FIG. 9.—The sugar-cane leafhopper (*Perkinsiella saccharicida*): Adult female. Much enlarged. (Kirkaldy.)

IMPORTATION OF BENEFICIAL PARASITIC INSECTS INTO HAWAII.

PARASITES OF THE SUGAR-CANE LEAFHOPPER.

We have just referred to the Hawaiian work in the introduction of parasites. About 1902 a leafhopper (fig. 9) was found upon the sugar cane in Hawaii. It appears to have been introduced with seed from Australia about 1898. It spread rapidly, and in 1903 damaged the crop to the extent

of $3,000,000. An expert was sent that year to the United States to look for parasites. The next year this expert and another went to Australia, collected more than 100 species of parasites of leafhoppers, and, though failing with their first consignment, sent in cold storage, were successful with later shipments. The parasites reached Honolulu alive, were reared in confinement, and liberated in the cane fields. The year 1905 showed enormous loss from the leafhopper on many plantations. In 1906 certain of the parasites (see fig. 10) began to multiply very rapidly.

In 1907 one very large plantation, whose crop had dropped from 10,954 tons in 1904 to 1,620 tons in 1905 and to 826 tons

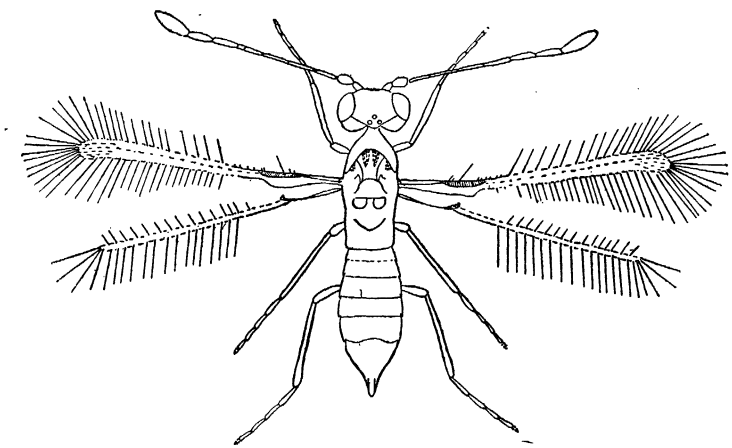

FIG. 10.—*Paranagrus optabilis,* a parasite of the sugar-cane leafhopper: Adult, highly magnified. (Perkins.)

in 1906, made the next year 11,630 tons, almost entirely as the result of the parasite introduction. In August, 1915, the writer visited Hawaii and found that the situation with regard to the sugar-cane leafhopper was almost perfect. The canes were not damaged in any respect so far as could be seen. The leafhoppers were still present, but in insignificant numbers. Where they had laid their eggs, these were almost invariably parasitized by one of the introduced parasites. There is, it is true, an occasional reappearance of the leafhoppers in numbers, following the destruction of the parasites by trash-burning, and, at the time of this visit, on one

large plantation on the island of Hawaii 10,000 acres were so badly infested that a yield of only one-half a normal crop was expected. But such recrudescences as this are, and probably will be, fugitive.

A PARASITE OF THE SUGAR-CANE WEEVIL BORER.

Other results almost as valuable have been accomplished in Hawaii by the introduction of a fly which is a parasite of the sugar-cane weevil borer (fig. 11), an insect which tun-

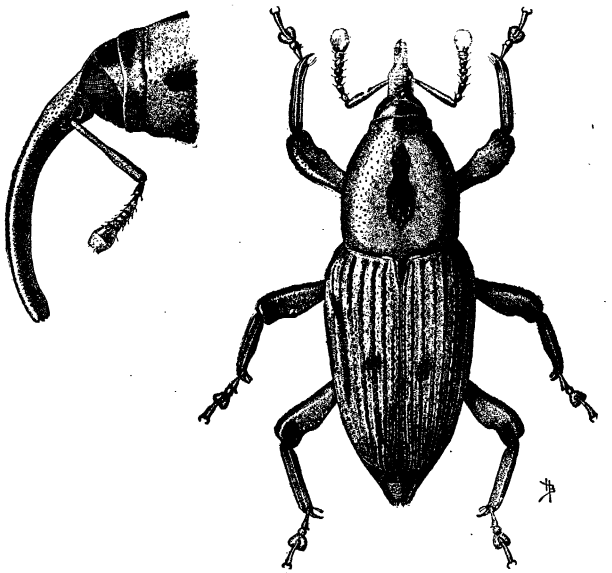

FIG. 11.—The sugar-cane weevil borer (*Rhabdocnemis obscurus*) : Adult weevil, from above; profile view of head and beak at left. Much enlarged. (Original.)

nels the canes and greatly reduces the crop. This parasitic fly was found in British New Guinea by Mr. F. Muir, an expert of the Sugar Planters' Association, and after much hardship and one failure it was successfully established in Hawaii with extraordinarily beneficial results.

This Hawaiian experience was described by Representative Mann in a speech made before Congress April 22, 1916, with the introductory remark, "I am going to narrate, very briefly, a fairy story"; but it was a true fairy story.

REASONS FOR THE SUCCESS OF THE HAWAIIAN WORK.

Here, again, there were good reasons for the striking success. The remote position of Hawaii and the simplicity of its native fauna—practically all of its pests having been introduced by commerce without their regular natural enemies and multiplying enormously on account of the very few native parasitic or predatory insects—account in part for the success, since in just the same way when natural enemies of imported pests are introduced they meet not only an absence of insects such as secondary parasites or native predatory species, but also find themselves in an equable climate permitting continuous breeding all the year round. As has been pointed out, the keen struggle for existence between the different native forms of insect life which is seen in continental lands is absent in these islands, and with introduced species the extreme simplicity of environment which they find is enormously favorable to their multiplication.

CONDITIONS UNDER WHICH THE PROBLEM IS SIMPLE AND EASY.

It follows, then, that with certain accidentally imported insects, nonfliers and attached to the same spot through practically their whole life, the introduction of active and more rapidly developing predators or parasites may reasonably be expected to be effective.

It follows, also, that injurious insects accidentally imported into such isolated islands as Hawaii in the north Tropics, which from their isolation have a very simple fauna, may be kept in check with some degree of certainty and with some degree of rapidity by the introduction, from their original home, of the parasites and natural enemies which there may have kept them in check.

WHY THE PROBLEM IS USUALLY COMPLEX AND DIFFICULT.

But with other kinds of injurious insects which have what is called a complete metamorphosis, and which may exist in the egg stage, in a crawling larval stage, in a quiescent pupal stage, and as a flying adult, and which in their native

homes are parasitized by whole series of species of parasites, some attacking them in one stage and some in another, and still others in a third, it is not such a simple thing to introduce and acclimatize the parasites necessary to reconstitute the normal environment.

Moreover, in a great continental country like the United States, with its very old assemblage of insect forms of infinite variety, with its remarkable variations in climate, in altitude, in rainfall, we again have a much more complicated problem.

The original claim of the Californians, that you have only to send abroad for *the* parasite of any injurious insect to bring about its subjugation, is thus obviously erroneous. No trained entomologist would for a moment consider such a problem a simple one, except under conditions such as those described.

Hence it follows that with almost every accidentally introduced insect pest the problem of bringing in its natural enemies from its native home possesses very many factors which must be considered, and these factors differ with almost each kind of insect concerned. It is unwise and most unpromising to attempt heterogeneous and miscellaneous importations of parasites without careful study of the host insect on its home ground and in its natural environment throughout the whole range of its existence and a similar biological study of its parasites and natural enemies under such conditions.

IMPORTATION OF PARASITES OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH.

Take the case of the gipsy moth and the brown-tail moth in New England, for example. Here we had two pests well known in Europe (the gipsy moth also being known in Japan) which had become accidentally established in New England and which multiplied and spread alarmingly. In their native homes entomologists had studied these insects in a way for many years. Many of their native parasites and other natural enemies had been recorded. It was well known that in ordinary years in their native homes 90 per cent of all that hatched were destroyed by these parasites and natural enemies. Hence, after the first effort to exter-

minate these insects before their spread had covered very many square miles had failed, owing to the stopping of appropriations by the State of Massachusetts, and the insects had again multiplied and spread over an area of nearly 4,000 square miles, it was considered to be a most promising operation to bring over from Europe and from Japan as many larvæ and pupæ of these insects as possible, with the certainty that a large percentage of them would contain parasites which, liberated upon American soil, would attack the gipsy-moth and brown-tail-moth larvæ and pupæ devastating the orchards and forests of New England. This was done, and by the wholesale, but with the distinct understanding that immediate beneficial results upon a noticeably gratifying scale could not be expected.

In varying numbers and with varying methods, the European and Japanese parasites of these two insects were imported every year from 1905 to 1913, further actual importation work being then interrupted by the great war. More than 30 species were imported during this time, and a number of the most important ones have been acclimatized and are rapidly spreading, and are at the present writing doing excellent work and in many localities destroying more than 50 per cent of the injurious insects. More than 18,000,000 individuals of the parasites have been colonized in parts of the infested area.

But this great experiment, extending over 11 years, has necessarily comprehended the methodical experimental study of all of the factors which affect the attempted acclimatization of species in a new environment, many of the characteristics of which are opposed to such naturalization. It has been, in the freely translated words of Dr. Paul Marchal, the eminent French biologist, "a gigantic biological analysis and synthesis bearing upon all the elements which constitute the harmonic groupings of plant-feeding insects, their predators, parasites, and hyperparasites—the taking apart piece by piece of the whole system, and its partial reconstruction in a new environment, forcing it to give the greatest possible stress to the elements most favorable to man and reducing to the minimum those which oppose their action."

DIFFICULTIES ENCOUNTERED IN THE WORK.

To indicate in a faint way some of the difficulties encountered and some of the fluctuations of hope and the contrary which came about from time to time, it will be only necessary to cite the experience with two of the imported species.

There exists in Japan an egg parasite of the gipsy moth, now known as the Schedius (fig. 12). The first specimens of this insect were reared from Japanese gipsy-moth eggs sent to this country in 1908, and others issued in April, 1909. They bred rapidly, laying their eggs in American gipsy-moth eggs (see fig. 13) brought into the laboratory,

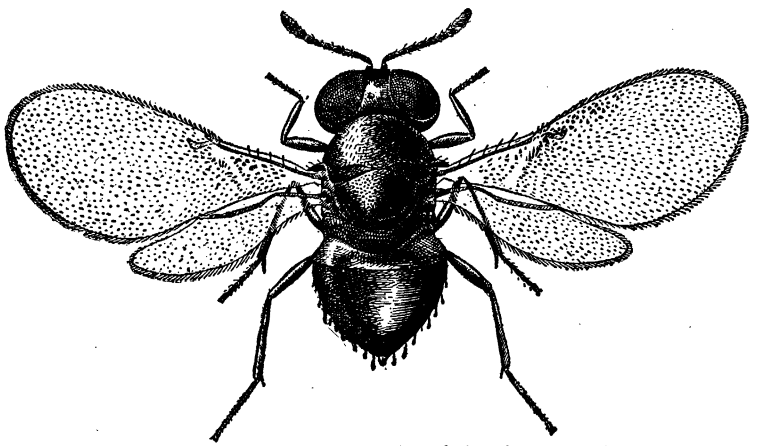

FIG. 12.—*Schedius kuvanae,* an egg parasite of the gipsy moth introduced from Japan: Adult female. Greatly enlarged. (Author's illustration.)

and on through the summer at the rate of one generation a month. By the first of the following year 1,000,000 individuals were present in the rearing cages in the field laboratory, and the following March the parasitized eggs were divided into 100 lots, each of which contained approximately 10,000 parasites, and were put out in colonies, while a large quantity of parasitized eggs remained and were placed in cold storage awaiting the appearance of fresh eggs of the gipsy moth in the latter part of the summer. This hope was vain, however, and when the eggs were taken from cold storage not a single living specimen remained. By the end

of 1910 hopes of the survival of the species in the field were almost abandoned, but in spite of this the insect has finally accommodated itself to New England conditions and is breeding rapidly and spreading slowly from points where it succeeded in maintaining itself, and now exists by millions in regions infested with the gipsy moth.

Quite different was the experience with one of the European parasites, the *Parexorista cheloniae* (fig. 14), a species which exists also in America but which here does not seem to parasitize the brown-tail moth larva because it is apparently without defense against the poisonous barbed hairs of this caterpillar. On the other hand, in Europe this parasite is represented by a race, apparently identical with the American race, but which has become adapted to the brown-tail moth physiologically and there parasitizes it with impunity. Attempts were made, therefore, to introduce the European form. It was brought over and colonized by the thousands. In the following year numerous brown-tail moth caterpillars were found to have been parasitized by it, and great hopes were aroused. The year after, however, the condition of affairs was completely changed; the caterpillars were absolutely free from attack. Then the curious discovery was made that the imported European race and its first generation of descendants had hybridized with the American race and that the offspring had lost the immunization against the brown-tail moth poison. It therefore appeared that all efforts to acclimatize the European race would be useless, since, however great the number of individuals imported, the race would be absorbed by the American form. Possibly the American race may eventually acquire immunity, but, with the abundance of other food, this would be an enormously slow process.

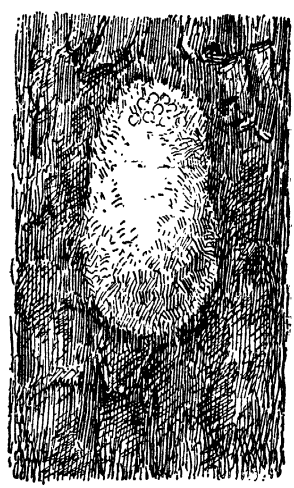

FIG. 13.—Egg masses of the gipsy moth. Enlarged. (Kirkland.)

GENERAL RESULTS ACHIEVED.

On the whole, the work has been very successful, and has helped in bringing about infinitely better conditions in New England so far as these pests are concerned, and, while it is practically certain that both gipsy moth and brown-tail moth will gradually spread westward, it is equally sure that the imported natural enemies will go with them, and that none of the long-continued disastrous outbreaks which we saw in Massachusetts in the years prior to 1905 will occur farther west.

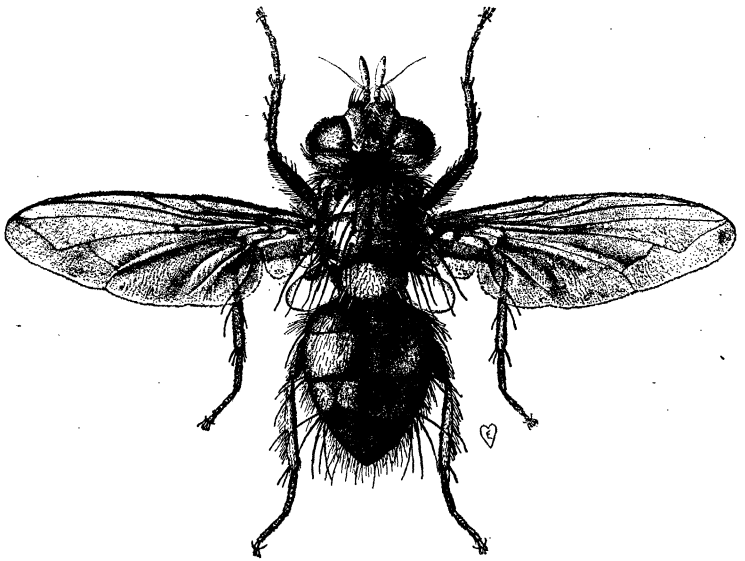

FIG. 14.—*Parexorista cheloniae*, a parasite of the brown-tail moth. Greatly enlarged. (Original.)

From all this it will appear that the practical handling of the natural enemies of injurious insects on the whole is by no means a simple rule-of-thumb operation. With a few species it can be done easily and with very perfect results; with other imported species it is a very complicated operation and will produce results which are palliative to a large degree, but by no means overwhelming in their effect.

INTRODUCTION OF THE PARASITE OF THE MULBERRY SCALE INTO ITALY.

Since the initial success with the Australian ladybird, literally hundreds of similar attempts have been made in

different parts of the world. Some have met with a certain amount of success; others have been absolute failures. One of the most successful ones which may be mentioned incidentally is the importation from America and Japan into Italy of a minute parasite of the Diaspis scale insect which threatened the entire extinction of the mulberry trees and consequently of the silk industry in Italy. This little parasite (fig. 15), imported by Prof. Antonio Berlese, of Florence, and carefully reared and distributed, has brought about the approximate extinction of the scale insect throughout a large part of Italy. Here again, however, we had a fixed scale

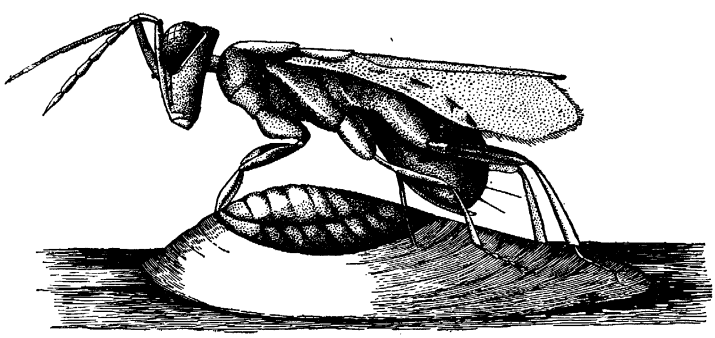

FIG. 15.—The parasite *Prospaltella berlesei* laying its eggs in a mulberry scale. Highly magnified. (Redrawn from Berlese.)

absolutely at the mercy of its imported natural enemy, which, at the same time, breeds naturally with greater rapidity than the scale insect.

OUTLOOK FOR THE BIOLOGICAL METHOD OF FIGHTING INSECTS.

There will be a very considerable development of this method of warfare against injurious insects in the future. It should be termed "the biological method of fighting insects," and, looking at the problem in a broad way, so far as this country is concerned, when we consider that more than one-half of our principal crop pests have been accidentally imported from other countries, there seems no reason why a systematic study of a very large number of parasitic and predatory insects native to the countries from which these pests were accidentally imported should not be made with a view of ultimate importation of all of them

into the United States. In fact, since there exist all over the world beneficial insects, many of which can undoubtedly be acclimatized here, and some of which will undoubtedly prove of value to American agriculture, carefully planned work should be begun looking to the ultimate increase of our insect population by the addition of as many of these beneficial forms as possible.

Of course this would mean a very great amount of careful biological study in the countries of origin by men specially trained in this sort of work, if results of value are to be obtained. Strikingly beneficial results could not be expected speedily and, in fact, we might not be able for many years to estimate the benefits derived from such a service; but it seems clear that we should have in this country as many of these surely beneficial forms as can be acclimatized.