BIOLOGICAL CONTROL

I. INSECT PESTS

BIOLOGICAL control, in the strict meaning of the term, embraces all agencies of a biological nature that exercise a restraining or controlling influence upon the multiplication of other forms of life. It represents, therefore, the sum-total of the activities of bacterial, fungal, and other diseases; of insectivorous birds and mammals; and of parasites and predators. In so far as the present article is concerned, reference is confined to the practical utilization of various species of beneficial insects, since it is in this connection that the greatest successes have been achieved.

The control of insect pests by biological methods has made rapid advances during recent years and there is now a bulky and increasing literature on the subject. It will be convenient to discuss these methods firstly with reference to the introduction of specific parasites, or predators, into countries where they did not previously exist: and secondly with regard to the utilisation of indigenous parasites.

Parasite Introductions.—Up to the present biological control has yielded the most satisfactory results in cases where injurious insects have become established in lands they did not previously inhabit, and have there developed into serious pests. In cases of this kind the noxious species have been free from the attacks of these parasites which restrain them in their lands of origin. Biological control therefore, aims at restoring a condition of natural equilibrium by the introduction of the missing parasite factor. It has to be remembered that introduced pests include some of the worst of the world's insect enemies of food supplies. The more trade is fostered between one country and another the greater are the chances of the spread of pests into fresh territories. Quarantine measures serve to delay and restrain such transfers taking place but sooner or later, one or other pest manages to run the gauntlet and establish itself in lands thus protected. Artificial measures of control have, in many cases proved impracticable and their application has involved expenditure of large sums of money to no real advantage. Biological control has consequently been resorted to as a sounder and, in the end, a less expensive measure. Every year brings fresh records of promising results achieved by its application, but it cannot be regarded as a universal panacea as the misinformed are too prone to view it. Each case requires the experience of skilled entomologists and has to be exhaustively considered on its merits. Biological control has had its failures and it cannot be assumed, as the growers did, at one time, in California, that all that is required is to obtain the natural parasites of a given pest and subjugation of the latter will follow.

Insular Conditions.—Up to the present time some of the most successful and complete examples of the biological method of pest control have come about when parasite introductions have taken place under insular conditions. There is the classical case of the Hawaiian Islands where biological methods have proved so successful that insecticides rarely form part of any control measure. Practically all the major pests of sugar-cane have been subjugated in this way. These include the cane leaf-hopper (*Perkinsiella saccharicida*), the Lamellicorn beetle (*Anomala orientalis*) and the cane borer weevil (*Rhabdocnemis obscura*).

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* By A. D. Imms, D.Sc., F.R.S., Rothamsted Experiment Station, Harpenden, in *Tropical Agriculture* Vol. VIII. No. 4, 1931.

In the last-mentioned example the control in certain localities is less complete and search for further parasites is being undertaken. To this list we have to add the successful control of the cottony cushion scale (*Icerya purchasi*) the avocado mealy-bug (*Pseudococcus nipae*) the cottony mealy bug (*Pseudococcus filamentosus*) and army worms. This is a most encouraging record yet it by no means includes all the successes achieved. Of the failures probably the most significant is in connection with the Mediterranean fruit fly: yet, in this case it is more properly regarded as a partial success than a real failure.

In Mauritius we find that the biological control of sugar-cane pests has also come to the fore. Among the most destructive enemies are larvae of several species of Lamellicorn beetles. One of these, *Oryctes tarandus*, is indigenous to the Island and is now largely kept under control by the solitary wasp *Scolia oryctophaga* which was introduced from Madagascar in 1917. With another species, *Phytalus smithi*, which got accidentally introduced from Barbados less complete control has been attained. The chief insect enemy of this beetle in Barbados is the solitary wasp *Tiphia paralella*. In 1914 the wasp was imported into Mauritius where it has since become established. Although the *Phytalus* has not so far been checked to the degree hoped for the *Tiphia* occasions considerable mortality. There is reason to believe that this parasite has not yet attained its full biological ascendancy, and that it will gradually exercise more complete control in future years. In the meantime, however, other methods of repression are still necessitated.

In New Zealand biological methods have resulted in a satisfactory control being achieved over the woolly aphis by the introduction of the Chalcid *Aphelinus mali* from the United States in 1921. The heavy expenses, entailed by repeated spraying of the orchards against this pest, has been very much reduced in consequence, with a resulting wider margin of profit in the pockets of the growers. Control of the blue gum scale (*Eriococcus coriaceus*) by the introduction of the ladybird *Rhizobius ventralis* from Australia, has been a complete success and the future control of the Oak Scale by biological means is stated to be well on the way towards being achieved. At the present time biological control is being applied with reference to a number of other pests which have found their way into New Zealand. In some cases the imported parasites have already become established, and the next few years should yield important results relative to the progress of these experiments.

The most recent example of the success of biological method comes from Fiji. The event has been celebrated by the appearance of a sumptuous monograph in 1930, wherein the whole campaign is recorded in detail. It is concerned with the repression of the coconut moth *Levuana iridescens* whose larvae, by destroying the palm foliage, threatened the copra industry of the islands with disaster. Since the *Levuana* proved to be free from natural parasites this fact suggested that its original home may be in some land other than Fiji. Search among the Pacific islands fail to reveal the incidence of this moth in any other locality so all hope of discovering its specific parasites had to be abandoned. Recourse, therefore, was made to allied coconut pests and the species, *Artona catoxantha*, was found to be subject to parasitism in Malaysia. On account of the close affinities of the two moths in question it appeared probable that *Artona* parasite would find in the *Levuana* an acceptable host. The campaign hinged on this possibility and after considerable difficulties the Tachinid parasite *Ptychomyia remota* was introduced from Malaysia, into Fiji. The success of the experiment was remarkable: six months after its introduction the Tachinid fly had spread throughout the area of Fiji affected by the *Levuana*. More than three years have now elapsed and the pest has remained under control, while the copra industry has undergone revival.

The successes just recounted appear to be largely due to a combination of favourable circumstances that feature more particularly in many, although by no means all, islandic areas. Under such conditions the native fauna is generally of a peculiar and restricted kind which has evolved as the result of long isolation. The indigenous parasite element in such faunas is often comparatively poorly developed and consequently introduced parasites meet with comparatively few enemies. In other words, they are able to establish themselves readily owing to the absence of any severe competition of a biological character. Furthermore, such islands have a warm equable climate which allows of the multiplication of parasites to go on unchecked by seasonal factors. Also, it has to be remembered that the area to be covered by introduced parasites is more or less circumscribed, particularly so in the smaller islands.

Continental Conditions.—Up to the present the most marked successes obtained on continental areas are with reference to more or less restricted territories, enjoying a warm and tolerably equable climate, and where the affected crops are not widespread. The early successes attending the importation of *Vedalia cardinalis* which preys upon the cottony cushion scale (*Icerya purchasi*) of citrus fruits are well known. This predator has subjugated its host in almost every country where it has been introduced. Local successes of this kind have been achieved in California, Florida, South Africa, Portugal, Syria, Egypt and the South of France. In California, also, the introduction of the beetle *Cryptolaemus montrouzieri* from Australia for purposes of controlling the citrophilous mealy bug (*Pseudococcus gahani*) has proved a far less expensive measure than spraying. Although the *Cryptolaemus* is unable to maintain itself from year to year, it can be induced to dominate the citrophilous mealy bug if it be continuously bred and liberated in large numbers. There are now a number of local establishments, or insectaries, through the citrus fruit area of Southern California that are given over to the propagation and distribution of the *Cryptolaemus*. The latter is a most efficient predator and speedily cleans infested groves. On the other hand, the host mealy bug continues to extend its range, with the result that the breeding and liberation of the *Cryptolaemus* has had to be extended and intensified. Believing that the efficiency of biological control would be strengthened if additional enemies, more especially internal Hymenopterous parasites, were available efforts have been made to locate the country of origin of the pest. In 1916 and 1917 Clausen explored a number of countries in the Far East without success. Further search was also made by F. Silvestri, on behalf of the Californian growers, in the Orient without discovering the parasite. In 1927 the citrophilous mealy bug was found by Compere in Australia which appears to be its natural home. Here it was found to be kept largely under control by natural enemies of various kinds and a number of the latter have now been shipped to California and are already safely colonised in some of the orchards. The next few years will reveal the results of those experiments and whether the degree of subjugation called for becomes achieved. There are other serious Coccid enemies of citrus fruits that have found their way into California, and whose repression forms part of an active programme of biological control today. Thus, the Chalcid *Laptomastidia abnormis* introduced originally from Sicily plays an appreciable part in the reduction of *Pseudococcus citri*. A serious enemy in the form of the black scale (*Saissetia oleae*) is causing great trouble today, and its control by biological means is one of the main projects of the Citrus Experiment Station at Riverside. Various introduced enemies obtained in South Africa have brought about a certain measure of control, but energetic measures are in progress with a view to augmenting their activities by the discovery of other parasites. The red scale (*Chrysomphalus aurentii*) and the purple scale (*Lepidosaphes beckii*) likewise have not so far been subjected to satisfactory biological control.

Passing now from citrus pests, the woolly aphis of the apple is one that troubles growers all over the world. Of recent years much attention has been devoted to the Chalcid parasite *Aphelinus mali* indigenous to North America. Reference has already been made to the successful introduction of this parasite into New Zealand. Its importation and liberation has also taken place in various continental areas: in many European countries it has so far proved of comparatively little value. In parts of Italy, however, it destroys its host at all seasons of the year and is proving an efficient parasite. In South America, especially in the Argentine, it has become particularly efficient, and is also giving promising results in parts of Australia. In South Africa it was at first a failure, but its re-introduction has been successful in certain localities.

Mention must also be made of the losses occasioned to the silk industry in Italy by the imported scale-insect *Diaspis pentagona*, which destroyed the mulberry. In 1891 the pest assumed such serious proportions that the Italian Government passed a legislative measure compelling mulberry cultivators to make strenuous efforts to cope with it. No satisfactory control was obtained, however, until the Chalcid parasite (*Prospaltella berlesei* was introduced and became established. Extensive and widespread liberations of this insect have since led to the subjugation of the *Diaspis* over a large part of Italy.

In Canada the enormous damage entailed by the European larch sawfly (*Lygaeonematus erichsoni*) to forests led to the introduction during 1912-13 of its Ichneumon parasite *Mesoleius tenthrendinis* from England. This parasite has steadily increased in efficiency and in 1927 was found in some localities to be destroying as much as 88 per cent of its hosts. It is now well established locally in South Manitoba where there appears to be no doubt that it has greatly reduced the prevalence of the saw-fly and its distribution among the forests of Eastern Canada is now being undertaken.

The successful introduction of the larch saw-fly parasite is now of especial interest and importance for the reason that the insect is subjected to the extremely cold winter conditions. For many years strenuous efforts have been made to control the gypsy and brown-tail moths in North America by biological means. Enormous numbers of parasites have been bred out and liberated and, in so far as the brown-tail moth is concerned, there is every indication that a tolerably successful degree of control has supervened. In 1924 the gypsy moth infestation reached its lowest level for twenty years and, in this connection, it is noteworthy that in the previous year the average collective parasiticism attained its greatest efficiency. Since then parasiticism has declined and a recrudescence of outbreak of the moth has occurred. The whole problem is complicated by many factors including climatic variations, wilt disease, reduction in plantng of favoured hosts, arsenical spraying and the wholesale destruction of the egg-masses. It is therefore difficult to evaluate the amount of influence that parasitization exercises. The special parasite laboratory at Melrose Highlands in the meantime continues its work of the mass breeding and liberation of beneficial insects. More recently a number of other immigrant insects have attained a widespread range in the United States and their control by biological means is under weigh at the present time. Among these pests: the alfalfa weevil (*Hypera variabilis*), the European corn borer (*Pyrausta nubilalis*), the Japanese beetle (*Poppilia japonica*) and the oriental peach moth (*Laspeyresia molesta*) are especially noteworthy. The alfalfa weevil was first reported in America in 1904, while the other pests mentioned are more recent immigrants. In the attempts to control these pests certain species of introduced parasites have become established, but the final outcome of the experiments can only be revealed in years to come. With the corn borer, for example, the greatest chances of success appear to be dependent upon the introduction of a whole range of parasite species, some being adapted to restrain their host in one part of its zone, and others in a different part. It seems unlikely that any one parasite, or group of parasites, will prove equally effective in relation to an insect which has already invaded over 100,000 square miles of territory, where there are notable climatic variations.

Utilization of Indigenous Parasites.—Suggestions have been frequently made, and actual attempts carried out, with a view to making use of indigenous parasites of native pests as agents in the control of the latter. It needs to be recollected that the subject involves somewhat different principles from those concerned with parasite introductions. In the latter case the building up of a condition of natural equilibrium by supplying the missing parasite element is aimed at. The utilization of indigenous parasites is largely concerned with efforts to modify a condition of equilibrium already highly adjusted. The operations consist either of conserving or increasing the numbers of a parasite or predator in a given area, with the object of obtaining a higher degree of control over an individual species of pest, or of attempting to colonise such parasites in a part of the country where they are scarce or wanting.

Conservation of Parasites.—The principle involved consists of either altering the host parasites ratio by the adoption of methods which allow of more hosts than parasites being destroyed; or, of the abandonment of measures tending to reduce the existing parasite population. Various attempts have been made or advocated in Europe towards these ends but no clearly proved success has been reported. Such methods are only likely to be successful when carried out by general agreement among cultivators over a wide area; on a small scale only a fraction of the insect population would be affected and no appreciable result likely to supervene. In recent years the method has been put into effect in Louisiana where the practice of buring the sugar-cane trash is claimed to be an ineffective measure for decreasing infection by the moth-borer *Diatraea saccharalis*. The trash, it appears, affords shelter to large numbers of hibernating parasites and, following this contention, it was left unburned at the sugar experiment station farm near New Orleans for a period of years, while the State planters as a whole burned their trash. During the years 1915 to 1921 it is stated that the percentage losses due to *Diatraea* were less by three per cent. to 17 per cent. over fields where the trash was left unburned.

Direct Increase of a Parasite Population.—It has been contended that the alteration of the host-parasite ratio in specific cases by the artificial quantitative breeding of suitable parasites is a practical possibility. A species of parasite where behaviour lends itself favourably to the application of the method is the Chalcid *Trichogramma minitum*. At the present day attention is being concentrated on this species in various parts of the world as a means of controlling the codling moth (*Cydia pomonella*), the sugar-cane borer (*Diatraea saccharalis*) and other moth pests. The *Trichogramma* is a very widely spread parasite of the eggs of such species: many generations a year can be reared in captivity on suitable hosts, and it is claimed that up to one million per day can be bred with comparatively simple standardized technique. Early in the season this parasite is comparatively scarce, while its spread is very slow owing to its limited powers of distribution, but it is maintained that if an intensive infestation can be induced at the right time, potential outbreaks of certain moth pests might be largely counteracted by the wholesale destruction of their eggs by this means. In a recent issue of *The Tropical Agriculture* (Vol. VII, pp. 292-295) R. W. E. Tucker has given an account of his experiments in controlling *Diatraea saccharalis* in Barbados by mass liberations of *Trichogramma*. The results so far obtained promise to give satisfactory control of the pest in question. In the meantime good work along similar lines is being carried out against the same pest in Louisiana; against the codling moth in California; and also against the oriental peach moth elsewhere.

Transference of Parasites to New Areas.—Theoretically this method appears to be a feasible one if the absence of a given parasite in a specific area is attributable to causes other than those of a climatic nature. As long ago as about 1872 experiments of this nature were stated to have yielded beneficial results, but it is not possible to discover whether such effects were permanent or not. Quite recently E. H. Hazlehoff has claimed to have achieved promising biological control of the sugar-cane aphid (*Oregma lanigera*) in Java by transfering its native parasite (*Encarsia flavoscutellum*) from established cane fields into newly-planted areas. Owing to the practice of crop rotation, it appears that the aphid establishes itself more readily than the parasite in new cane fields, but the parasite when artificially introduced readily adapts itself and holds its host in check.

L. O. Howard in his *History of Applied Entomology* (1930) instances two very recent experiments of a similar nature. In one case, an experimental reafforestation area in Nebraska was suffering severe losses of its young coniferous trees from larvae of the moth *Rhyacionia frustrana*. The transfer of colonies of an Ichneumon parasite from Virginia, and their liberation in Nebraska, led to an extraordinary change in the situation. In areas where the parasites were liberated as much as 80 per cent. of the hosts were attacked by them, and the percentage of affected trees declined by 60 per cent. In the summer of 1929 there was definite promise that the parasite would be the solution of a very difficult problem. The other case instanced concerns sugar-cane pests in the Island of Negros (*Philippines*), where W. Dwight Pierce, by redistribution of certain of the indigenous parasite among areas where they were scarce, is stated to have secured a greatly increased destruction of their hosts in such areas. An official report on this work has yet to be published and its appearance will be awaited with considerable interest.

The Outlook for Biological Control.—Biological control aims at bringing about a permanent measure of pest repression. In the most successful cases it may render the application of artificial measures no longer necessary, while in others it may serve to supplement insecticidal or other treatment. It is only in comparatively rare instances, and in a very favourable environment, that almost complete suppression of a pest results, while in many cases a successful outcome is regarded as having been achieved once an appreciable degree of permanent control over a given pest has come about. The subject has shown itself to be infinitely more complicated than it was believed to be about 20 years ago and a great deal of work has been carried out.

The general result of accumulated experience all tend to support the essential soundness of its basic principles. Every project, however, must be considered on its own merits and has to be regarded as an experiment whose final practical outcome cannot be forecasted with certainty. The operations of biological control have often failed through ill-advised or wrong procedures and it cannot be too strongly emphasised that they require expert knowledge, special equipment and special methods. Technical knowledge of the behaviour of specific parasites in relation to their hosts is essential: it enables the most suitable parasites to be selected and the chances of failure, with the consequent waste of both energy and money, to be reduced as far as possible. Experience in the handling and transfer of delicate living insects over, perhaps, many thousands of miles of land and water is also called for. At the destinations of these living cargoes familiarity with the technique of breeding and liberating parasites, under favourable conditions, is of the utmost importance, or the efforts expended on their discovery and transmission will be discounted.

It has been pointed out, earlier in this article, that some of the most pronounced successes in biological control have resulted in its application under insular conditions. The remarkable work carried out in the Hawaiian Islands is partially due to the special combination of favourable conditions present in oceanic islands of this type, but every credit must be given to the insight and sound knowledge that prompted such schemes and brought so many to a successful conclusion. Probably all oceanic islands afford a more or less favourable environment for the prosecution of similar methods. Many islands of the continental type, as exemplified by New Zealand, Ceylon, the West Indies and others, appear also to lend themselves favourably to such experiments. In a few years' time we shall learn much with regard to the various biological control projects now under weigh in New Zealand and the experience so gained will be of the utmost value.

Over continental areas it has already been pointed out that certain localised conditions appear to be more favourable than others. California, bounded partly by the Pacific Ocean and partly by barriers of mountains and desert, is isolated physiographically to an exceptional degree. Conditions more or less analogous to those obtaining in this State prevail in other parts of the world. Thus, in Australia as R. J. Tillyard has observed, there are large areas bounded by mountains or by desert that are ecologically almost comparable with islands. Looked at from this point of view Western Australia, the elevated apple lands of South Queensland and other parts, should afford favourable conditions for the application of biological methods of pest control. Egypt, limited as it is by desert and sea, Mesopotamia, Palestine, Syria, and other lands likewise appear to be favourable for parasite introductions.

The biological control of pests menacing crops widely distributed over vast continental areas, where there are pronounced seasonal changes including hard winters, and a great variety of other ecological conditions, has to contend with manifold difficulties. The establishment and spread of an effective parasite population, over such areas, can scarcely result until after the elapse of a number of years. We have, as yet no proof that parasites alone will attain sufficient control and it remains to be seen whether artificial means will, or will not, be still necessitated as supplementary aids. The possibilites of utilizing indigenous parasites need much more thorough exploration than has yet been accorded to them. There is no promise that this method will become of general application but, so far as can be foretold, it is likely that it may prove efficacious under especially favourable conditions. Finally, the international transfer of the most valuable types of parasites between one country and another is a possibility held for the future. We may say in conclusion that, given due consideration of the factors so briefly outlined, the outlook for biological control is one full of promise. This also is borne out by the increasing number of examples of its application that are being put into being in countries practically all over the world. For a full discussion of the technique, and underlying principles of biological control, the reader cannot do better than digest the recent Bulletin by W. R. Thompson entitled *The Biological Control of Insect and Plant Pests*, published by the Empire Marketing Board, London, **1930**, price **1s.** net.