Biological Control of Insect Pests in the Hawaiian Islands *

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One of the outstanding results of the great commercial and agricultural developments of the past century has been the enormous increase of insect pests. Some of these pests have been distributed by commerce and many of them have become great pests only after leaving their home country. We need mention only a few of these which have been carried by commerce from one land to another, until now some are practically cosmopolitan, such as the black scale, the fluted scale, certain plant lice or aphids, the house-fly, etc. Others are somewhat less widely distributed such as the Hessian fly, the codling moth, and the Mediterranean fruit fly. Still others have limited distribution in their new habitat but are exceedingly destructive there, such as the gipsy moth in New England, the alfalfa weevil in Utah, the Popillia beetle in New Jersey and the sugar-cane leafhopper in Hawaii. Another group of pests includes those that have taken advantage of the changes in ecological conditions wrought by man and have become obnoxiously abundant because of great increases in their food supplies. A good example of these species is the Colorado potato beetle. This species also has greatly increased its range by natural spread and more lately has been introduced into Europe by commerce.

This enormous increase in insect pests during the past fifty years has incited the development of economic entomology, and it has been found expedient to develop and use many different methods of control, such as by farm practices, including rotation of crops, spraying, dusting, fumigation, and by ecological or biological factors. Moreover, the prevention so far as possible

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of the further spread of injurious species has been attempted by means of inspection and quarantine work.

The control of insect pests by ecological factors, to wit, by natural enemies, purposely introduced into any given fauna by man is a comparatively modern method of fighting such pests and is still in its infancy. This method is capable of unlimited development and offers great possibilities, but good results are obtained only by a prodigious amount of hard and careful work, attended by many disappointing failures.

Although it probably had occurred to thoughtful men years before that insect pests might be controlled by the introduction of their enemies from one country into another the first big attempt to carry this idea out was made, I believe, in 1888, nearly 40 years ago, when Albert Koebele, working for the U. S. Department of Agriculture, discovered the Vedalia beetle in Australia and successfully introduced it into California. The result of this introduction was phenomenal; the fluted scale was brought into subjection within a remarkably short time and ever since has never been more than a minor pest in California.

Encouraged by the success of Vedalia against the fluted scale in California, certain foreign countries which were troubled with the same pest sought to establish the Vedalia within their own boundaries. Among these was Hawaii, at that time an independent monarchy and a few years later a republic. As I understand the situation existant in Hawaii at that time the fluted scale had not spread to any great extent but had made itself conspicuous on street trees near the waterfront in Honolulu. The situation, however, in regard to both this and other pests was serious enough, and the services of Mr. Koebele were secured in 1893, by the Hawaiian Government. The Vedalia

EXPLANATION OF PLATE XIX.

4. *Olla abdominalis*.
5. *Coelophora inaequalis*.
7. *Coelophora pupillata*.
8. *Platyomus lividigaster*.
Cane aphis and introduced enemies.
had already been sent over from California at that time, in fact as early as 1890, and effected a cleanup quite as efficient as in California. Even to this day the fluted scale has been held in subjection, apparently more perfectly even than in California, so that rarely any more than a few scattered scales are found by the entomologist and an extensive infestation is entirely unknown. One of Koebele’s first acts on moving to Hawaii was to secure colonies of Cryptolaemus, which he had previously introduced into California from Australia. This ladybird was required at that time to help control the extensive infestations of *Pulvinaria psidii* Mask. on coffee and other plants. Other introductions from Australia probably through California were *Lindorus ventralis* (Erich.) and *Lindorus lophantha* (Blaisd.).

In 1894 to 1896 Mr. Koebele traveled extensively in Japan, China, Ceylon, Fiji, and Australia, and his introductions at that time include: *Coelophora inaequalis* (Fab.), a lady beetle from Australia, feeding on plant lice or aphids and especially needed at that time to feed on the sugar-cane aphid; *Brachymeria obscurata* (Walker), a small hymenopterous parasite of Lepidoptera and especially desired to control the destructive coconut leaf-roller; *Microbracon omiodivorus* (Terry), another hymenopterous parasite, found by Koebele with the preceding in China and introduced for the same purpose; *Scymnoides lividigaster* (Muls.), an efficient little lady beetle from Australia, feeding on plant-lice; *Coelophora pupillata* (Schön.) from China, another lady-beetle, more inclined to inhabit trees than low vegetation and much rarer in Hawaii than the ubiquitous *inaequalis*; *Orcus chalybactus* (Boisd.) from Australia and *Chilocorus circumdatus* Schön. from southern China, both of these valuable ladybeetles predaceous on diaspine scales, the Orcus found principally on the foliage of trees and the Chilocorus on the trunk and branches. A considerable list of other beneficial insects was introduced at that time, including several other species of ladybeetles, some of which flourished for a time but later died out. The records of that period are very incomplete and a number of important hymenopterous parasites, especially of scale-insects, which were found established in the islands later were probably introduced by Koebele at that time. The principal accomplishment of the period, however, was the introduction of ladybeetles, which were
always favorites with Mr. Koebele following the success of Vedalia. Fourteen species of ladybeetles now more or less common in the Islands and possibly one or two others belonging to the genus *Scymnus*, of which we have no exact records, were introduced between 1890 and 1895. At least seven other species of ladybeetles introduced at that time disappeared a few years later.

The practical results of these introductions are hard to evaluate at the present time inasmuch as the seriousness of the infestations of scale and aphids has not been fully recorded. However, in one place in the Fauna Hawaiensis, Dr. Perkins mentions the enormous number of aphids found on the trees and shrubs in the native forests before the introduction of the ladybeetles and it is at least reasonable to suppose that similar conditions prevailed in the low lands in regard to the infestation of scale insects and aphids on the introduced flora. The fact, also, that nearly all of Mr. Koebele's earlier introductions were planned to control these pests, indicates that the situation at least was not satisfactory. Today Honolulu is remarkably clean in regard to the infestation of aphids and scales on trees and shrubbery, although the situation has been greatly helped in some respects by more recent introductions. Mr. Fullaway in 1923 has the following to say in regard to a certain class of scale insects: "Undoubtedly the present situation with regard to mealy-bug infestation represents a great improvement over the conditions prevailing, say twenty or twenty-five years ago, and much of this improvement is due to the excellent work done by the numerous species of coccinellid beetles introduced by Koebele from the Orient and Australia."

In consequence of the success of these initial introductions by Koebele, practically all subsequent entomological work in the Islands has been directed along the same lines and one serious pest after another has been either greatly reduced or entirely controlled by enemies discovered in Africa, America, Australia and the Orient by Koebele, Perkins, Muir, Silvestri, Bridwell, Fullaway, Osborn, Williams and Pemberton.

In 1900, the sugar cane industry of the Islands began to be seriously checked by a very small insect known as the sugar-cane
leafhopper (*Perkinsiella saccharicida* Kirk.), which somehow had become established from Australia a few years earlier. This insect is extremely prolific and when multiplying unchecked it increases to such an extent that the sugar cane is badly stunted and finally killed. The adults migrate especially at night from one field to another, flying generally from the older cane to younger fields. By 1904 the situation had become extremely bad and the whole industry was suffering enormous losses and was threatened with entire destruction by this insect. There seemed to be no practical means of combating it, as spraying was impractical on account of the great acreage involved and the jungle-like growth of the older cane. What natural enemies there already were in the Islands, including spiders, ladybeetles, a dryinid parasite, several species of endemic flies belonging to the genus *Pipunculus*, a native mimesid wasp, a predaceous earwig, etc., were inconsequential in controlling the increase of the leafhopper. Due directly to the ravages of this insect the Entomological Department of the Hawaiian Sugar Planters’ Experiment Station was organized in 1904 and Dr. Perkins was placed in charge. Other members of the staff at that time or soon afterward were Koebele, Kirkaldy, Terry, Swezey and Muir.

In 1903, Koebele began investigating enemies of related leafhoppers in North America, conducting most of his work in Ohio and California. Certain parasites were discovered and sent to Honolulu, but without any practical results except, I suspect, that two secondaries, parasites of dryinid cocoons, either escaped or were liberated without knowledge of their habits. At any rate they were discovered in the cane fields a few years later. This was unfortunate as these secondary parasites effectively precluded any efficient control by two species of Dryinidae that were later introduced and established, one from Fiji in 1906 and the other from China in 1907. They also have almost exterminated the Fairchild dryinid, which is possibly a native species, at

EXPLANATION OF PLATE XX.

1. Sugar cane leafhopper *Perkinsiella saccharicida*.
2. Sugar cane leaf hopper *Perkinsiella saccharicida*, shortwinged female.
3. *Echthrodelphax fairchildii*.
Cane leafhopper and parasites.
least not known elsewhere and which was first discovered on Kauai in about 1902. This parasite at one time was propagated at the Experiment Station and distributed to the different sugar plantations. Mr. Koebele's work in North America, however, laid the foundation for future work which could not have been conducted otherwise so thoroughly and expeditiously.

In May, 1904, Dr. Perkins and Mr. Koebele went to Australia, where they spent nearly the rest of the year principally at Cairns and Bundaberg in Queensland studying and shipping parasites of the sugar cane leafhopper to Honolulu. The leafhopper was found everywhere present in the cane fields of Queensland, but hardly abundant enough to be injurious and never as numerous as on the least infested plantations in Hawaii. The parasites of numerous other leafhoppers were also studied and over a hundred different kinds of parasites of this group of insects were discovered.

Most careful efforts were made to send the extremely minute mymarid egg parasites to Honolulu but this was successful only after many attempts. Two ways of shipping the material were tried. Small cuttings of cane leaves especially of the midrib were shipped in cold storage but with little success, the low temperature apparently killing the delicate parasites. A more successful method tried later was the use of small cages containing living cane plants on which both leafhopper and parasites could live and reproduce en route.

In this way three mymarid egg parasites were successfully introduced, propagated at Honolulu and established as rapidly as possible on all of the plantations. The most important of these species, as subsequent results showed, was the one named *Paranagrus optabilis* by Dr. Perkins. Another egg parasite belonging to a different group and called *Ootetraslichl/r bealus* Perkins was sent over from Queensland and a little later by Koebele from Fiji. This also became established in the Islands, but did not later prove to be so important as Dr. Perkins thought it might become at the time of introduction. Other introductions of Koebele and Perkins during that year were an epipyropid moth parasitic in the larval stage on the leaf-hopper, two species of *Verania* and *Leis testudinaria* (Muls.), these
three being ladybeetles, a species of Dryinidae and a predaceous syrphid-fly of the genus *Baccha*, but none of these became established.

In 1906, Mr. Frederick Muir introduced *Haplogonatopus vitiensis* Perkins, a dryinid parasite of the leafhopper from Fiji,
and *Pseudogonatopus hospes* Perkins, another species of the same family from China, the following year. The latter species was lost sight of for nearly ten years but was found well established and widely distributed in the Islands in 1916.

As the result of these introductions and very largely through the work of the egg parasite, *Paranagrus optabilis*, the leafhopper was brought more or less perfectly under control, or at least to such an extent that sugar cane could be grown profitably throughout the Islands; the extremely heavy monetary losses amounting to millions of dollars, that were suffered during 1904 and the few preceding years, were very largely stopped.

Beginning about 1915 and continuing for several years there was a recrudescence of leafhopper outbreaks, involving sometimes nearly whole plantations but only a few plantations at one time. These outbreaks generally started during the cooler winter months and sometimes lasted well into the summer, and on one plantation situated on the windward and wetter side of Hawaii, the condition became chronic and lasted through several years. These outbreaks were due either to conditions unusually favorable to the leafhopper itself or in some cases to conditions distinctly unfavorable to the egg parasites.

On account of these outbreaks it became desirable to import, if possible, additional enemies of the leafhopper, and in 1916 Mr. Muir brought back from Formosa another egg parasite, later described as *Ootetrastichus formosanus* Timb. This species was propagated in Honolulu and distributed from there during the following year, but although it soon became established it failed to produce any appreciable effect on the severity of the outbreaks. In the fall of 1919 Mr. Muir went to Australia and while there discovered that a common mirid bug, *Cyrtothinus mundulus* (Brededin), instead of being a plant-feeding species like most members of the family to which it belongs, lives instead on the eggs of the leafhopper. After a very careful and prolonged investigation of the habits of this little bug it was decided to try to establish it in Hawaii. When Mr. Muir returned to Honolulu in 1920 he brought along a small number of *Cyrtothinus* and Mr. Pemberton soon afterwards departed to Fiji, where the species is also common, to collect and ship
larger numbers of them to Honolulu. This was successfully accomplished and the species was also propagated in cages at Honolulu and distributed during the fall of 1920 and the following winter to the plantations that were suffering most from leafhopper outbreaks. The species was found established on one plantation the following summer and soon had increased enormously and become distributed throughout cane growing areas of the Islands, even appearing on certain Islands where it had not been purposely distributed.

The effect of this introduction was soon apparent. Ewa Plantation on Oahu, where the leafhopper had occurred previously in large numbers year after year, was no longer afflicted. At Mountain View section of Olao Sugar Co., on windward Hawaii, the leafhopper was also brought under control after several years of continuous and severe infestation.

![Cyrtorhinus mundulus](image)

As the result of the introduction of Cyrtorhinus the biological control of the sugar cane leafhopper has apparently been completely solved in Hawaii. This control came as a result of work extending over a period of nearly twenty years and the investi-
igation of the enemies of the same or related species of leaf-
hopper in North America, Formosa, China, the Philippines, Java,
Fiji and Queensland, requiring several foreign trips by Koebele,
Perkins, Muir, Williams and Pemberton.

Another important pest of sugar cane in Hawaii is the sugar
cane borer, *Rhabdocnemis obscura* (Boisd.), thought to have
been accidently introduced by importations of seed cane from
Tahiti in 1854 and known to have damaged cane in the vicinity
of Lahaina, Maui, as early as 1865. It is presumably native to
New Guinea and the adjoining islands, and the original food
plants appear to have been sago palm and other palms and banana.
It is now widely distributed in the islands of the Pacific and in
northern Queensland, but does not occur in Java, Malay Peninsula,
Borneo or the Philippines.

This pest had for many years caused losses that have been
conservatively estimated at about one million dollars annually
for the entire industry. The infestations were always very
irregular, in some fields ranging so high that 50 per cent or
more of the crop was destroyed. A few plantations that offered
more favorable conditions for the beetles suffered much greater
losses than others, even up to one-fourth of their total
annual crop.

The great success following the importation of the parasites
of the sugar-cane leafhopper undoubtedly encouraged the plan-
ters to undertake the search for natural enemies of the cane
borer, and this arduous undertaking fell to the lot of Mr.
Frederick Muir. The work was begun in 1906 and was com-
pleted in 1910. In July, 1906, Mr. Muir left Honolulu and
spent about six months in southern China and several months in

EXPLANATION OF PLATE XXI.

1. Cane showing work of borer.
3. Egg *in situ* in rind of cane.
4. Larva of borer.
5. Pupa of borer.
6. Cocoon *in situ*.
7. Adult tachinid fly, *Ceromasia sphenoaphori*.
8. Borer larva with maggots of tachinid issuing.
Rhabdocnemis obscura, its work, life history, and its parasite, the New Guinea Tachinid (Coromasia sphenophori).
the Malay States and Java without finding any trace of the cane borer. Later in the year of 1907 he proceeded to Amboina and Larat and found the beetle in great numbers in Larat in sugar cane, pinang palm and sago palm, but without a trace of parasites. Returning to Amboina from Larat Mr. Muir discovered the beetles there in sago palms and associated with them a tachinid parasite.

The great problem now was to ship this newly discovered parasite to Honolulu alive by a very round-about route, via Macassar, Hongkong and Japan. Mr. Terry was sent to Hongkong to take care of the shipments as they arrived from Amboina. The flies, however, were always dead when they reached Hongkong, due to the poor connections at Macassar. Mr. Muir finally brought a consignment of flies to Hongkong personally but the last ones died for unknown reasons only a day before the destination was reached.

It was therefore decided that it would be impossible to transport the parasite via Hongkong and in November, 1908, Mr. Muir proceeded from Hongkong to Ceram in hope of working out a new system of transportation or of finding another locality whence the parasites could be shipped more easily via Australia and Fiji. In Ceram the beetle and its parasites were both found, but Mr. Muir decided to try New Guinea, which had better means of communication with Australia. Consequently in April, 1909, Mr. Muir proceeded to Port Moresby, Papua, where he immediately found the beetle and its parasite. He decided that the best course would be to stock cages with the beetle larvae, expose the latter to the parasites and personally accompany the shipment to Honolulu. If the flies hatched out en route they were to be kept alive if possible until they reached their destination. Unfortunately for the success of this plan Mr. Muir had contracted typhoid fever in Papua and on arriving at Brisbane was forced to go to a hospital. His cages were forwarded to Honolulu, but the flies had all hatched out and died before reaching the destination. After recovering from the fever Mr. Muir returned to Honolulu to regain his strength before attempting to make another shipment of the parasites from Papua.
On account of the short life cycle of the parasite it was decided that it would be better to arrange breeding stations in Australia and possibly also in Fiji, and in January, 1910, Mr. Muir departed for Brisbane, where he had arranged to meet Mr. Kershaw. A little later Mr. Muir went on to Papua and Mr. Kershaw to Mossman, where arrangements had been made to establish a breeding station. Preliminary attempts to dispatch the parasite from Papua to Mossman by mail having failed, Mr. Muir gathered together a large consignment of parasites and departed for Mossman. Due to unfortunate delays in the boat service Mr. Muir arrived at Mossman on May 5th, about eleven days late, and most of the flies had hatched out and died en route. However, about 90 adult flies were eventually obtained at Mossman from the Papua material and these were placed in cages prepared by Mr. Kershaw. The flies were propagated successfully in the cages and Mr. Muir proceeded to Fiji with a part of the first generation. Before leaving Papua he had contracted malaria fever, from which he had suffered both at Port Moresby and at Mossman. On arriving at Suva he was forced to go to a hospital but not until he had placed his parasites in a suitable breeding cage. On Aug. 9 Mr. Kershaw arrived at Suva with the second generation of parasites bred at Mossman, a part of which Mr. Muir took on to Honolulu on the same boat which had brought Mr. Kershaw, together with material which had been bred in Fiji. Mr. Muir arrived in Honolulu on August 16, 1910, with material from which many flies hatched, and a month later Mr. Kershaw arrived bringing additional parasites which had been bred in Queensland and Fiji. From this material the fly was successfully bred at Honolulu and distributed eventually to all of the plantations, on most of which it soon became established.

The economic results of this introduction which cost Mr. Muir so much time, hard labor, sickness and other hardships, was the reduction of the borer infestations throughout the Islands about 90 per cent and the consequent saving of many tons of sugar annually and many thousands of dollars. Inasmuch as one beetle larva can do considerable injury to a stalk of cane, sometimes causing it to be entirely lost through breakage by wind, even a 90 per cent control may permit of a considerable eco-
nomic loss, caused by the remaining 10 per cent. The control of the sugar cane borer is not perfect therefore, and some preliminary work has recently been conducted towards discovering and introducing additional natural enemies to more thoroughly control the cane borer.

The Mediterranean fruit-fly (*Ceratitis capitata* Wied.) was discovered in Honolulu in 1910, having been introduced by commerce, probably from Australia, a few years earlier. This pest found conditions in Hawaii extremely suitable for its rapid development and increase and not long after its discovery there it was found widely distributed in the Islands and soon increased to great abundance. This was due to the warm equable climate and the large number of suitable fruits ripening in rapid succession. This was true not only of cultivated fruit, but also of wild fruits, the valleys and hillsides in the uncultivated districts furnishing an almost constant supply of wild guavas. Due to the great variety of cultivated fruits and the unlimited supply of wild fruits often close to the cities and towns it was found impracticable to control the fruit-fly by spraying or clean culture. The control by natural enemies did not appear to be any too promising, as the pest was known to exist without any appreciable check by parasites in the Mediterranean region, South Africa and Australia. The Board of Agriculture and Forestry in Honolulu, however, decided that there was a possibility that the fruit-fly was native to the more equatorial parts of Africa and engaged Dr. Silvestri to investigate that part of the continent for natural enemies. This work was planned in the spring of 1912 and in July of that year Dr. Silvestri left Italy for West Africa, visiting French Guinea, Senegal, Nigeria, Dahomey, Gold Coast, Kamerun and the Congo. The fruit-fly was found in Nigeria and Dahomey but it was extremely rare and apparently controlled by parasites. Several species of parasites, some obtained originally from other species of fruit-flies, were then brought from West Africa to Cape Town, where they were bred and then taken on to Australia and from there to Hawaii. Dr. Silvestri left Cape Town on March 26, 1913, arriving at Sydney on April 19 and at Honolulu on May 16. He brought with him *Opilus humilis* Silv., *Dirhinus giffardii* Silv., *Galesus*
silvestrii Kieffer, from Africa and *Diachasma tryoni* Cam., which he had collected in Australia.

All of these parasites were successfully propagated at Honolulu and liberated in the Islands, but only the opine parasites, *Diachasma* and *Opinus* proved later to be of much consequence.

A second expedition to West Africa was undertaken by Messrs. Fullaway and Bridwell in 1914 which resulted in the introduction of two additional parasites. Mr. Fullaway returned to Honolulu in October, 1914, bringing with him living specimens of *Diachasma fullawayi* Silv. and *Tetrastichus giffardianus* Silv. Both of these parasites were propagated at Honolulu and later became well established. Mr. Bridwell stayed in Nigeria after Mr. Fullaway left, to make further studies on fruit-fly parasites, but was later forced to proceed to Cape Town on account of severe sickness. He made his way back to Honolulu, via Australia, arriving home in the fall of 1915.

These introductions have not resulted in the perfect control of the fruit-fly in Hawaii, but nevertheless have brought about a great reduction in numbers. The parasites have now reached a stage of equilibrim in their control and produce a mortality of about fifty to sixty per cent. The larval habits of the fly make further reduction practically impossible, as the character of much of the fruit infested affords a large measure of protection to the larvae. In the thin-fleshed fruits like the coffee berry the percentage of parasitism rises much higher. But it is possible now to grow fruit in Honolulu, with a fair chance of obtaining plenty for the table, and almost every residence has at least one avocado or mango tree. In fact the people of Hawaii would be disposed to regard the fruit-fly rather lightly if it were not for the stringent quarantine imposed by the mainland, which causes no little inconvenience to the tourists and other travelers.

About the time that the fruit-fly was discovered in Honolulu, another pest of sugar cane began to attract attention. This was *Anomala orientalis* (Waterh.), one of the scarabaeid beetles, which presumably had been imported with nursery stock from Japan or China at least several years before its discovery. As the species spreads very slowly and lives almost all of its life underground it might have been present for years without being
noticed if it had not chosen for its habitat some of the choicest cane land on Oahu. In certain spots on two plantations which naturally came to be called anomala spots, the larvae of this beetle became very numerous and feeding more or less extensively on the roots of the sugar-cane as well as on refuse plant tissues in the soil, they caused the cane to become badly stunted and in many cases killed whole stools of the cane outright.

In 1913 Mr. Muir began to investigate the enemies of this and related beetles in Japan, China, Formosa, Java and the Philippines. Several species of *Tiphis*, a carabid beetle from Japan and at least two species of dextiid flies were sent to Honolulu and liberated in greater or less numbers, without any of them becoming established.

In the Philippines Mr. Muir found that *Scolia manilae* Ashm. works on several allied species of beetles and that it could be readily propagated in small cages or glass tumblers. Mr. Osborn and later Dr. Williams were sent over to the Philippines to assist in the rearing of this species. In the winter of 1915-16 shipments of this parasite began to arrive in Honolulu from Los Banos. The shipments that arrived during the winter gave very discouraging results as very few of the wasps emerged from the cocoons and the few that did emerge had little vitality and died in a few days. It was finally decided that the cold weather encountered by the steamers on the trip from the Orient was proving fatal to the parasites although the shipments were not made in cold storage. It was thought that shipments made later in the season, when the weather became warmer, would produce better results and such proved to be the case. A considerable number of lively, healthy wasps were secured during the summer of 1916 from the later shipments and these wasps were liberated in the Anomala spots. Others were kept for breeding which was carried on successfully until the establishment of the Scolia was fully assured. In September, 1916, much sooner than was expected, the Scolia was found established in the field. By the following summer the wasps had become extremely abundant in the Anomala-infested districts and were collected by the thousands and distributed to the other Islands. This distribution was
undertaken partly to forestall any further spread of the Anomala, but mostly as an attempt to control the related Adoretus beetle which had been a pest for many years on rose bushes, grape vines and many other trees and shrubs throughout the Islands.

Within two years from the time of its introduction the Scolia had brought about a marvelously complete control of the Anomala beetles, and within that time, or later, it also became established on several of the other Islands, thus showing it could work equally well on Adoretus. It, however, has not done nearly as much to control the Adoretus as was hoped for at first and this without question is due to the fact that the Scolia prefers the open, light soils of cultivated lands whereas the Adoretus breeds most abundantly in sod lands. But if the Scolia had saved the day for the sugar-planters and many thousands of dollars in losses to the sugar crop what more could be expected of it? The Adoretus perhaps some day will be controlled by another introduction, such as a Tiphia, and doubtless it would have been brought under control long before now if it were a pest of one of the staple crops of the Islands.

The armyworm formerly was a pest of great importance in the Islands. After the winter rains had produced an abundant growth of grass and weeds, the caterpillars appeared annually in enormous numbers and devoured almost every green vegetation in their path, frequently invading cultivated crops such as sugar cane. Koebele in the nineties had introduced several parasites, including two ichneumon flies, Amblyteles koebelei (Sw.) and A. purpuripennis (Cress.), probably from California, and one or two tachinid flies, but better results followed the introduction of the mynah bird. Since this bird was introduced the number of armyworms has been greatly reduced and they now appear in injurious numbers, during the late winter and spring, only locally. They still continued to cause considerable damage to sugar cane on some plantations and remained a pest of considerable importance to the dairy and cattle raising industry, especially at higher elevations on the islands of Maui and Hawaii.

In 1922, Mr. Osborn, who was working in Mexico, sent to Honolulu several armyworm parasites, of which the most im-
important was *Euplectrus platyhyponae* How. This little parasite deposits a group of eggs on the back of the caterpillar, which in a short time hatch and eventually destroy the host by sucking its juices. The Euplectrus proved to be a very easy parasite to propagate and was reared and distributed in large numbers. Finally, in October, 1924, it was found established in several places on Hawaii. In 1923, Mr. Osborn sent another important army worm parasite from Mexico, which for some reason failed to propagate, but nevertheless was liberated in considerable numbers. This was *Apanteles militaris* (Walsh). It is perhaps too early to say that this introduction has failed, as the parasite may be recovered later.

Several other less important pests have been brought under control or considerably reduced by introduced parasites, but perhaps it would not be worth while to discuss these in as much detail. In 1916, Mr. Fullaway imported *Opus fletcheri* Silv. from India, which has done good work on the melon fly, so that watermelons, cucumbers, and some other vegetables can be grown successfully once more.

In 1922, Mr. Osborn introduced from Mexico, *Pseudaphycus utilis* Timb. and several ladybeetles, which brought about a spectacular control of a mealy-bug, *Pseudococcus nipae* (Mask.), which for years had been a bad pest on avocado, fig, mulberry, guava and banyan trees. This remarkable cleanup was mostly accomplished by the Pseudaphycus, a small, yellow internal parasite, but at least one of the ladybeetles, *Hyperaspis silvestrii* Weise, also became established.

In spite of good quarantine work certain seed-infesting beetles, known collectively as Bruchidae, have been constantly appearing in the Islands until now some ten or twelve have become established. Certain of these cause considerable damage in stored

**EXPLANATION OF PLATE XXII.**

1. Mexican armyworm parasite, *Euplectrus platyhyponae*.
2. Cluster of eggs on armyworm.
3. Parasite larvae on armyworm.
4. Parasite larva, highly enlarged.
5. Dead armyworm fastened to leaf by cocoons of the parasite.
Mexican armyworm parasite (*Enplectrus platyhyptena*) and its life history.
beans, or even attack these in the field. Others attack the seeds of the mesquite, the pods of which form an important item of cattle feed in the Islands. In 1910, Mr. Fullaway brought about the establishment of two parasites, which had been sent from Texas by the Bureau of Entomology. One of these was a tiny egg parasite, *Usca semipennata* Gir. and the other a braconid, called *Heterospilus prosopidis* Vier. The establishment of the latter was not known to the entomologists until 1917, but at that time it was found to be common and a little later it was found widely distributed in the Islands. In 1921, Mr. Bridwell, working for the Bureau of Entomology, collected several other bruchid parasites in Texas, which were brought to the Islands and propagated by Mr. Willard. These include two additional braconid parasites, *Glyptococastes bruchivorus* Crawf. and *Urosigalphus bruchi* Crawf., also two chalcid flies, *Lariophagus texanus* Crawf. and a species of *Horismenus*. All of these have become established and are doing good work in reducing bruchid infestations in mesquite pods.

Fern weevil parasite (*Ischiogonus syagrii*).

In 1916, Mr. Osborn sent over from Los Banos a small mymarid which is parasitic on the eggs of the corn leafhopper. This is
very similar to the important mymarid parasite of the sugar-cane leafhopper and soon became established. Because of the discontinuous planting of corn both in time and space the parasites of the corn leafhopper do not have much chance to show their real worth, and the leafhopper itself carries over better to the next crop.

Fern weevil parasite ovipositing on fern weevil grub, and parasite larvae feeding on fern weevil grub.

The fern weevil is another Australian immigrant that soon spread to the native forest and threatened to destroy an important element of the undergrowth. The forests of Hawaii have been declining for many years, due principally to the inroads of cattle, wild pigs and goats, and it was a matter of concern to have an insect pest increase the damage. After Mr. Pemberton had finished his work in Fiji in 1920 in regard to
the importation of Cyrtorhinus, he went on to Australia to hunt for a parasite of the fern weevil. Deep in the forests of New South Wales he found the fern weevil and several other related species, although they were rare and well controlled by parasites. The principal parasite was a braconid, named later *Ischiogonus syagrii* Ful., which was sent to Honolulu in 1921. This parasite was liberated in the forests, where the fern weevil was at work, and soon became established. Later investigations show that the introduction of this parasite has been successful in checking the weevil.

At this point it would be well to mention two other introductions made by Pemberton in 1921 and 1922. These were the fig insects, *Pleistodontes froggatti* Mayr, and *P. imperialis* Saund., essential to secure the seeding of two important Ficus trees, *Ficus macrophylla* and *Ficus rubiginosa*. Of these two trees only a few specimens existed in the Islands, and the botanists of the Experiment Station, H. S. P. A., in Honolulu thought they would become valuable reforestation trees, if the insect pollinators that live in the fruit could be introduced and established. This has been accomplished and the trees are now setting large crops of fruit and large quantities of seed have been gathered and distributed in the forests, in some cases by the aid of airplanes. When this work was started in 1920, it was planned to introduce the insect pollinators of several other species of Ficus, but so far this plan has not met with success.

Before closing this account of the beneficial insects introduced into Hawaii it will be necessary to consider another group of insects, quite different from an ecological standpoint from any heretofore mentioned. I have reference to the insects introduced by Koebele in 1902 from Mexico to control or to prevent the

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**EXPLANATION OF PLATE XXIII.**

1. Ripe Moreton Bay fig showing flowers.
2. Flowers of fig highly enlarged: A, female flower; B, gall flower; C, male flower.
3. *Pleistodontes froggatti* on bract enclosing fig.
4. “ “ entering fig.
5. “ “ entering fig.
6. “ “ ovipositing in gall fig.
7. “ “ issuing from ripe fig.
Pleistodontes froggatti.
spread of Lantana. This shrubby plant is a native of the warmer parts of America but has escaped from cultivation in Hawaii, Australia and India. In Hawaii it became a great nuisance to the dairy and cattle men, as it spread so rapidly and occupied valuable pasture land. It was grubbed out with considerable labor and expense only to spring up again from the seed.

The attempt to control a noxious plant by introducing insects that feed upon it was at that time an entirely novel proceeding, and it caused considerable worry and fear to Dr. Perkins and Mr. Koebele lest they introduce some insect of such generalized habits that it could turn from the Lantana to a more valuable plant host. These entomologists, therefore, exercised extreme care in their selections of the Lantana insects of which Mr. Koebele had found many species in Mexico. Some of the most important species which Mr. Koebele recommended from his study of their habits in Mexico, never were received in Honolulu in sufficient numbers to permit their colonization and establishment, but nevertheless eight species of insects were finally established. This list includes two species of butterflies and two moths, the larvae of which feed on the inflorescence, one leaf-mining moth, a tingitid bug that feeds on the leaves and causes them to drop, and two dipterous enemies, one a small Agromyza feeding in the seeds and the other a trypetid forming galls on the stems.

The effect of these introductions has been a steady, gradual decline of the Lantana although now a stage of equilibrium has probably been reached. The plant is no longer feared by the cattle men and does not spring up again from the seed in any great numbers after having been grubbed out. It is still common everywhere through the Islands but hardly produces more than enough seed to keep it from dying out. The introduction of the Lantana insects has therefore been very successful, and although two of the insects have occasionally been found feeding on other plants, these plants have little or no commercial importance in the Islands.

There is a considerable amount of current and uncompleted work on biological control in the Islands. Dr. Williams was
searching for wire worm parasites for several years in the Philippines and South America, and Mr. Pemberton in Australia; but both without success. In the meantime the need and demand for wire worm enemies has greatly lessened, as the pest has proved recently to be less important than formerly and controllable by cultural methods. The need for biological ecological control of the horn fly has been long felt in the Islands by dairy and cattle men and numerous attempts have been made to introduce certain beneficial insects for this purpose from Australia, North America and Europe. These introductions have included both direct enemies of the horn fly, that is, parasites and predators, and also certain insects like tumble beetles and other scarabaeid dung beetles, which either scatter or bury the dung, the establishment of which would tend to lessen the breeding places of the horn fly. This problem is evidently difficult and not much benefit has been derived from the introductions up to the present time; the work, however, has been conducted in a more or less desultory fashion on account of lack of financial support.

Additional work is also needed for the control of Adoretus and the sugar cane borer, as has been already noted. The corn aphid has recently received attention, after the discovery that it carries the mosaic disease from grasses and corn to sugar cane. The control of this aphid to such an extent that it will no longer be feared as a carrier of disease, is, I am afraid, an impossibility. Unfortunately there are already present in the Islands several secondary parasites of aphids, which would lessen the efficiency of any internal parasites and even if a ninety or even ninety-five per cent control could be brought about, this probably would not be sufficient to prevent the aphid from spreading the disease.

The pineapple planters have had some trouble with a mealy-bug, known as *Pseudococcus brevipes* (Ckll.), the injury caused by which, I believe, is mostly indirect. Plants infested with the mealy-bug attract many ants, which crawling about over the flowers are thought to cause cross pollination and the setting of seed. Seedy pineapples are the bane of the packers and the percentage of seedy fruit has been steadily increasing. Mr. Osborn discovered two parasites of this mealy-bug in Mexico in 1922 and Mr. Fullway in 1924 found several others in Panama, but attempts at the establishment of these parasites have so far failed.
In conclusion it would be well to point out one of the main reasons why so much success has been attained in Hawaii with beneficial insects. It is because the insect fauna of the Islands is extremely simple in comparison with that of the temperate zone of the mainland and still much more so in comparison with continental tropical faunas. The introduced parasites are generally free from all secondary enemies and soon increase to their maximum efficiency.

Yet there have been many failures. Probably not more than one introduction in ten has been established, even if we count only those insects which were introduced in sufficient numbers apparently to insure establishment. A few species have become established after the liberation of half a dozen females, and others have failed after the liberation of thousands of specimens. I believe that many failures of this kind are due to one complicating feature of the fauna, namely the great abundance of an obnoxious ant known as *Pheidole megacephala* (Fab.). Another reason for failure is the transportation difficulties. Many tropical insects which are to be imported have a short life history. They can not stand cold storage, and the long distances that they must be transported make it nearly impossible to get specimens to Honolulu alive. But if no expenses are spared to bring about results even this difficulty can be overcome in one way or another, as in the case of the introduction of the cane-borer tachinid.