OUR FRIENDS THE INSECTS.

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There is necessarily such a preponderance of emphasis on the losses man sustains through insects that a statement of the credit the hexapods are responsible for is occasionally desirable to maintain a correct mental perspective in regard to their relation with man's welfare. It is a common and logical principle in educational psychology that instead of setting up a long series of "don'ts" to regulate childrens' conduct we aim to substitute legitimate and desirable activities for those we would prohibit. In a somewhat parallel manner, much has been done, and much more may perhaps be accomplished in the future, toward subduing injurious insects by establishing beneficial forms among the undesirable species. Instead of creating a partial biological vacuum in nature by killing insects by artificial methods, we may plant a benefactor where a criminal rules, lest the house that is swept clean and vacated be eventually filled with seven times more devils than at first. Obviously this plan has limitations inasmuch as effective natural checks do not exist for all pests.

Biological Control.

The method of combatting insect pests by the utilization of natural agencies that hold the destructive forms in check, is perhaps the most fascinating chapter in the history of insect control and at once the least known by the people as a whole. The present attempt is only to prepare a brief, simple account of the growth, methods and accomplishments of this phase of warfare against insects. The subject stated comprehends other phases of entomology than this, but the present article will be limited to a consideration of our friends, the parasitic insects. The term "parasitic", as used here, is defined to include only such insects as live upon other insects, spending a whole stage or more on or in another individual which is designated the host.

Ever since man began supplying himself with food by tilling the soil, he has, no doubt, had to fight six-legged enemies of his crops. And when our agrarian ancestors made more or less intelligent observations on them, they probably perceived also, though more rarely, that certain kinds make their living by preying upon, or by eating, the bodies of their own relatives. And as observations in the field of natural history became more purposeful and systematic, the idea of pitting the latter against the former, the benefactor against the foe, probably grew, in a few minds, to a conviction and a personal experiment, and eventually to practice. Doctor Howard (1) tells us that the "gardeners and florists in England for very many years have recognized the value of the ladybirds and have transferred them from one plat to another." But a similar use of parasites is not likely to have been made at that time on account of their small size, and chiefly because of the general lack of knowledge even regarding the nature of their habits. It is not too much to say that no one knew that such a phenomenon as parasitism existed until certain naturalists (1, pp 16-17) discovered it in the seventeenth century. Aldrovandi, in 1602, is supposed (1, p. 16) to have been the "first to observe the exit of the larvae of *Apanteles glomeratus* L.", a common small wasp-like parasite of the imported cabbage worm. But it was probably not until more than a half century later that Vallisnieri (1661-1730) discovered (1, p. 17) "the existence of true, parasitic insects" and the real nature of insect parasitism. "Reaumur (1683-1757) and DeGeer (1720-1778) each studied the life histories of living insects with great care and, among them, worked out the biology of a number of parasites." Ratzeburg observed the bionomics of Hymenoptera parasitic on forest insects, but did not believe that their efficiency could be increased by man.

Hence, although several biologists had become familiar with the fact of parsitism, and apparently considered that man might utilize it in control, the artificial manipulation of parasites was not definitely suggested until after the middle of the nineteenth century. Earlier hints at the feasibility of biological factors for pest control applied to predaceous forms, chiefly the lady beetles and ground beetles, whose manner of checking their prey by direct feeding was more easily comprehended generally. Hence, the movement for the use of parasitic insects in what we now call biological control has been begun and carried forward in the past nine decades, and the outstanding ingenious accomplishments of an extensive and practical nature are the work of the past forty years, and fall mainly within the lifetime of that chief enthusiast for, and sponsorer of, the utilization of insect parasites, Doctor L. O. Howard, who began urging biological control in 1880 and is still engaged in his favorite field.

The Nature of Parasitic Insects.

A very small number of the present population of the world is aware of the true nature of the white oval bodies seen so commonly on the backs of certain caterpillars. Aldrovandi, in 1602, supposed them to be eggs which, he probably thought, gave rise to many more caterpillars to eat the rest of his crop. His supposition also implies that he was also unfamiliar with the phenomenon of metamorphosis of moths and butterflies. The nature of these so-called "eggs", their source, and their ultimate end, could not be appreciated then, as now, until the fact of metamorphosis among the parasites, and their hosts as well, is understood. Parasitic insects that attack other insects have a common mode of development from the egg to the parent, or adult stage. These friends of ours usually begin life as an egg which the parent places into, on, or near the host. Wasp-like parasites or Hymenoptera have hollow boring instruments, or ovipositors, by means of which the eggs are usually passed into the very bodies of their hosts, whereas two-winged flies or Diptera deposit their eggs on the surfaces of the host, and the responsibility of entering the body of the latter belongs to the young parasite or larva. Certain true wasps, the Tiphiidae and Scoliidae, are parasitic upon beetle grubs in the soil, and their larvae are ectoparasitic, clinging to and feeding only on the outside of their hosts. The Rhipiphoridae, a family of beetles, are also ectoparasites of white grubs, while the little-known minute twisted-winged parasites spend the larval stage in the bodies of wasps and leaf hoppers. When the parasite larvae become full-sized they do, or do not, leave the host, if they happen to be endoparasitic. Wasp-like parasite larvae often spin silken cocoons, either in the empty shell of the host, or near by outside: the "maggots" or larvae of flies retain their last skin instead of shedding it as before, and live in it as a covering or puparium. In the puparium or cocoon the larva transforms to the adult stage, the process of transformation being called pupation, and the insect during the transition period is referred to as being a pupa or in the pupa stage. Each of the four stages—egg, larva, pupa and adult—is remarkably different from each of the others, for which reason this mode of development is named complete metamorphosis. On the other hand, insects like the grasshoppers and true bugs have young resembling the adults in form and have only three stages, lacking the pupa. None of the insect parasites of other insects have this type of metamorphosis. Only the larval stage of parasitic insects feeds upon its host, which ordinarily lives only as long as necessary for the parasite to become mature. The parasites do not feed upon the vital organs of the host, but instead are nourished from the blood which flows about through the open spaces of the host's body, and from the fat body which represents the reserve food supply of the victim. While residing in the host's body the hymenopterous parasite larva retains in its alimentary canal, which is sac-like and closed behind, all the wastes from the digestive process. The waste materials are voided concurrently with the last moulting.

It is a significant fact that all parasitic insects attacking others of their class have complete metamorphosis. The larva is no doubt more adaptable to a multitude of circumstances of life than the nymph type of young, such as is present in grasshopper life cycles. While limited in locomotor capacity, the larva has a flexible body capable of entering the soil or boring into and out of a host, and by its tenacious hold on the host, or by virtue of its position in the host, ceases to use, and has long since lost, all the legs it ever had. The parasitic larvae have been engaged in the business of living at the expense of others a long time, as witness the reduction of the legs, antennae and mouthparts. That they once possessed these organs is suggested by the facts that some non-parasitic relatives still have them, and that some parasitic larvae, notably of the ichneumonoid flies, retain their large falcate mandibles in the first larval instar, but lose them when they moult the first time. While the nymphs of such external parasites as the sucking lice of mammals and the chewing lice of birds are parasitic, they do not exhibit the versatility in choice of, and fitness for, life in a considerable variety of host situations such as hymenopterous and dipterous parasitic larvae display. Among the many thousands of species of parasitic insects there is material for a very interesting study of the multiplicity of form and habit changes or adaptations,—such as the means by which the parent gets its progeny upon or into the host, how and in what stage the parasite emerges again, and the variety of hosts it may attack. In a single superfamily, the Ichneumonoids, we find one species an ectoparasite on caterpillars, another an internal parasite in a hard shelled, swift-running beetle, a third in a minute sluggish soft-bodied plant louse, and a fourth more than a hundred times larger than the former and carrying a set of drills much longer than itself for reaching into the burrow of a tree borer which is the larva of another member of its own order. In fact, one stage or more of some member or members of practically all the twenty-four orders of insects are probably subject to attack by one species or another of parasitic insects. Furthermore, some parasitic larvae have come to attack other parasite larvae, and the latter may be subjugated by a third parasite, which, better than anywhere else in the animal world, illustrates well the poem of the fleas that have lesser fleas, and so ad infinitum. We see, then, by these examples that parasitic insects are by no means limited to any particular place, host or host stage, and still they are so bound to their habits by heredity that they select their hosts within certain group limits and die without progeny if certain hosts, or sometimes a single species of host, are not available. It is this relative uniformity, and furthermore their limitation to a parasitic life, that makes them dependable for use in biological control.

Methods of Biological Control.

It is necessary to admit at once that the use of parasites to combat their injurious relatives has limitations. Where a native parasite of an indigenous pest already exists and fails to hold its host sufficiently in check, there is not much that has been done to increase the numbers of the benefactor, but new methods may possibly be originated in the future. Their rate of growth is much controlled by weather and the available numbers of the host, and men can scarcely hope to regulate these influences. However, even in the instance of native parasites various means of utilizing them are known or may be developed. It is a well known fact that winters reduce the numbers of parasites considerably below their status of the previous year. The host is likewise reduced, oftentimes, but the parasite can not reproduce extensively until its host is first plentiful. Consequently the host is free to do more or less damage in the first months of the growing season, whereas the parasite requires a month or two to "catch up" or reach effective numbers. At present, projects begun in California are under way in several states of this country to develop an abundance of the egg parasite (*Trichogramma minutum*) of certain moths in laboratories during the early spring. They are then released in orchards for the control of the codling moth, or in southern fields to hold the cane stalk borer or celery leaf tyer in check, while the outdoor parasites are building up a controlling number. The method of securing the parasite in plenty is to use the Angumois Grain Moth which reproduces in stored grains indoors under warm conditions during the early spring and whose eggs can, therefore, be secured in large numbers. These eggs are exposed to the adult parasites which deposit their eggs into those of the moth. The life cycle of the parasite is short, hence a good number of generations is produced annually and many thousand individuals are reared quickly with proper mechanism and management.

The variation in the beginning of the growth period from the north to the south extreme of the United States amounts to several weeks. For example, between southern Ohio and Illinois and the northern boundaries of these states there is, in the instance of some crops, a difference of three weeks. As an illustration, let me cite the instance of the imported cabbage worm and its *Apanteles* parasite in Ohio. In the Muskingum Valley of that state early cabbage harvest is begun by the fourth of July, whereas some cabbages are only being set into the field in the north part at the same time. The chief pest of cabbage there is the imported cabbage worm, whose very efficient parasite was intentionally introduced from Europe many years ago to check the worm. In the first two generations the worm gradually develops injurious numbers, but the parasites also multiply rapidly. By the time that the cabbage crop is removed the parasites dominate the situation, but must soon be weakened in numbers again because the host grows scarce due to parasitism, and many thousands of parasites die without reproducing. At this time, the worm is probably doing its worst damage two hundred miles north. Valuable cabbages grown in the vicinity of large cities like Cleveland and Toledo are probably being injured, or artificial control may be practiced. Inasmuch as many thousands of the parasite may be gathered in a few days at Marietta, it would seem feasible to ship or carry such for release in the north parts to greatly supplement the work of the individuals present there and perhaps prevent severe damage to the crop and possibly avoid the extensive use of insecticides.

Perhaps the most feasible mode of favoring parasites of insect pests is to modify slightly the application of certain other insect control measures. When a pest is known to possess one or more effective parasites, wholesale slaughter of the hosts should be avoided in order to permit the parasites to increase. For example, the large green injurious tomato and tobacco horn worms are freely parasitized by a small wasp-like species whose mature larvae issue through the back of the host and spin their white cocoons there. When such cocoons begin to appear, many caterpillars could easily be assembled and placed in a screened cage, from which the parasites can go forth but which retains any moth that might have escaped the parasite. Many other insects might be kept at a minimum in this manner or a modification of it without excessive costs, if their parasites were better known and this method of biological control were studied with reference to them. Probably no other plan for the use of parasites has been more frequently suggested in earlier times.

In spite of careful state and interstate inspection service to prevent the spread of insect pests, some of these inevitably penetrate into new territory. Trade within and between states has been instrumental in transporting or disseminating such insects. It occurs also that their parasites are not spread at the same time, permitting the host to multiply to unprecedented numbers and to greatly increase damage. The common asparagus beetle, a European species, is capable of causing severe loss under favorable conditions. In the east, it is in part checked by a chalcid egg parasite which, as far as known from several attempts to locate it in Ohio and Illinois, has not followed its host into all its present geographical range in America. On the other hand, the squash bug, a native species of general distribution, seems to be without its egg parasite in Illinois, whereas such a species is known to exist in the eastern states. Providing a more extended study of these, and other insects, should confirm such findings as the above, the artificial spread of the parasites of these pests might be undertaken, and the parasites could probably be established with little cost or difficulty. Deserts, mountain ranges or large bodies of water may act as deterrents or barriers to the spread of parasites into the areas which may be reached with relative ease by their hosts on account of their better equipment for long distance travel.

The most obvious as well as most productive use that can be made of parasites is based on the fact that some of our plant-eating insects are of foreign origin. These have usually come to our country without their natural enemies, hence multiply without limitations and constitute some of our "millionaire" insect pests. A few major examples are the European Corn Borer, the Gypsy and Browntail Moths, the Japanese Beetle, the Codling Moth and the Imported Cabbage Worm. It has been recognized for about forty years, since the Gypsy Moth problem became acute, that one of the fundamental steps to take in attempts to control such imported and liberated pests is to study them in their native situations. These studies soon revealed that the insects were usually of relatively small importance in their old homes and that this difference in their status was caused by the work of one or more parasites. Thus was suggested the idea of bringing these parasites to this country where it was hoped they would eventually perform the same good service as in their native lands. The result is that many species of parasitic insects have been introduced and successfully established here in the last four decades and with more or less of the desired effect.

The procedure in such introductions naturally varies much due to the difference in habits of the parasites and their hosts and the advantage taken of earlier experiences for development of better methods of handling them. But the general essentials are as follows. Specialists in parasitic insects are sent by the states or usually the Bureau of Entomology of the United States Department of Agriculture to the native abode of the pests and their parasites. These men go for a year, or several years, or more, and establish laboratories in a crucial area where the host and its enemies are carefully studied before shipments of parasites to this country are attempted. Such studies are in the nature of bringing out facts that will lead to the intelligent manipulation of the parasites when they are transported, and even more for the sake of ascertaining whether the beneficial primary parasite may have parasites of its own, or secondary parasites, which, if introduced, would more or less impair the efficiency of the primary species. By means of laboratory technique, the secondary parasites may be eliminated, and a quantity of free primaries obtained for shipment. Other species have no secondary enemies. Native men, women and children are employed to collect the parasitized insects desired and deliver them at the laboratories. After their habits and life histories are studied, numbers of them are packed for shipment. They may be in the egg, larva, pupa or adult stage when sent, the stage preferred being determined by the knowledge man has gained of the ways of the parasite and its host. Frequently the parasite is a larva in the egg or other stage of the host, or in a cocoon of its own, out of, or in, the hosts' body or cocoon. A convenient time to send some parasites is in a cold season, when they are naturally dormant due to low temperature, or if sent in a warm season they have frequently been stored in refrigerators at temperatures of 40 to 50 degrees Fahr. on ship to prevent further development before they reach their destination. Or food and hosts may be supplied in cages to enable the parasite to continue its growth in a normal way in transit. If the parasite larva be in the host when sent, it may reach the pupa or even the adult state by the time it arrives after a journey lasting from one to two weeks.

If the parasites make the trip successfully, they are next placed in a laboratory to study further their habits, to determine whether hyperparasites may be present, and to develop large numbers for liberation. The breeding is done in many ways, depending again on the species concerned, and a considerable variety of cages and technique are employed. The hosts are provided in these cages to allow the parasites to multiply upon them. Usually when thousands are developed, they are taken, at the most opportune time known, to selected spots where the host is abundant, and where the environment is otherwise favorable to the survival of the parasite. Thereafter the parasite is dependent entirely on its own persistence in finding its hosts and in resisting the climate and other untoward influences. Sometimes our own parasites attack it, even when its native enemies have been left behind. Probably less than half the species introduced from other countries are established, or, if established may be of minor importance as factors in host control. Success depends on so many influences that the entomologists concerned need have intimate knowedge of every phase that composes the parasite's environment as well as of its habits and development. However, in spite of failures due to inadequate facts, the specialists who are close to the work are optimistic for the future, and Dr. L. O. Howard (2, p. 282) says "work of this kind is in its infancy, and its possibilities are great." It is necessary to point out again, however, that this method of combatting insect pests is not advocated as a panacea for all insect troubles, and can not be regarded as a solitary substitute for any or all other methods now in use.

Instances of Parasite Transportation.

The transportations of parasitic insects have by no means been to the United States alone, although this country started this type of work on a large scale. Porto Rico imported experimentally in 1911-13 from our own state certain wasp parasites (*Tiphia* sp.) for the control of the sugar cane grubs which are related to the Illinois corn-root destroying white grubs.

The Mulberry Scale threatened the silk industry in Italy (3), but it was almost completely freed of this pest by a minute parasite (*Prospaltella berlesei*) established there from America and Japan.

Australia inadvertently received the woolly apple aphis, a notorious louse pest of the apple, because its covering of woolly secretion protects its body against ordinary contact sprays. The apple industry had prospered greatly in that favorable country, until the arrival of this aphis. Professor Tillyard of Australia, with the aid of our entomologists, received importations of a small wasp-like parasite from the United States where it holds this pest in check. The parasite is flourishing in Australia, and as a result, the apple industry is doing the same.

The larch forests of Canada have been severely injured by an imported sawfly, whose larva eats foliage. About fourteen years ago, one of its foreign parasites was established, and by gradually increasing has now practical control of the host, the last reports indicating over seventy per cent mortality due to the parasite.

The Hawaiian islands present a peculiar biological situation in that they originally harbored few native crop pests. By international commerce the sugar cane leaf hopper became established there, and created heavy losses amounting in 1903 to $3,000,000. By 1906 some species of egg parasites obtained in Australia were multiplying rapidly, and after ten years Dr. Howard (3, p. 7) found that the leaf hoppers had been reduced to practical insignificance. This is only an example of numerous other instances of complete success with imported parasites in Hawaii. But this case is not typical of most introductions into the United States and elsewhere, for the reason that parasites taken to Hawaii have no native secondary enemies awaiting them, hence multiply with extraordinary rapidity.

Extensive attempts have been made with varying success to establish foreign parasites of imported pests in the United States. California has always been a leading state in experiments with biological control, and (4) "because of the spectacular results of the introduction of *Vedalia* the Australian ladybird, in the early days of California horticulture, the general public was inclined to favor this method of control to the exclusion of all others." The black scale "is still the most important pest of citrus in the state", and effective natural enemies are still being sought.

From 1911 to 1913 (5) the cocoons of the parasite of the alfalfa weevil were sent to Utah where alfalfa culture was damaged by this snoutbeetle. By 1922 the parasite "was practically covering the weevil territory", and parasitism sometimes reached 85 to 90 per cent or more.

Generally, the appearence of a new insect pest of importance in this country is a signal for the beginning of a search for its parasites. In the New England States thousands of acres of woodlands, and shade and forest trees have been defoliated at various times since 1889 by the caterpillars of the gypsy and brown-tail moths, both of which are of European origin. Than this there is no more extensive instance of damage by introduced pests and there is scarcely an example of a more far-reaching, attempt to control such pests by its introduced parasites. Since 1905 (6) "over 60 species of parasites" of these enemies of trees, "including predacious beetles, have been imported from Europe and Japan." Mr. Burgess indicates that many attempts failed, for "of this number 16 species have become established in New England. One-half of these have not become very abundant and are probably of slight importance." The damage, however, decreased "with more or less regularity until 1924, when only a small number of localized areas were defoliated." Observations over many years indicate that the number of parasites fluctuates with the result that occasional injury of more or less extent may be expected in the future. The same consequences will normally result in the instance of any other pest for whose control parasites are chiefly employed. The ideal of parasite importation in this and other instances is perhaps to find and establish a series of parasites, one or more attacking each stage of the host, and thus developing a sequence that will strike the host at various seasons of the year and perchance effect an adequate control in spite of variations in factors governing host and parasite abundance. However, this point of view has been criticized, and certain other plans may be more effective.

While the gypsy and brown-tail moths were the occasions for the first large-scale biological control project of the United

States Bureau of Entomology, others of large dimensions have since been instituted. The Japanese beetle is a relative of our common May Beetles or white grubs. It was first seen in this country in New Jersey in 1916 and the grubs in the soil wrought havoc on lawns, meadows and golf courses since that date, while the adults have done likewise to foliage, flowers and fruits in general. In 1920, the study of its natural enemies, including parasites, was begun in Japan (7), and up to January 1927, nine species of parasites were found there and in Chosen (Korea). One of the three Tachinid flies parasitizing the adult beetle frequently destroys from 50 to 100 per cent of its host and this species, among other parasites, has been introduced into this country. Six other species attack the host in the larval stage.

Among other pests of primary importance are the Mexican Bean Beetle, the Oriental fruit moth, and the European corn borer, all of which have occasioned the investigation of their native parasites, but those of the corn borer, the worst threat we ever had on our corn crop, deserve special mention. Although six two-winged (Diptera) parasites and seventeen wasp-like species (Hymenoptera), all native, have been found attacking the eggs, larvae and pupae here, ''the combined parasitism'' by these species ''has totaled less than one percent of the larvae and pupae collected each year'' (8). The native parasites are therefore ''practically negligible except in the case of the sporadic egg parasite, *Trichogramma minutum* Riley'' (8). Eight species of Diptera and Hymenoptera that parasitize the corn borer in Europe had been liberated in the infested area of the United States up to February 1927. Two of these (*Microgaster tibialis* Nees and *Exeristes roborator*) had been recovered incidentally at that time. It can not be predicted what the status of the imported species will be in the future. Ten years or more are sometimes necessary for a normal adjustment of parasites to their new surroundings and to reach their maximum efficiency, providing they become established at all. It is generally believed that parasites of the corn borer can not be expected to become an adequate check alone on this pest, the chief factor operating against a high proportion of mortality seeming to be the habit of the host of feeding sheltered within the corn stalk most of the time during the stages susceptible to attack.

The amount of hope to be placed in the method of control by the use of entomogenous insect parasites is obviously various according to the species considered. But whether they are in themselves sufficient to keep to an insignificant minimum the economic loss occasioned by their host, or must be supplemented by other methods of control, our friends, the parasitic insects, constitute one significant ally of man. Their importance does not permit them to be omitted from any program of control for foreign introduced pests and furthermore, it may be truthfully said that the appreciation of the possibility of their use against native pests has probably only begun.

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