No. 12 has something to do with the Kirra maker murdu or totem, but I cannot quite grasp what relation it has to the Moora. It is not the emblem of the Mooras. There were two of them. Their emblem was a slender cylindro-conical stone each, but this stone, so the blacks tell me, is "cousin belong Kirramurakoo. Himshow which Moora "them two stones belong."

The two women who were the ancestors of the Kirra maker murdu became Mooras because they killed another Moora who was notorious for his molestation of women. He worried the two women, and they got rid of him some-how, then went back to their camp, where they made a boomerang (kirra) each, and when the Moora annoyed them again they killed him with the kirras they made.

The stone is five inches long by about 2 inches wide at its widest part, and was found about eighteen miles west of this place.

The present holder of the Kirra maker Moora stones was very anxious to get this, as he says it completes his Moora, this part having been lost in his grandfather's time.

No. 15 represents some seed unknown.

No. 19 ensures to the possessor a plentiful supply of eggs. I found it among the bones of a skeleton of a man who had been shot at Neaylons Swamp, near Mungeranie. Directly I picked it up I showed it to a blackfellow who was with me. He very promptly pocketed it, and I had to struggle with him to get it back. He was very sulky with me for a couple of days, but finally brought a deputation of old men over to me to try and persuade me to hand it over to him, but the old men advised me to keep it myself. They assured me that I would always have a plentiful supply of eggs as long as I kept it, but, somehow, it does not work for me.

Nos. 20 to 30 represent various seed stones. Most of the white pebbles are wirrha bush seeds, but the use of the darker ones is unknown. Their highly polished appearance, and the fact that they are foreign to the country, is all that makes them magical.

THE BIOLOGICAL CONTROL OF NOXIOUS WEEDS.

By

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Plates XI.-XVIII., and One Text Figure.

In the rush and hurry of this present age, in which the speed of the world's evolution is greater than ever before, few opportunities are given to the ordinary man to pause and look backward, if only for a few moments, so that a little piece of the past may be viewed, and thereby a truer perspec-tive of the present gained. To-night we are gathered together in this hall to do honour to a great pioneer of bio-logy in Tasmania; and you have done me the very great honour of asking me to deliver this, the third R. M. Johnston Memorial Lecture, in memory of that pioneer. My prede-cessor in this lecture, Professor Wood Jones, whom, I am sure, we are all delighted to welcome back once more to Aus-tralia, said that the best way to honour the memory of this great man was to give of one's best in return. This I shall endeavour to do to-night.

Looking back to the time when R. M. Johnston lived and worked, I think the most striking thing was the immense field of research covered by the biologists of that time. A man could, if he chose, take the whole of Biology as his subject, and do original work in many diverse groups. There were even professors at some well-known Universities, who taught their students the three subjects of zoology, botany, and geology, and taught them well, too. Nowadays the various branches of science have enlarged their boundaries to such an extent that this wide field is no longer possible for any single human mind. As the boundaries of our knowledge extend, as the blank wall of ignorance is pushed farther and farther back, the conquered territory spreads out before us in every direction, and the man of science of the modern world has to choose his exact location in this great domain earlier, and set his direction of original exploration far more exactly, than did the great biologists of the past. Thus the modern scientific man is becoming more and more specialised in his knowledge; as the human brain remains much the same size as before, and the human mind is still only capable of holding a limited content of knowledge, he has to lose on the wider outlook of his predecessors, in order to gain the greater degree of specialisation in the narrower field.

At the present day, the subject of Entomology, which is only one of many branches of Zoology, is probably much greater in its content of knowledge than was the whole science of Zoology a hundred years ago. It is almost impossible to-day for any one man to cover the whole field of Entomology; we can only be specialists in some particular section of it, in which we work with the hope of wresting further secrets from Nature and turning them to the use of mankind. It has been my good fortune to work in several such fields, and it has seemed to me right and proper that, in striving to follow up Professor Wood Jones's dictum, I should select one such field suitable to the occasion, and give you a complete summary of the work so far done in it by modern workers. As the world looks more and more to Science to carry it forward on its evolutionary course, and needs more than ever before that scientific methods should be applied to the solution of its most pressing economic problems, I have selected that economic aspect of the science of Entomology in which I am most interested, as the subject for this lecture, viz., "The Biological Control of Noxious Weeds." I think that there is also another good reason for the choice of this subject, in that, of all countries in the world, Australia and New Zealand appear to have suffered most from the free spread of noxious weeds, and have the greatest need of assistance from science in controlling them.

I propose to divide the subject into five sections, as follows:—

(1) The General Principles of Biological Control of Noxious Weeds.
(2) The Early History of Biological Control of Noxious Weeds.
(3) The Biological Control of Prickly Pear in Australia.
(4) The Biological Control of Noxious Weeds in New Zealand.
(5) The Biological Control of Noxious Weeds in Australia.

I. THE GENERAL PRINCIPLES OF BIOLOGICAL CONTROL OF NOXIOUS WEEDS.

A weed has been well defined as "a plant out of place." Some weeds, when introduced into new countries like Australia or New Zealand, appear to have an almost infinite capacity for getting "out of place"; the term "noxious weeds" is suitably applied to such as these. When a weed has such a capacity to spread that it interferes with agriculture and checks the production of crops of economic value to the community, it is certainly a noxious weed, even though it may not be proclaimed as such by law. Every State of the Commonwealth now has a long list of these noxious weeds, some proclaimed as such throughout the entire State, some proclaimed only within limited areas such as a given shire or county. In their totality, they constitute an immense problem, rendered more difficult by the sparsity of population in the country districts, and the large areas held as units of cultivation. The total loss incurred by Australia through the checking of production of cultivated crops and the immobilising of large areas of potentially productive land, must run into many millions of pounds *per annum*. Owing to the heavy cost of labour in Australia, mechanical control of weeds is only practicable on restricted areas of the more valuable types of land. Chemical control is also costly, both as regards the materials employed and the expense of application. Control by intensive cultural methods is only applicable to a limited number of types of weeds, such as those of the ordinary vegetable or flower garden; at the one extreme we have the weeds of uncultivated lands, which are gradually replacing the native vegetation; and, at the other, the "weeds of cultivation," such as Hoary Cress and Skeleton Weed, which are actually being spread more and more through the ordinary cultural methods, such as ploughing. These weeds constitute one of the greatest dangers to the future prosperity of Australia.

Weeds are spread in many ways. Many of them seed profusely, and the seed may be carried far and wide by the wind or by floods, or it may be spread by the agency of birds or animals, or it may simply be scattered intensively over a limited area. Other weeds spread by means of the underground stem or rhizome, sometimes by creeping horizontal growth, sometimes by the persistence of every scattered portion of such stem cut off and cast aside in the processes of cultivation of the ground. Many of the monocotyledonous weeds possess bulbs, and spread by means of bulbils as well as seed. The most difficult weeds to control are those known colloquially as "double-headers," i.e., those which have two ways of spreading themselves, as in the case of the Cape Tulip, which spreads both by seeds and by bulbils.

The method of Biological Control applied to insect pests consists of the scientific study of the ecology or bionomics of the insect concerned, with a view to discovering how it is controlled in Nature, and then applying the guiding principles thus discovered to the problem of controlling it in its new environment. For instance, the Woolly Aphis of apple-trees (*Eriosoma lanigera*) is a native of America, and is controlled in that country by a number of natural enemies, the chief of which are certain species of ladybirds, hover-flies, and a small internal parasitic wasp known as *Aphelinus mali*. Woolly Aphis has been spread from America all over the world, wherever apples are grown, and was for a long time one of the major pests of apple orchards in Australia and New Zealand. My first attempt at controlling this pest in New Zealand was made with the ladybird, *Hippodamia convergens*, which is considered highly effective in California. This attempt met with failure. My second attempt was made with *Aphelinus mali*, and proved very successful. The strain of this insect used was a mongrel or cross between races sent to me from widely separated localities in the United States of America by Dr. L. O. Howard, and it is this same strain which is now working effectively to control woolly aphis in many parts of Australia.

In the above example of biological control, we distinguish three units all connected together ecologically. First of all, there is the plant, in this case the Apple-tree; secondly, there is the insect attacking the plant, viz., the Woolly Aphis; and, thirdly, the enemy of that insect, which may be either a predator or a parasite. By *predator*, we indicate those forms, like the larvæ of ladybirds and hover-flies, which attack their prey freely from outside and devour it. By *parasite*, we indicate those forms which deposit their eggs inside the body of their hosts or place them in such a position that the host either swallows them inadvertently or exposes itself to attack from the young larva which may succeed in boring into it; in all such cases, the larva of the parasite lives and grows inside the body of its host, and thus is strictly speaking an *internal parasite*. There are also a number of cases of parasites attached to their hosts permanently but outside; these are also included under the term parasites, and are distinguished as *external parasites*. *Aphelinus mali* is an example of an *internal parasite*.

In Nature, this process of parasitism may not end with the third unit mentioned above. A large number of cases are known in which the parasite or predator itself is attacked in its turn by a secondary parasite or *hyperparasite*, and even this, in its turn, may have enemies which may help to control it. One hesitates to use once more the well-known rhyme that so well illustrates this subject:—

"Great fleas have little fleas upon their backs to bite 'em,
"Little fleas have lesser fleas, and so *ad infinitum*."

But the truth is, that only one famous man has ever dared to express this thought in poetic form, and he has done it so well that his verse must suffer the inevitable consequence of being quoted to the point of becoming hackneyed.

I trust that the above example will indicate to you the sequence in Nature whereby the undue increase of one species of insect is checked by another. The principle applies so generally throughout Nature that there are indeed very few insects of any kind of which it can be said that more or less effective enemies are not known to exist. It is the study of the inter-relationships of the great mass of insect forms which is now the chief aim of the science of entomology, and this study has provided the material for some of the chief triumphs of entomology in the economic field.

Turning back again for a moment to our illustration of the Apple-tree and its enemies, I now wish to impress on your minds another idea. It is the value of the Apple-tree in relation to Mankind that rules also our valuation of the whole series of insects connected with it. *Because* the apple is a valued food for Man, the Woolly Aphis which attacks it is regarded as an *injurious insect*, and the parasite or predator which attacks the Woolly Aphis is regarded as a *beneficial insect*. These terms are applicable *only in relation to Man*. The Woolly Aphis, if it could think and reason, would certainly not class *Hippodamia* or *Aphelinus* as a beneficial insect; nor would *Hippodamia* class the Woolly Aphis as an injurious insect, seeing that it is its favourite food!

These terms, then, being only comparative, and depending entirely on the relationship existing between the plant in question and Mankind, let us now take a survey of the inverse problem, in which the plant studied, instead of being valuable to Man, is inimical to him and his primary industries. This introduces you at once to the problem which is the subject of this lecture, viz., the *Biological Control of Noxious Weeds*. If a plant valued by Man can be protected and saved from destruction, by making use of the natural enemies of those insects which attack it, it appears equally logical to argue that a plant inimical to Man might be controlled or even possibly entirely eradicated by making use of the insects that feed upon it in Nature, provided that the enemies of those insects are first of all eliminated from the scheme. From this point of view, the insect which attacks the weed must now be considered as a beneficial insect, while its predators or parasites must be classed as injurious.

I think the comparison can now be brought home to you in a more striking form by considering the relationship of a single species of insect to two very distinct problems. The insect which I shall select is a well-known ladybird beetle, of Australian origin, *Cryptolæmus montrouzieri*. This little beetle is normally, in the larval stage, a predator on various species of native Mealy-bugs in Australia. Introduced into California, where it is reared artificially in millions every year and distributed to citrus-growers, it has proved a very effective control of the deadly Citrus Mealy-bugs (*Dactylopius* spp.) which have threatened the very existence of the great citrus industry in California. This ladybird is parasitised, in Australia, by a number of smaller insects, chiefly Braconid wasps. All such parasites were, of course, eliminated from the consignments introduced into California, and thus the potency of the insect was very greatly increased.

Now let us consider this same insect in relation to Prickly Pear control. When this problem was taken up in Australia, one of the first groups of insects studied was the Cochineal Insects, which happen to be a sub-division of the Mealy-bugs of the genus *Dactylopius*, i.e., of that very group which has been doing so much damage to citrus-trees in California. The genus was the same, but the species were different. After it had been proved by exhaustive tests that the particular species of *Dactylopius* that feed on Cactaceæ would not attack citrus or any other economic plants, these insects were introduced into Australia for the attack on prickly pear. As is now well known, one of them, *Dactylopius tomentosus*, was found to attack the pest pear vigorously, and is now being widely used in controlling it. Now the native ladybird *Cryptolæmus montrouzieri* attacks this new introduction, belonging to the genus *Dactylopius*, just as if it were one of the native species of Mealy-bug of that genus on which it normally feeds. Fortunately, the attack is not

a severe one, and does not check the valuable work of the Cochineal Insect to any great extent. But the point is that, in so far as *Cryptolæmus* makes this attack, it must be classed as an *injurious insect*; whereas, in attacking the Mealy-bugs of citrus trees, it must be classed as a *beneficial insect*.

The contrast is best illustrated by means of a Table, as follows:—

TABLE.

Organism	Relationship to Man.			
	Type	Example	Type	Example
1. Plant	Beneficial	Orange and Lemon Trees	Injurious	Prickly Pear (in Australia).
2. Insect attacking plant	Injurious	Mealy-bugs (*Dactylopius* spp.)	Beneficial	Cochineal Insect (*Dactylopius tomentosus*).
3. Insect predatory or parasitic on 2.	Beneficial	Ladybird Beetle (*Cryptolaemus montrouzieri*)	Injurious	Ladybird Beetle (*Cryptolaemus montrouzieri*).
4. Secondary parasite (hyperparasite) on 3.	Injurious	Species of *Braconidae*, etc.	Beneficial	Species of *Braconidae*, etc.

I think the above table shows very clearly the idea that I am intending to convey, viz., that *the problem of the Biological Control of Noxious Weeds is the inverse of the problem of the Biological Control of Insect Pests*. In the latter case, we seek to protect the plant by the destruction or control of its insect enemies, utilising their predators or parasites for this purpose. In the former case, we seek to destroy the plant, by the utilisation of its insect enemies, after having first eliminated their predators or parasites from the problem.

It being now generally admitted that Biological Control of Insect Pests is sound in theory, it follows logically that the inverse problem is also sound in theory; for the two problems do not differ *fundamentally*, but only differ in their orientation to the viewpoint of mankind.

It having also been proved, by many striking examples, that Biological Control of Insect Pests may be made to yield valuable results, and may achieve these at a cost which is trifling compared with other known methods, we have now to examine the problem as to what conditions are required in order that the inverse problem of Biological Control of Noxious Weeds may also be made to yield valuable results.

The first point which will strike everybody is this:—

When an injurious insect pest gains admittance into a new country, it becomes capable of, and frequently inflicts, far greater damage than it did in its country of origin. This known fact, transferred to the inverse problem of the control of noxious weeds, may be rendered in two ways:—

(1) If an insect known to be injurious to a given noxious weed is introduced into a new country, it may be expected to do far greater damage to that weed than it did in its country of origin.

(2) On the other hand, if this same insect can also attack any other plant besides the given noxious weed, and such other plant is of economic value, equally serious damage may be anticipated to that plant; and the gain to the country in the control of the weed may be more than offset in the loss to the industry in which the other plant is of importance.

These facts being admitted, we have now to inquire into the safeguards necessary to ensure (a) *the maximum attack upon the weed itself*, and (b) *the elimination of all risks to plants of economic value.*

With respect to (a), it is only necessary to say that the obvious method of procedure is to introduce only strong and healthy strains of the insect, preferably from regions not differing too markedly in climate from that of the country of introduction, and to make sure that all parasites or other enemies of the insect in question are eliminated from each consignment before it is forwarded.

With respect to (b), we have to consider first of all the *theoretical* risk and then tackle the problem of *reducing that risk to a practical minimum.*

The Theoretical Risk.

Theoretically, the risk taken in introducing any given insect to attack a given noxious weed is more or less closely related both to the *degree of specialisation* of the insect and to the *botanical position* of the weed in question. It is well known that the great majority of species of plant-feeding insects are more or less restricted in their diet. The more highly specialised the group of insects concerned, the more marked is this restriction. This is not to be wondered at, when we consider for how many millions of years the higher insects have been evolving, and more especially when we recall that the fossil record indicates that they reached a stage of practical stability in their reactions to food and other stimuli two or three million years ago, long before Man came on the scene. We have, then, first of all to consider the *type of insect* that we propose to introduce, and secondly, the *type of weed* which we desire to attack.

Insects have now been studied long enough for an immense mass of information to have been gathered together and published about a very large number of them. This is particularly true about the insects of Europe and North America, the two countries from which we may expect to draw most of our supplies of insects for control of noxious weeds. It follows that we shall be able to classify our insect into one of the three following groups:—

(1) Insects which have been recorded as attacking plants of economic value.

(2) Insects only recorded as attacking the genus to which the noxious weed belongs, or allies of it having no economic value.

(3) Insects not well enough known or sufficiently studied to enable them to be placed either in (1) or (2).

Generally speaking, if an insect falls into group (1), it should not be considered for noxious weed work. Insects of group (3) should be followed up by fuller study in their countries of origin, until they can be placed either under (1) or (2). Insects of group (2) are suitable subjects for further research, especially those in which the records run back far into the past without showing anything dangerous to economic plants in their recorded habits.

The next point to consider is the botanical position of the noxious weed under consideration. Does it stand far apart from any of the groups which contain our most valuable economic plants, or does it, on the other hand, belong to such a group? It must be obvious that the risks of the work are reduced to a minimum in such cases as Prickly Pear or St. John's Wort, where the weed is highly specialised, and stands far apart from any group of economic plants. In such a case, it is reasonable to suppose that a series of careful tests carried out upon any insect, with a view to discovering its feeding range, would indicate clearly that certain species were entirely, or almost, confined to the weed in question. On the other hand, in such cases as Blackberry or Hoary Cress, where the weed in question stands botanically right in the middle of a group of the highest economic value, the risks must be regarded as very great, and the likelihood of discovering any single species of insect that would be confined to such a food-plant is exceedingly small.

There is also another point which must not be lost sight of, viz., that, even though a given noxious weed may belong to a group of economic value, it may be so specialised in the morphology of one or more of its parts that there is still a good chance of finding a specialised insect which would attack that part, without any risk to related plants, in which that same part is quite differently specialised. This can be well illustrated by two examples:—

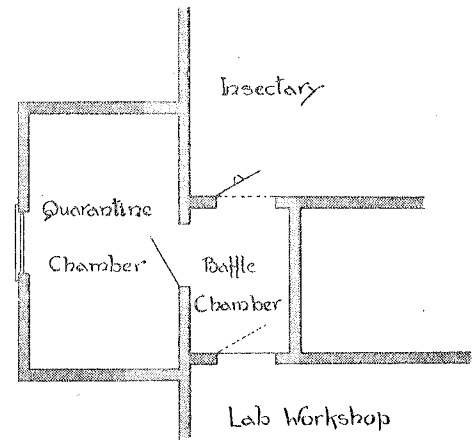
(1) Piri-piri (*Acæna sanguisorbæ*) belongs to a genus closely related to Strawberry (*Fragaria* spp.). The leaves of the two genera are closely similar, but the fruit are specialised in two very different directions. It might therefore be expected that a leaf-feeding enemy of *Acæna* would attack the leaves of strawberries also; and such is actually the case with the Australian beetle *Haltica pagana*, which only feeds in nature on *Acæna*. In attempting, therefore, to control piri-piri in New Zealand, a search should be made for a fruit- or seed-feeding species. (See p. 76.)

(2) Gorse (*Ulex europæus*) is a member of the Natural Order Leguminosæ, which includes also a large number of our most valuable vegetables and fodder crops. It is, however, specialised in being a prickly shrub and in its peculiar type of seed-pod. It is not to be expected that an insect that feeds naturally inside the seed-pod of gorse would also attack the pods of peas, beans, clovers, or lucerne. Tests carried out on the little gorse weevil, *Apion ulicis*, show that it cannot even accustom itself to the pods of the allied genus Broom (*Cytisus*). It is therefore a safe insect to work with.

To sum up, then, the theoretical risk is least when the plant to be controlled is unrelated to any group of economic plants, or, if related, is distinguished from them by the possession of some morphological specialisation; it is also reduced in proportion to the degree of specialisation of the insect intended to be used.

Practical Methods of Eliminating Risk.

The practical methods of eliminating risk in Noxious Weeds Control work, or of reducing it, at any rate, to a minimum low enough to justify the continuance of the work, are by now fairly well understood, as the result of the experience of the past few years. The first consideration is so to arrange the experiments in the country of introduction that they are *under quarantine control conditions*. This is ensured by the construction of *quarantine insectaries* conforming to the requirements of the Commonwealth Department of Public Health as quarantine areas. Plates XV., XVI., XVII., and XVIII. give a good general idea of such insectaries. They have to be entirely insect-proof, protected from damage from the outside, and provided with a properly constructed *baffle-chamber* with interlocking doors, as shown in Text Figure.



Diagrammatic Plan to show arrangement of Baffle Chamber and Insectary at the Cawthron Institute, Nelson, New Zealand. The Insectary can only be entered from the Laboratory Workshop through the Baffle Chamber, the two opposite doors interlocking so that, when one is opened, the other is automatically shut. The insect trap is indicated by the small cone on the insectary side of the inner door. The Quarantine Chamber or Store is also entered only from the Baffle Chamber, by means of a side door.

Only the workers actually engaged upon the research should be allowed to enter them when work is in progress, and such workers have to be very carefully instructed in the use of the baffle-chamber, and in ensuring that they do not carry insects in or out of it on their clothing.

The second point is to ensure that only such insects are allowed into the country of introduction as can be definitely classified in group (2) on p. 59. For this purpose, a worker has to be employed in the country of origin, to determine, by means of a series of *starvation tests*, what the feeding range of the given insect may be. A list is drawn up, including all the principal economic plants which grow in that part of the country of origin infested by the weed. The insect is given the choice of either feeding on one of these, or of starving. If it prefers to starve to death, it is a reasonable inference that it will not eat this same plant when supplies of its natural food are also available. In order to make these tests as full as possible, the insect is tested in this manner at various stages of its life-history from the newly-hatched larva to the adult. Each test is controlled by dividing a batch of insects into two equal parts, say twenty larvæ in each batch; one batch is then placed in a cage on the economic plant to be tested, while the other batch is placed in a similar cage on the normal food-plant. If the latter batch feeds freely while the former starves, the test is regarded as valid.

Assuming that the insect under observation in its country of origin successfully passes all its tests, it is then necessary for the scientist in charge of the work to draw up a full account of its known life-history, giving information on the specific points of its capacity to damage the weed in question, its inability to do harm to other plants, and the proposed line of work to be carried on in the country of introduction. This document is sent in to the Department of Public Health with the application for a *quarantine permit*. If such a permit is granted, the insect has then to be received into the quarantine insectary,* and a further series of tests has to be carried out there. These tests consist of a repetition of the starvation tests under the new conditions of climate, etc., in the country of introduction, together with a certain number of oviposition tests designed to determine the oviposition responses of the insect. (Sometimes an insect will lay eggs on a plant on which the larvæ cannot feed; or it may happen that the larvæ will feed on a particular plant, but the insect may refuse to oviposit on it. In either case, an accurate knowledge of the oviposition responses of the given insect is highly desirable.) The starvation tests are also increased to include native plants of economic value, not available in the country of origin, e.g., in the case of Australia, eucalypts and wattles.

Permission to test any given insect in the field is only sought in the case of such insects as have undergone all the above stringent tests with negative results. This means, inevitably, that the work to be done will be long and arduous;

*I have purposely omitted from this account a discussion of the important problems of the carriage of live insects through the Tropics and the subsequent difficulties of acclimatisation in the new country.—R.J.T.

but it undoubtedly reduces the risks of the work to a minimum, and its results, as shown in the case of the Prickly Pear work in Queensland, are such as to ensure public confidence in the method.

In the case of an insect which successfully passes all its tests and for which an open permit for liberation in Australia is granted, there still remains the difficult task of devising methods whereby it can be reared in sufficient quantities and distributed rapidly enough in the infested districts to ensure the destruction of the weed. This is a separate problem, which I do not propose to enter upon here.

I trust that I have shown you, in this first section of my lecture, that Biological Control of Noxious Weeds is sound theoretically, and that the practical safeguards devised are such as to protect the country in which the work is to be carried out. I now propose to go on to the other sections of my lecture, in which the four main experiments in Noxious Weeds Control work to date are studied in detail.

II. EARLY HISTORY OF BIOLOGICAL CONTROL OF NOXIOUS WEEDS.

The great credit of inaugurating work on the biological control of Noxious Weeds must be given to that extremely progressive body, the Hawaiian Sugar Planters' Association, and their very capable entomologists. It is just about thirty years ago that the first experiment in this direction was undertaken by this body. The plant *Lantana camara*, originally introduced about the year 1860 as an ornamental shrub, soon began to take possession of large areas of land in the various islands of the Hawaiian group, just as it has done over large tracts of similar land in the warmer portions of Eastern Australia. The well-known entomologist Koebele, while collecting in Mexico in 1898, noticed that the seeds of this plant in its native state were damaged by insects which bred in them. This suggested to him the idea that the profuse seeding of the plant might be checked, or even completely prevented, if these insects could be firmly established on the weed lantana in the Hawaiian Islands. Four years later, his idea having been officially approved, he again visited Mexico, and this time made a thorough study of all the insects that feed on lantana. More than twenty different species of these were shipped back to the Chief Entomologist, Perkins, in Honolulu, and eight of these were soon successfully established on the Island of Oahu, of which Honolulu is the capital. Of these the most important were the species that prevent the seeding of the plant. The larvæ of an Agromyzid fly, *Agromyza lantanæ*, proved to be the most effective of these; it attacks the berries before they are mature, and causes them to shrivel up, destroying the seeds within them. The rapid spread of this insect in all the drier areas of the Hawaiian Islands was most marked. Other valuable introductions were the Tortricid Moth, *Crocidosema lantana*, and the two Hairstreak Butterflies (family Lycænidæ), *Thecla echion* and *T. bazochii*. The larvæ of the first-named are stem-borers, attacking chiefly the tender flowering stems and thus destroying both flowers and fruit. The Butterfly larvæ feed chiefly on the flowers, and are therefore also of great value in preventing the formation of the fruit.

The result of these introductions was a very marked decrease in the amount of infestation by lantana in the drier parts of the islands. With the aid of some judicious mechanical clearing, these parts have now been rendered safe for all time from being overrun by this dangerous weed. In the wetter portions of the island, especially on Hawaii itself, where there are great tracts of lava particularly suitable to the growth of lantana, the attempt at control has not been so successful; but, from the economic point of view, these lands are not of much importance.

I want now to emphasise to you a very important point, viz., that, in this first experiment with biological control of noxious weeds, a very grave risk was taken, viz., that some of the introduced insects might have proved capable of attacking valuable economic plants, and might have themselves become worse pests than the lantana. That this did not happen might be said to have been more by good luck than good management; for no stringent tests were applied beforehand to discover fully the habits of the introduced insects. Luck was on the side of the experimenters! Even so, one of the introduced insects, *Thecla echion*, occasionally selects the fruit of the egg-plant as its food in the larval state, though it has not become a serious pest on that plant. This example only serves to show, I think, what a "near thing" it was for this first experiment in noxious weeds control. Had any single one of these insects turned out to be a major pest on any important economic plant, such as sugar-cane or pineapple, I think it is safe to say that entomology in the Hawaiian Islands might have received its deathblow.

Needless to say, though the experiment on lantana control was to a large extent successful, there was no lack of

critics ready to point out the danger that had been run, and for a long time afterwards the policy of the Hawaiian experimenters was rather to "lie low and say nuffin'," being content with their success, than to attempt to draw any general conclusions from the work they had accomplished. Later on, however, the work was taken up again by a new generation of Hawaiian entomologists, and at the present time attempts are being made at the biological control of three important noxious weeds in these islands, viz., Nut-Grass (*Cyperus rotundatus*), Pamakani (*Eupatorium glandulosum*), and Gorse or Furze (*Ulex europæus*). The last of these is, as you know, a serious pest in New Zealand and Tasmania.

III. BIOLOGICAL CONTROL OF PRICKLY PEAR IN AUSTRALIA.

We must now turn our attention to the second experiment in biological control of Noxious Weeds, viz., the attempt to control Prickly Pear (*Opuntia inermis*) in Australia. I venture to say that, whatever may be its ultimate result (and I, for one, have little doubt of its success), this great undertaking will rank for all time as one of the most instructive and interesting pieces of biological research ever undertaken by mankind. There will always be, no doubt, many individuals who will refuse to allow that it is a success until the last clump of prickly pear has gone by the board. But, looking at the matter from a broader view, I think we may claim already for this work, firstly a complete success on the scientific side, in so far as it has firmly established the value of the principle of biological control of noxious weeds, and secondly already a considerable economic success, in view of the effectiveness of the safeguards established, and the large measure of economic control of the weed already attained.

Various species of Prickly Pear (*Opuntia*) were introduced into Eastern Australia many years ago as botanical curiosities. In addition to the interest created by their curious habit of growth, the plants themselves are used in several parts of the world for making dense, impenetrable hedges, and their fleshy, slightly acid fruit is esteemed as a delicacy. As many birds share in this liking for the fruit, and as the plant can stand any amount of drought, and every little piece of it, if thrown away haphazardly, is able to take root and become a separate plant, it is not to be wondered at that, in the course of time, this plant became the pest weed, *par excellence*, of the warmer parts of Eastern Australia.

When it became known that some 60,000,000 acres of land in Queensland and northern New South Wales had been over-run by this plant, and that it was increasing at a rate of more than 1,000,000 acres a year, public opinion soon become translated into legislative action; for this was, surely, nothing less than a national calamity which threatened the future existence of two States. As the story of the inauguration of the Prickly Pear Board and the results of its ten years of fruitful work has been very fully told in the publications, firstly, of the Commonwealth Institute of Science and Industry, and, later, of the Commonwealth Council of Scientific and Industrial Research, it is not necessary here to refer to more than its bare outlines.

The Prickly Pear Board was founded late in 1919, and held its first meeting in 1920. It consisted of three members, one representing the Commonwealth of Australia, one the Government of Queensland, and one the Government of New South Wales. The Commonwealth representative was Mr. Gerald Lightfoot, M.A. (now Secretary of the Commonwealth Council of Scientific and Industrial Research), who is at the present time still a member of the Board. The State representatives were the Under Secretaries for the Department of Public Lands in Queensland and Agriculture in New South Wales. The Board was financed by an annual grant of £8,000, half of which was contributed by the Commonwealth, and one quarter by each of the States concerned. From the beginning of 1926, this amount was increased to £12,000 in the same proportional contributions.

In October, 1926, the Board was strengthened by the addition of a fourth member, Professor E. J. Goddard, of the University of Queensland.

The main factors in the adoption of the principle of biological control may be briefly summarised as follows:—

(1) *Mechanical control* (i.e., by cutting out the plant with hand labour or by the agency of various mechanical devices) has been found to be slow, costly, and arduous.

(2) *Chemical control*, though valuable in the case of land above a certain value per acre, is too expensive to offer a general solution of so immense a problem. The land of agricultural value to which chemical control could be profitably applied is only a small portion of the total huge area of infestation, and would be continually reinfested from the untreated portions, as long as these latter were neglected. Dr. Jean White's earlier work on the use of arsenic acid and arsenic trichloride for the control of this pest was of great value in indicating the cheapest and most effective chemical methods that could be used. These methods cannot be applied to the major problem, as they are too expensive; but they are of great value in assisting the work of biological control.

(3) *Utilisation of the pear* on a large scale has been shown to be impracticable. Even if the pear could be turned into cattle fodder, the annual increase in Australia is far more than sufficient to feed all the cattle we possess!

The one remaining hope was the application of the principle of biological control. Here the Board had the guidance of Professor T. Harvey Johnston, who, with Mr. Henry Tryon, had already formed a Travelling Commission for the Queensland Government, and had submitted a report embodying the results of two years of travel in many of those countries in which the genus *Opuntia* occurs. The main point that emerged from this preliminary work was that most of the large number of species of insects that naturally fed on *Opuntia* were not known to attack other plants, and therefore they might reasonably be experimented with in Australia, *provided proper safeguards were adopted.*

Professor Harvey Johnston was appointed Scientific Controller of the Prickly Pear work as from June, 1920, and held that post until his resignation in February, 1923. This post was then discontinued, and an Officer-in-charge was appointed to carry on the work. The first Officer-in-charge was Mr. J. C. Hamlin, who held office only for a short time, and was succeeded by Mr. W. B. Alexander, who was succeeded in 1926 by the present occupier of the post, Mr. Alan P. Dodd.

The work on biological control of Prickly Pear may be divided up into the following main sections:—

(1) *Collecting the insects in the field*:—For this purpose, an intensive survey of all the countries in which *Opuntia* occurs as a native plant has now been carried out. These countries range from Texas and Florida in the North to Argentina in the South.

(2) *Testing of the insects before shipment to Australia*:—A central testing station was established at Uvalde, Texas, where each species of insect was reared in cages, freed from its native parasites, and then tested out on a large selection of economic plants. Insects which successfully passed these tests were then shipped to Australia.

(3) *Shipping the insects to Australia*:—This important and difficult operation was overcome by packing the insects in specially designed Wardian cases, carried as deck cargo, and for the most part shipped direct from San Francisco to Sydney. Insects from Southern America were treated similarly, but shipped from Panama.

(4) *Work at the Central Laboratory*:—This laboratory (Plate XIII.) was established at Sherwood, a suburb of Brisbane, Queensland. The introduced insects are received at this station, and are there bred in large numbers for distribution to the field stations.

(5) *Work at the field stations*:—Three field stations were established in the main areas of infestation, viz., one at Westwood, near Rockhampton, in Queensland, one at Chinchilla, Queensland, and one at Gravesend, in north-western New South Wales. Later on, the Westwood field station was discontinued, and a new one opened at Gogango, a more suitable locality. In these stations, the introduced insects are reared in sufficient numbers to allow for liberal distribution in the open.

Let us now look at the results of this work to date.

Five groups of *Opuntia*-feeding insects have been acclimatised in Australia, after successfully passing the tests on economic plants. Arranged in their order of importance from the economic viewpoint, these are as follows:—

(1) *Tunnelling caterpillars* (larvæ of Lepidoptera of the family Pyraustidæ):—The first of these to be studied and liberated were two species of the genus *Melitara*, one of which (*M. junctolineella*) readily attacks the pest pear (*O. inermis*) while the other (*M. prodenialis*) only attacks *O. stricta*. But by far the most important of all the pear-controlling insects is the later importation from the Argentine, *Cactoblastus cactorum*, introduced in 1925. This voracious feeder attacks *O. inermis*, *O. stricta*, and *O. aurantiaca*, causing destruction of its host-plant out of all proportion to its numbers, owing to its association with a soft-rot bacillus, which causes the rotting away and destruction of the tissues. The only event which, apparently, can check the complete triumph of this remarkable insect enemy of Prickly Pear would be its gradual secondary control by parasitism from native Hymenoptera or Diptera. To date, this has only occurred to a very minor degree, not sufficiently marked to produce any decided effect on its onslaught.

(2) *Cochineal Insects* (Hemiptera-Homoptera of the family Coccidæ):—These insects are mealy-bugs of the genus *Dactylopius*. The first species introduced was found to attack only the tree-pear, *O. monacantha*, which it very soon almost completely eradicated. Later, another species, *D. tomentosus*, was introduced to feed on *O. inermis*. Three strains of this insect are now at work in Australia, having been very widely distributed. They do splendid work in destroying young seedlings, in killing off old plants, and in attacking pear infestations in forest country, but do not work as rapidly as *Cactoblastus*.

(3) *Red Spider*:—The Prickly Pear Red Spider, *Tetranychus opuntiæ*, is, of course, not an insect, but an Arachnid of the group Acarina. It was introduced from Texas in 1924. These little red mites feed on the surface of the pear, and cause great damage, followed by collapse of the plant and often by its death. They are particularly valuable in attacking dense infestations of *O. inermis*.

(4) *Plant-sucking Bugs* (Hemiptera-Heteroptera of the family Coreidæ):—Four species of the large bugs of the genus *Chelinidea* have been introduced from North and Central America. One of these, *C. tabulata*, has increased very greatly, and is doing excellent work in attacking the pest pear and weakening it by piercing and sucking the sap.

(5) *Tunnelling Beetle Grubs* (Coleoptera, family Cerambycidæ):—Several species of the genus *Moneilema* have been introduced, but only one, *M. ulkei*, has been established in the field. The adult longicorns of this genus are wingless.

A sixth type of insect attacking *Opuntia* is a group of fruit-feeding species. Of these, the most promising appeared to be *Asphondylia opuntiæ*, one of the Cecidomyiidæ (Order Diptera). This insect, however, has proved an exception to the general rule in *Opuntia*-feeding insects, as exhaustive tests have shown that the larvæ may damage certain other fruits of economic importance. Under these circumstances, the attempt to utilise it has been abandoned.

We may summarise the work of the Prickly Pear Board on the biological control of Prickly Pear by saying that, to date, it has progressed probably even better than its most ardent supporters hoped. To-day it stands as the one scientifically founded method of attempting the control of this serious pest with an expenditure that may be considered to lie within reasonable limits of national finance. While it would be foolish to attempt to prophesy what the future has in store, bearing in mind the possibilities still existing of a check occurring in the work of any given insect, either through parasitism by native insects, attacks by native predators, or through a slow change in the insect organism itself, whereby it may become more normally accommodated to its host-plant under its new environment, I think it is not too much to say that the prospects of a satisfactory ultimate controlling stage being reached are extremely good. We have to remember that the result aimed at will be attained, even without complete eradication of the weed, provided that the introduced insects can reduce its spread to proportions that may be considered negligible from an economic standpoint, and can succeed in preventing it from ever again obtaining the upper hand in Australia.

IV. BIOLOGICAL CONTROL OF NOXIOUS WEEDS IN NEW ZEALAND.

As I have already indicated to you, ten years ago the general principles of biological control of an insect pest by its natural enemies were by no means generally admitted even amongst entomologists, while the number of such who would at that time have supported biological control of noxious weeds was very small indeed. My first acquaintance with the subject of this lecture was in 1920, when I paid my first visit to the Hawaiian Islands. While that visit showed me to a considerable extent the success that had attended the attempt to control lantana by this means, yet the little that one could learn about the technique of the experiment did not tend to influence one in favour of repeating it. It was thus with quite an open mind that I paid my first visit to the Central Laboratory of the Prickly Pear Board at Sherwood, in 1924, when I was shown the work in progress at that time through the kindness of Mr. W. B. Alexander. Here I found a much more thorough and scientific piece of work being carried out, and was able to gather my first impressions of the complexities of the problem. The result of this was to send me back to Nelson, New Zealand (where I was then working as Chief of the Biological Department of the Cawthron Institute of Scientific Research), in a frame of mind bent on examining the possibilities of applying the new method to the serious problem of New Zealand Noxious Weeds. As the most important of these weeds is Blackberry (*Rubus fruticosus*), an extremely close ally of the two valuable fruits

Raspberry and Loganberry, and also a fairly close ally of Roses and a host of valuable orchard trees, I am sure you can imagine the state of mind produced by having to face this problem, and having to decide once and for all whether to drop the method as being too dangerous, or to go on with it and risk the danger.

I hope you will all approve of the decision which I reached, at a time (let me emphasise this) when not a single other scientist in New Zealand was prepared to give me the slightest support in it,* and when I met with severe and at times unreasoning opposition from those who ought at any rate to have listened impartially before prejudging the position. My decision was to give the method a thorough trial, but to increase the safeguards to the utmost, in proportion as the problem of control of such weeds as blackberry appeared to carry with it risks of a graver nature than was the case with Prickly Pear.

Fortunately the Cawthron Institute is blessed with a Director and a Board of Trustees who are broad-minded men, and who listened to the proposal put before them with impartial minds. The outcome of it was that I was given permission, in 1926, to visit Europe and America in order to discuss this and other matters with leading entomologists, and to see what could be done to set going a practical scheme.

Before leaving New Zealand, I had drawn up, in consultation with the officers of the Department of Agriculture, a scheme of regulations in the form of safeguards for the control of the work (Tillyard, 1927a, p. 1). These regulations admittedly made the proposed research very difficult, but they were absolutely necessary in view of the obvious risks entailed. With this set of regulations agreed to, I then set out to win over my old friend and counsellor, Dr. L. O. Howard, at that time Chief of the Federal Bureau of Entomology in Washington, and so far succeeded in my endeavour that he gave me cautious support and at the same time wrote a letter to Dr. G. A. K. Marshall, Director of the Imperial Bureau of Entomology in London, commending my plan for his consideration. In England I gained the support of Dr. A. D. Imms, Chief Entomologist at Rothamsted Experimental Station, and obtained the consent of Sir John Russell to the carrying on of some experimental work along the proposed

*As I write this (September, 1929), I have before me the report of a speech by a member of the Legislative Council of New Zealand (Hon. G. M. Thompson) still attacking the Cawthron Institute at this late stage for undertaking this work!—R.J.T.

lines at Rothamsted, under Dr. Imms's supervision. Dr. Marshall also very generously gave me official support, though he was not personally in favour of the work.

With all this accomplished, I was then able to approach the Empire Marketing Board with a proposal for a grant in aid of this work. Again I was fortunate in meeting with men who had open minds on the subject, and could clearly see the Imperial aspect of the work. The result was that an offer was made by the Board to the Cawthron Trustees, in the form of a grant of £2,000 for the necessary buildings, and £2,000 a year for five years for the actual carrying out of the research, on condition that the New Zealand Government and the Cawthron Trustees together also expended an equivalent annual sum. This offer was accepted, and the work was begun in 1927. A committee was set up by the newly formed Department of Scientific and Industrial Research in Wellington to control the work, of which I was put in charge, with Mr. A. L. Tonnoir as Field Entomologist working under me at the Cawthron Institute, and Mr. W. M. Davies as Entomologist working under Dr. A. D. Imms at Rothamsted.

Building being reasonably cheap in Nelson, the grant of £2,000 for that purpose was found to be sufficient to erect a small biological control station with attached insectary (Plates XIV. and XV.). The station contains two research rooms, a dark-room, a large general laboratory, a cool-store, and a small workshop. It was connected directly with the large quarantine insectary, about fifty feet square, by means of a baffle-chamber (see Text Figure), the doors of which were interlocked in such a manner that neither of them could be opened until the other was firmly shut. The baffle-chamber also communicated with a quarantine store-room at the side. These buildings were completed in 1927, and were officially opened by the Right Hon. L. S. Amery, P.C., Chairman of the Empire Marketing Board, on the occasion of his visit to Nelson. The Noxious Weeds work was carried on, under my direction, by Mr. A. L. Tonnoir as Field Entomologist, with the assistance of two cadets, Mr. R. Mayson and Mr. E. Newman.

The weeds chosen for research at the start were blackberry, ragwort, and gorse. Later on, an investigation into piri-piri or bidi-bidi (*Acæna sanguisorbæ*) was begun as well. The first selection of likely insects was made by myself during my visit to Europe in 1926, and resulted in the work being concentrated upon the following species:—

For Blackberry:—*Thyatira batis*, *Corœbus rubi*, *Agrilus ruficollis*, and *Bembecia marginata*.

For Ragwort:—*Tyria jacobææ* and *Homœosoma vagella*.

For Gorse:—*Apion ulicis*.

Blackberry (*Rubus fruticosus*) is generally considered to be the worst pest weed in New Zealand; it is also a very serious weed in many parts of Australia where the rainfall is high enough to favour its spread. The total acreage under blackberry in New Zealand has never been computed; but it is very evident that the weed has a great hold on the country, and is spreading at an alarming rate. One of the chief agents in this spread is the introduced Blackbird, which feeds greedily upon the ripe fruit, passing the seeds out in its droppings. There is a well-known saying on the west coast of the South Island that in that district they have only one blackberry bush, but it is two hundred miles long!

The attempt to control blackberry is a most difficult one, from whatever angle it may be viewed. Here is a most vigorous weed, which not only seeds freely, but sends up shoots readily from its underground stems and responds as readily to hacking and cutting as a fruit-tree does to careful pruning. Attempts to destroy it with chemicals have met with some success, but are very expensive owing to the rampant growth of the weed and its ability to seize and hold the most inaccessible places. From the point of view of biological control, it is about as unfavourably placed botanically as it could possibly be, as the genus to which it belongs (*Rubus*) also includes the very valuable fruits Raspberry and Loganberry, and lies in the very centre of that great complex of related forms, the Natural Order Rosaceæ, in which are included most of our valuable deciduous fruit trees, as well as the Queen of Flowers, the Rose, and a host of other garden flowers and ornamental trees and shrubs. It seemed from the outset that there would only be a small chance of discovering an insect which could distinguish clearly between blackberry and its near allies. The application of the requisite tests brought about the speedy downfall of the first insect studied, *Thyatira batis*, which was found to feed readily on raspberry and also failed to do sufficient damage to blackberry to make it worth while continuing the tests. The most promising insect appears to be the Buprestid beetle *Corœbus rubi*, known to attack the roots and crown of blackberry in the south of France, and only recorded otherwise on *Rosa indica*, used as a stock for ornamental roses around Grasse.

This stock not being used in New Zealand to any extent, a good case was presented for continuing with this beetle. At the present time, an unexpected difficulty has presented itself, after the initial problem of the successful transport of the delicate beetle grubs to New Zealand had been overcome, in that the New Zealand bred females of the beetle, though paired and fertilised by the males, have apparently not yet produced any fertile eggs. The factor inhibiting fertility is at present not understood, and the research cannot move forward until this problem is solved or some other insect is discovered more promising than *Corœbus*.

A similar difficulty appears to have intervened in the case of what appeared at the beginning to be a most promising insect for controlling gorse or furze (*Ulex europæus*). This weed, originally introduced as a hedge-plant into New Zealand, is a very vigorous seed-producer, and has spread over immense areas of hilly land in the Dominion, while it is also a problem in parts of Tasmania. In England and France the seeding is often controlled to a very great extent by the attacks of the larvæ of a small weevil, *Apion ulicis*, which inserts its eggs into the young pod, where the larvæ live and entirely destroy the seed. Large consignments of this beetle have been imported into New Zealand, and to a certain extent acclimatised; but this same problem of infertility again presents itself as a barrier, and the cause of it has not yet been discovered. Added to this is another barrier to success, viz., that in New Zealand the gorse is predominantly a winter-flowering plant, and the introduced insects are unable to synchronise their life-cycle with the flowering period of the plant. Thus we see how, even in a case where the insect is a safe one to work with (for this little weevil will feed on nothing but gorse), unforeseen difficulties may arise which prevent the fulfilment of one's legitimate hopes. It seems fairly clear by now that some other insect, such as *Tortrix ulicitana*, will have to be taken in hand in the effort to control gorse.

The best measure of success in these difficult New Zealand problems has been met with in the work on control of ragwort (*Senecio jacobæa*). Here the most promising insect appeared to be *Tyria jacobææ*, the well-known Cinnabar Moth, which feeds on ragwort in England, and frequently almost entirely destroys it over large areas. The first consignment of pupæ of this moth was brought back by me to New Zealand in 1927, and many more consignments have been supplied from Rothamsted since. Very full tests have been made on a long series of native and economic plants with this insect, particular attention being paid to potato owing to there being a fallacious record of the larva having been found eating this plant. The moth, however, successfully passed all these stringent tests, and is undoubtedly a safe insect to try out in the field. My last official act before leaving Nelson to take up my present position, after receiving a permit from the New Zealand Government to place this insect out in the open on an experimental plot near the new laboratory in Nelson, was to put the caterpillars out on the ragwort plants growing there. Since that time, my successor, Dr. D. Miller, has carried this work forward to the stage when large numbers of the insects are available for distribution in the field. With the aid of the field staff of the Department of Agriculture, some half-million eggs of *Tyria* have been distributed in selected areas of infested country around Te Puke, Hamilton, Stratford, and Invercargill, and their effect on the weed will be watched with great interest. The principal danger appears to lie in the possible checking of the work of the moth, either through attacks from native parasites of the closely allied Magpie Moth, *Nyctemera annulata*, or in the destruction of large numbers of the caterpillars in the field by a polyhedral wilt disease, such as occurs in the rearing-cages when too great a concentration of the larvæ is allowed to take place.

I have given these New Zealand researches at some length, because they help to dispel the feeling, which one cannot help getting from a study of the splendid results with Prickly Pear, that biological control of noxious weeds is "fairly plain sailing." This is emphatically not the case, even in so favourable a case as that of prickly pear. The factors that may make it appear so are, in that case, two only, viz., the isolated position of the weed botanically, which made it appear *a priori* as very unlikely that any *Opuntia*-feeding insects would attack other species of plants outside of the Cactaceæ, and the sub-tropical climate, which greatly facilitated the work of introduction and acclimatisation. In the case of the New Zealand weeds, neither of these factors operates. The climate being temperate, but the country in the Southern Hemisphere, a difference of six months has to be overcome in the life-cycles of the introduced insects; possibly this may be one of the major factors in the remarkable cases of infertility already mentioned. Two of the weeds studied occupy unfavourable botanical positions: the case of blackberry has been already specifically outlined, and gorse is a member of the Natural Order Leguminosæ which contains many valuable economic plants. Ragwort is a member of a genus, *Senecio*, which is widely represented by native herbs and shrubs in New Zealand. Of the three, the most promising case is that of ragwort, and, as might have been anticipated, the greatest progress has been made with it. The presence of native species of *Senecio* in New Zealand is not in itself of great moment, since none of them is of economic value, though many are very beautiful shrubs; but it is of importance indirectly, as this genus is the food-plant of the common moth *Nyctemera annulata*, a close ally of *Tyria*, and it is the parasites of this moth which may become the most probable factor in limiting the success of the work of *Tyria* in New Zealand in the future.

Acæna sanguisorbæ, the native piri-piri or bidi-bidi, causes serious losses in New Zealand through its burrs adhering to the wool of sheep. This weed is also native to Australia, and is controlled in many districts by a Chrysomelid beetle, *Haltica pagana*, which entirely destroys it. This little beetle, however, is known also to have a taste for strawberries, a fruit which is, botanically, very closely allied to the genus *Acæna*. This fact rules *Haltica* out, and Dr. Miller is now searching elsewhere for an insect which will attack *Acæna* without showing a partiality for strawberries. In 1927, I initiated inquiries in Chile and the Argentine about natural enemies of the genus *Acæna*, which has its headquarters in those regions. Through the kindness of Dr. L. O. Howard, I got into touch with Brother Claude Joseph of Temuco, Chile, who recommended a trial of the native Sawfly *Antholcus fractinervis* (Order Hymenoptera, family Tenthredinidæ). This insect completely destroys the flowerheads of a number of native species of *Acæna*. Two small consignments of this insect in the pupal stage were forwarded to New Zealand; but unfortunately, owing to unsuitable packing, no emergences took place there. This experiment will be repeated by Dr. Miller on a larger scale.

When arrangements were made with the Director of the Imperial Bureau of Entomology, Dr. G. A. K. Marshall, for an Australian worker on Noxious Weeds Research to carry on his work at Farnham House Laboratory, Farnham Royal, Bucks., the work then being done on behalf of New Zealand at Rothamsted by Mr. Newton, the successor to Mr. W. M. Davies, was also transferred to Farnham Royal. The present arrangement is that New Zealand makes an annual grant of £1,000 to the Imperial Bureau for the carrying out of the

work, which is now in the hands of Mr. Watt, an officer of the Bureau. Mr. Tonnoir severed his connection with the Nelson end of the work this month (September, 1929) on taking up his new appointment on the staff of the Division of Economic Entomology at Canberra, and a rearrangement of the work in Nelson has consequently been made.

To sum up the position as regards the New Zealand work:—The original grant from the Empire Marketing Board was made for five years, it being recognised that at least that period would be needed to show results. A little more than half of this period has now passed. To date, only one insect has become successfully acclimatised and passed all the severe tests imposed upon it, viz., the Cinnabar Moth, *Tyria jacobææ*. The present summer should go far towards indicating the value of this insect against ragwort in the field. The researches with two other promising insects, *Corœbus rubi* on blackberry and *Apion ulicis* on gorse, are held up through the development of infertility in the females after acclimatisation in New Zealand. Much will depend upon whether the cause of this occurrence can be discovered and remedied. For gorse, there are also a number of other promising insects to be studied. For piri-piri, research is still in the early stages, but I think the outlook for control is quite promising. The blackberry problem remains the most difficult of all; but the work must go on and every possible avenue must be explored, for the alternative to successful control by biological means would appear definitely to be a steady increase in the hold that this weed is obtaining on farm-lands in New Zealand, with disastrous consequences to the Dominion in the future.

V. BIOLOGICAL CONTROL OF NOXIOUS WEEDS IN AUSTRALIA.

The changed outlook towards this problem in Australia must be placed to the credit of the marked success now being attained in the work against Prickly Pear. Not only has the general public reacted very favourably towards the new line of research, but the Legislatures of the Commonwealth and States are now favourably disposed towards it. Consequently the way was opened towards the organisation of further researches along the same lines in Australia, and, in my original report to the Council of Scientific and Industrial Research in 1927, I recommended that, when the Division of Economic Entomology was formed, a full Section should be allocated for research on the Biological Control of Noxious Weeds. The scheme classified the weeds to be studied into two groups, as follows:—

(a) Weeds on which no research is being carried out elsewhere:—

St. John's Wort (*Hypericum perforatum*).
Hoary Cress (*Lepidium draba*).
Saffron Thistle (*Kentrophyllum lanatum*).
Bathurst and Noogoora Burrs (Genus *Xanthium*).
Stinkwort (*Inula graveolens*).
Star Thistle (*Centaurea calcitrapa*).
Paterson's Curse (*Echium plantagineum*).
Skeleton Weed (*Chondrilla juncea*).

(b) Weeds which are being studied at the Biological Control Laboratory, Nelson, New Zealand:—

Blackberry (*Rubus fruticosus*).
Gorse (*Ulex europæus*).
Ragwort (*Senecio jacobæa*).

In pursuance of the above policy, two quarantine insectaries have been erected at the back of the main laboratory building at Black Mountain, Canberra (Plates XVI., XVII., and XVIII.). Each of these is a modification of the original design already in use in Nelson. The principal differences in construction are related to the difference in climate as between Canberra and Nelson, the greater proportion of sunlight at the former place, the greater extremes of temperature, and the greater likelihood of damage by hail. Each insectary is about forty feet square, divided into sixteen equal units approximately ten feet square each. Each unit is supplied with a tap for watering, and eight of them can be entirely closed off as separate chambers by screens of muslin stretched on wooden frameworks, while the middle sections can also be closed off as two larger chambers each twenty feet square. A concrete path runs right round the insectary, and duck-boards are used to give access to any part for cultivation purposes. Electric light and power are provided.

The design of the baffle-chamber and attached store-room is a modification of the original Nelson design (see Text Figure). The interlocking system between the outer door and the one opening into the insectary proper is of very strong construction, while powerful springs also help to close the doors automatically after opening. The store-room has a

protected gauze window, a biological bench, and a set of shelves. The baffle-chamber itself is painted dull olive green, and its inner door has, on the insectary side, a strongly built box-cage with glass-funnel entry, for recapture of any insect that might accidentally obtain access to the baffle-chamber.

The panels of the insectary proper are partly of phosphor-bronze gauze, sixty meshes to the inch, and partly of reinforced glass. The amount and arrangement of the glass panels differ in the two insectaries, thus affording a basis for comparative observations on the effect of glass panels on the heating of the interior and the growth of plants. The roof is of reinforced glass (hail-proof), and is not raised as high as in the Nelson Insectary; but, on the other hand, a more complete system of ventilation has been secured.

For the work on Noxious Weeds, Mr. G. A. Currie, late of the Entomological Branch of the Department of Agriculture and Stock, Brisbane, has been appointed Entomologist-in-charge, working under my personal direction. At Farnham Royal, Mr. S. Garthside, Junior Entomologist of the Section, is working chiefly on the insects attacking St. John's Wort in Europe. A research student, Mr. S. G. Kelly, is working on the problem of insects attacking *Xanthium*, under Professor G. A. Dean, Department of Entomology, Kansas State Agricultural College, Manhattan, Kansas.

St. John's Wort (*Hypericum perforatum*) was the first noxious weed to be studied, for several reasons. Botanically, it is sufficiently isolated to indicate a reasonable chance of the insects feeding upon it being confined to the genus *Hypericum*. Economically, it is a very bad weed indeed, as it takes complete possession of the land, killing off every other plant except only trees and strong shrubs. Even bracken goes under to it. It will take possession of any type of land except such as is essentially either swampy, on the one hand, or not receiving a rainfall of about twenty-five inches a year on the other. It is also a poisonous plant, causing acute dermatitis in horses and cattle with any white colouring on them; sheep can eat it for a time only, but suffer greatly if the diet is continued for any length of time. At the present time, an area estimated at from 250,000 to 400,000 acres in Victoria is badly infested with this weed, chiefly in the Ovens River Valley and the more mountainous portions of Gippsland. There are also serious infestations near Tumbarumba and Mudgee, New South Wales, and smaller ones in South Australia and Tasmania. The indications are that land invaded by this weed soon becomes entirely covered with it, and goes out of cultivation for good. Those who know the plant in England as a rather delicate, beautiful herb, seldom more than a foot in height, would be astonished beyond measure to see it growing in dense masses up to more than five feet in height in Victoria, a single plant producing as many as fifty upright stems, each with immense masses of flowers in large heads.

Salting has been tried with some success for this weed, but the process is costly, and, as soon as the effect of the salt has worn away, seedlings spring up in great abundance. A somewhat cheaper and more effective method appears to be the use of a solution of sodium chlorate; but this again cannot be used on the immense areas of mountainous country infested in Victoria.

A preliminary study carried out by Miss Nellie Paterson, B.A., of Cambridge University, in 1926-7, indicated the value of certain species of beetles of the genus *Chrysomela* in controlling this weed. This work has been continued by Mr. S. Garthside at Farnham Royal, who has found three species of this genus attacking the weed, viz., *C. hyperici*, *C. varians*, and *C. didymata*. A long series of tests on a wide variety of economic plants, including all the most useful types of vegetable and field crops, small fruits, cereals, grasses, fruit trees, and garden flowers, shows that these beetles do not feed on anything but *Hypericum*, either in the larval or adult stages. This initial measure of success is most promising. A permit has now been issued for the importation, under quarantine restrictions, of these species of *Chrysomela*, and the first consignment of them is due to arrive in Canberra in October, 1929. Meanwhile Mr. Currie and myself have visited all the chief centres of infestation in Australia, and have studied the ecology of the weed very fully. Large supplies of healthy plants have been brought back from various districts and planted out in No. 1 Insectary, and a wide range of economic plants is also being grown in the same insectary for the purpose of repeating the economic tests under Australian conditions.

Mr. Garthside has also done a considerable amount of work on the species of gall-midges (family Cecidomyiidæ) which attack *Hypericum*, and has studied some Lepidopterous larvæ which attack the plant, the most promising being the Tortricid moth *Lathronympha hypericana*.

The present position as regards the work on biological control of St. John's Wort may be said to be most promising.

It is yet too early to be certain that the valuable insects already discovered, that will attack this weed, can all be successfully acclimatised in Australia, but the prospects are hopeful. The gall-midges present a difficult problem in acclimatisation which has not yet been overcome, as the adults are extremely delicate flies that only live for a day or two. Acclimatisation of beetles is always a difficult matter, and much still remains to be done in improving the technique of this type of work, and in discovering the causes that lead to infertility in such cases. An effective seed-capsule feeder has yet to be found to complete the attack. The progress made, however, after little more than a year's work, is at least as rapid as it was in the case of the Prickly Pear insects.

The problem of the Cockle Burrs (genus *Xanthium*) is a most interesting one from the point of view of biological control. In Australia we have the well-known Bathurst Burr (*X. spinosum*) and the even more troublesome Noogoora Burr (probably *X. pungens*, but authorities do not yet agree as to the exact species). These are annual herbs spread by means of the seed. Noogoora Burr, more particularly, is rapidly gaining ground in Southern Queensland. Botanically, it is a curiosity, in that the capsule contains two large seeds, one of which germinates the summer after ripening, while the second lies dormant until the following season. Thus the chance of the weed surviving is greatly enhanced, and the occupation of new areas of land by seed spread about over rich flats by means of flooded rivers is made very easy. Noogoora Burr, in fact, is the outstanding weed problem of Queensland, now that Prickly Pear is well on the way to being controlled.

The genus *Xanthium* is classified as a member of the Natural Order Compositæ, but differs markedly from most genera in that Order, in that the plant, which is monœcious, bears unisexual flowers, the male flowers maturing before the female. The seed-capsule is covered with strong hooks which catch in the wool of sheep, causing losses to the wool industry which must run into very high figures, though no attempt has been made to estimate them at all accurately. From the point of view of biological control, the problem is a fairly favourable one. It is true that the Order Compositæ contains some valuable economic plants, such as Lettuce and Jerusalem Artichoke, and a large number of ornamental garden plants; but the genus *Xanthium* stands far enough apart from all these to make it reasonably certain that a considerable number of the insects that feed upon it naturally will not attack other genera. In particular, if a species can be found that feeds inside the seed-capsule, it will be extremely unlikely to attack the seeds of other Compositæ, since it is here that the genus *Xanthium* is most specialised. A search for this type of insect is now being carried on by Mr. Kelly in North America.

Some preliminary work has already been carried out regarding the Thistles, Hoary Cress, and Skeleton Weed, but not much progress can be made with these until more workers can be added to the staff. In the case of Hoary Cress, the problem is a most difficult one, almost as bad as that of Blackberry; for this weed is not only a "double-header" (i.e., it spreads easily in two ways, either from the seed or from any broken or cut portion of the underground stem), but it is closely related to a host of valuable economic plants of the Natural Order Cruciferæ. Skeleton Weed is also a difficult problem, as it is another "weed of cultivation," being spread mainly from the broken pieces of the underground stem left in ploughed land; but it is not so unfavourably situated botanically as is Hoary Cress.

Turning to the weeds already being studied at the Cawthron Institute, Nelson, New Zealand, work has already been begun upon Ragwort (*Senecio jacobæa*). A portion of No. 1 Insectary has been planted with this weed, both well-grown plants and seedlings, and a plot of ground in the open has also been planted with them. As the moth *Tyria jacobææ* has already passed all necessary tests satisfactorily in New Zealand, permission has been given for its importation into Australia without further testing. The first consignment of pupæ was brought over from New Zealand by Mr. Tonnoir this month (September, 1929), and the moths are shortly due to begin emerging. I have already indicated to you that the principal obstacle to success, in the case of this moth, is caused by the great abundance of the common allied species *Nyctemera annulata* in New Zealand, and the resulting possibility of the work of *Tyria* on ragwort being checked by the attacks of the known parasites of *Nyctemera*. As far as my observations go, it would appear that the allied Australian species *Nyctemera amica* is not particularly common in ragwort-infested areas, so that the prospects of success for *Tyria* in Australia may be considered more promising than in New Zealand on this point. On the other hand, the

climate of Australia may not prove to be quite as suitable for the moth, which is confined in nature to the cooler parts of Western Europe.

Blackberry is, of course, a very bad pest in parts of Australia. No work, however, can be undertaken on this weed here pending the completion of the researches at present being carried out at the Cawthron Institute. We must be content with the assurance that every possible avenue of control will be explored; should any one of them prove successful, the results will be almost immediately available for Australia. The same remarks apply to gorse.

I have now outlined to you the relationship of the special problem of Noxious Weeds Control to the problem of Biological Control in general, and have shown that this type of work rests upon a secure scientific foundation. This has been followed by a general survey of the types of problem presented by different kinds of weeds. In subsequent sections of this lecture, I have dealt with the history of Biological Control of Noxious Weeds, taking, in chronological order, the four examples of this type of work that have been, or are being, undertaken, viz., the Hawaiian experiments, the Prickly Pear work in Australia, the work at the Cawthron Institute, Nelson, New Zealand, and the work now being carried on at the Central Entomological Laboratory of the C.S.I.R. at Canberra. If I have thereby succeeded in enabling you to grasp the immense importance of the problem to Australia, its innate difficulties as well as its splendid promise in individual cases, I shall feel that the main purpose of this lecture has been achieved.

BIBLIOGRAPHY.

1919. ALEXANDER, W. B. The Prickly Pear in Australia. Bull. No. 12, Institute of Science and Industry, Melbourne, 1919, pp. 1-48, pl. 1.

1925. ——— Natural Enemies of the Prickly Pear and their introduction into Australia. Bull. No. 29, Institute of Science and Industry, Melbourne, 1925, pp. 1-80, 13 plates.

1922. BLANCHARD, E. E. Notes on *Zophodia analamprella* and other Lepidoptera living on Cactaceæ. Physis, No. 21, 1922, pp. 119-123.

1928a. DAVIES, W. M. The Bionomics of *Apion ulicis*, Forst. (Gorse Weevil), with special reference to its role in the control of *Ulex europæus* in New Zealand. Ann. Applied Biology, vol. 15, No. 2, 1928, pp. 263-286, 3 plates, 3 figs.

1928b. ——— Notes on the Feeding Habits of *Habrosyne derasa*, L. Bull. Entom. Research, Dec., 1928.

1927. DETMERS, F. Canada Thistle, *Cirsium arvense*, Tourn. Field Thistle, Creeping Thistle. Bull. Ohio Agri. Exp. Sta. No. 414, 45 pp., 13 figs., 56 refs. Wooster, Ohio, Nov., 1927.

1927a. DODD, A. P. The Biological Control of Prickly Pear in Australia. Bull. No. 34, C.S.I.R., Melbourne, 1927, pp. 1-44, 9 plates.

1927b. ——— The Biological Control of Prickly Pear. Investigations of the Commonwealth Prickly Pear Board. Journ. C.S.I.R., vol. I., No. 1, Melbourne, August, 1927, pp. 48-54, 4 plates.

1929. ——— The Progress of Biological Control of Prickly-Pear in Australia. Commonwealth Prickly-Pear Board, Brisbane, October, 1929, pp. 1-44, plates I.-XII.

1919a. FROGGATT, W. W. *Icerya hyperici*, parasite on roots and basal stems of St. John's Wort. Agric. Gazette N.S.W., July, 1919.

1919b. ——— The Lantana Fly. Agric. Gazette N.S.W., Vol. XXX., p. 665.

1927. FULLAWAY, D. T. Report of Entomologist, Jan., 1925, to Dec., 1926. Hawaii. Report Bd. Agric. and Forestry, 1925-6, pp. 39-46.

1926. GURNEY, W. B. Lantana Fly in the North Coast Districts. Agric. Gazette N.S.W., June, 1926, p. 477.

1924. HAMLIN, J. C. The Australian Prickly Pear Problem. Jour. Econ. Ent., vol. 17, No. 1, 1924, pp. 60-64.

1925. ——— Important *Opuntia* Insects of the United States. Biological Notes on the Moth-borers (Pyralidæ). Pan-Pacific Ent., vol. 2, No. 1, 1925, pp. 1-11.

1927. IMMS, A. D. The Biological Control of Insect Pests and Injurious Plants in the Hawaiian Islands. Ann. Applied Biology, vol. xiii., No. 3, August, 1927, pp. 402-423, pl. xii.

1916. JEPSON, F. P. The Lantana Seed Fly (Agromyzidæ). Dept. Agric. Fiji, Suva, Pamphlet 31, 1916.

1923. JOHNSTON, T. H., and HITCHCOCK, L. A bacteriosis of Prickly Pear Plants (*Opuntia* spp.). Trans. and Proc. Roy. Soc. S. Australia, vol. 47, Adelaide, 1923, pp. 162-164.

1914. JOHNSTON, T. H. and TRYON, H. Report of the Prickly Pear Travelling Commission, 1st Nov., 1912, to 30th April, 1914. Brisbane: Govt. Printer, 1914, 131 pp., 66 figs., fcap.

1924. KNIBBS, Sir G. H. Work in Progress. Second Annual Report, Institute of Science and Industry, 1922-23, Melbourne, 1924, pp. 9-48.

1924. KOEBELE, A. Report on Enemies of *Lantana camara* in Mexico, and their Introduction into the Hawaiian Islands. Ent. Bull., vol. 16, H.S.P.A., 1924, pp. 54-71.

1928. KUNHI KANNAN, K. The Control of Cactus in Mysore. Mysore Agric. Calendar, 1928, pp. 16-71, 1 pl.; Bangalore.

1929. MILLER, D. (See foot-note on p. 1). Control of Ragwort through Insects, Experimental Work with Cinnabar Moth. N.Z. Jour. Agric., vol. xxxix., No. 1, July, 1929, pp. 9-17.

1928. NORTHCROFT, E. F. The Blackberry Pest. N.Z. Jour. Agric., vol. xxxvi, No. 4, April, 1928, pp. 261-275.

1924. OSBORN, H. T. A Preliminary Study of the Pamakani Plant (*Eupatorium glandulosum*, H.B.K.) in Mexico with Reference to its Control in Hawaii. H.P.R., vol. xxviii., 1924, pp. 546-559.

1924. PERKINS, R. C. L., and SWEZEY, O. H. The Introduction into Hawaii of Insects that attack *Lantana*. Ent. Bull. 16, H.S.P.A., 1924.

1929 PETIT, G. C.R. Acad. Agric. Franc. Vol. XV., No. 9, pp. 410-416. (Introduction of *Dactylopius* into Madagascar.)

1915. SWEZEY, O. H. Some Results of the Introduction of Beneficial Insects in the Hawaiian Islands. Journ. Econ. Entom., vol. viii., pp. 450-456, 1915.

1928. TAYLOR, T. H. C. Report on investigations in Trinidad on *Liothrips urichi* as a parasite for *Clidemia hirta*. Legis. Council Paper, Fiji, 5 pp., Suva, 1928.

1926. TILLYARD, R. J. The Progress of Economic Entomology (with special reference to Australia and New Zealand). Trueman Wood Lecture. Jour. Roy. Soc. Arts, 1926, vol. lxxv., No. 3860, pp. 3-20.

1927a. ———— Insect Control of Noxious Weeds. Joint Scheme initiated against Blackberry and other species. N.Z. Jour. Agric., Feb., 1927, pp. 1-7.

1927b. ———— Biological Control of St. John's Wort. N.Z. Jour. Agric., July, 1927, pp. 1-4.

1928. ———— Entomological Research; A General Scheme, Jour. C.S.I.R., vol. I., No. 4, May, 1928, pp. 193-201.

1929. ———— The Work of the Division of Economic Entomology for the year 1928-29. Melbourne, 1929. (See pp. 11-13.)

1919. TRYON, H. The St. John's Wort Pest. Proposal to utilise insect enemies for its eradication. Queensland Agric. Journal, March, 1919.

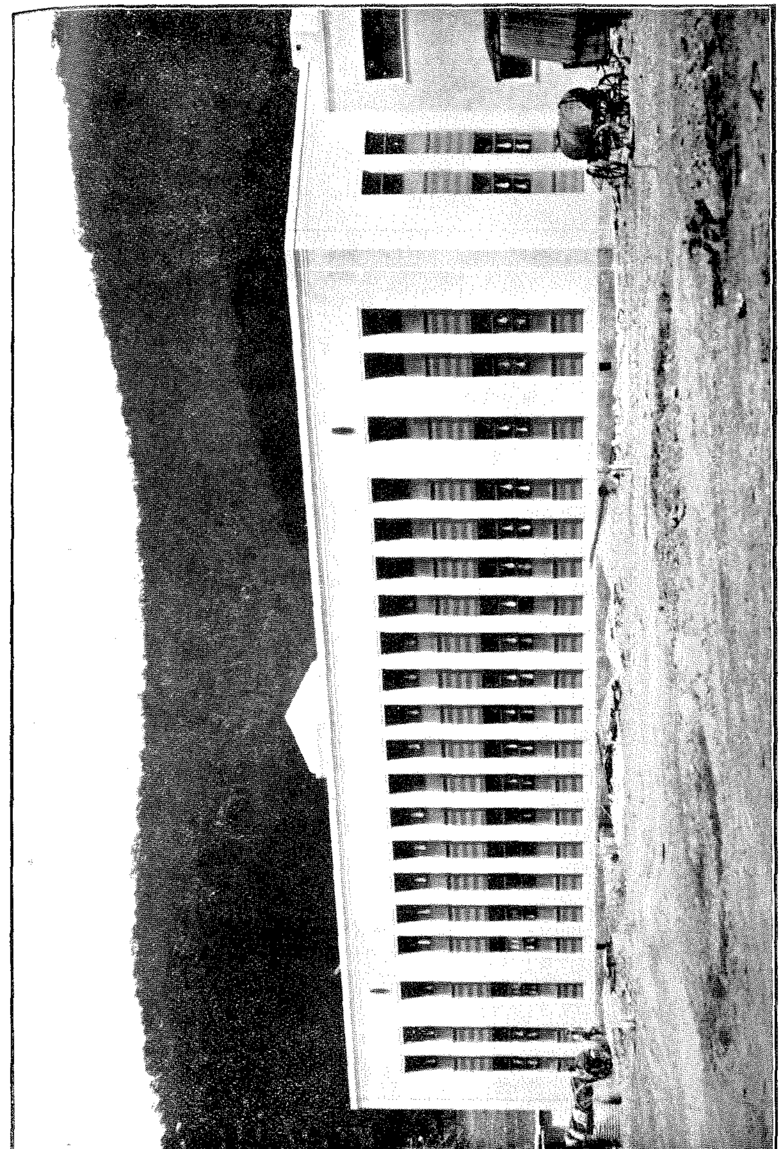
Articles published without author's name.

1912. Destruction of Lantana. Journ. d'Agric. Trop., p. 154, 1912.

1924. Lantana Parasites. Agric. Circ. Dept. Agric. Fiji, Vol. V., No. 1, p. 74. Suva, Jan.-June, 1924.

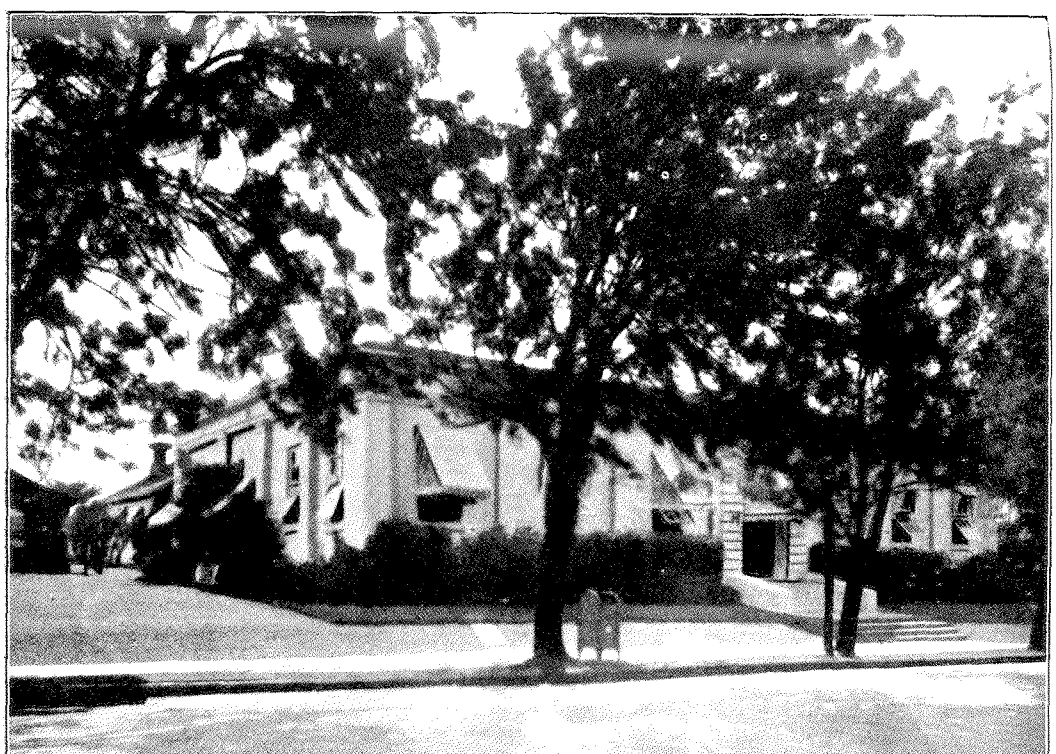
1929. Department of Scientific and Industrial Research, Wellington, New Zealand. Annual Report, 1929, pp. 18-19. (Noxious Weeds Research.)

Plate XI.

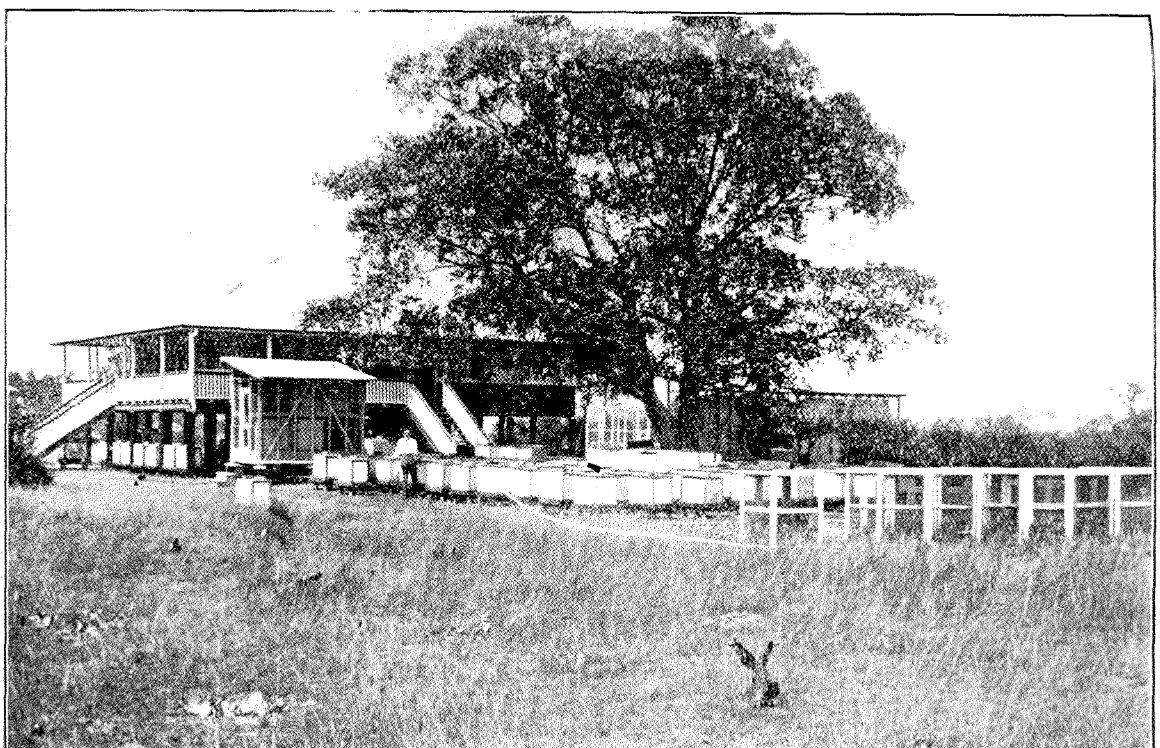


Front elevation of the new Laboratory Block, Division of Economic Entomology, C.S.I.R., Black Mountain Site, Canberra, F.C.T., Australia. This building is designed to be the left wing of a complete building having a central Administrative Block and a right wing similar to the left for the Division of Economic Botany.

(Photo. by J. Mildenhall.)



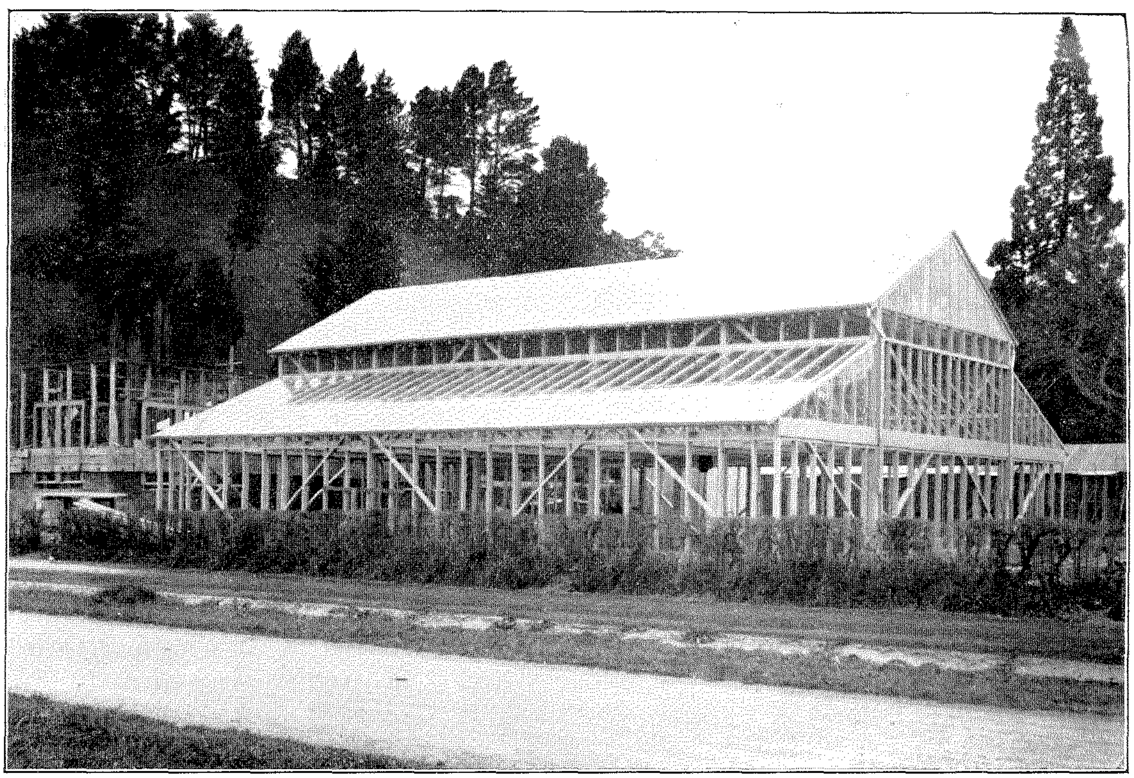
The Experimental Station of the Hawaiian Sugar Planters' Association, Honolulu, Hawaiian Islands.



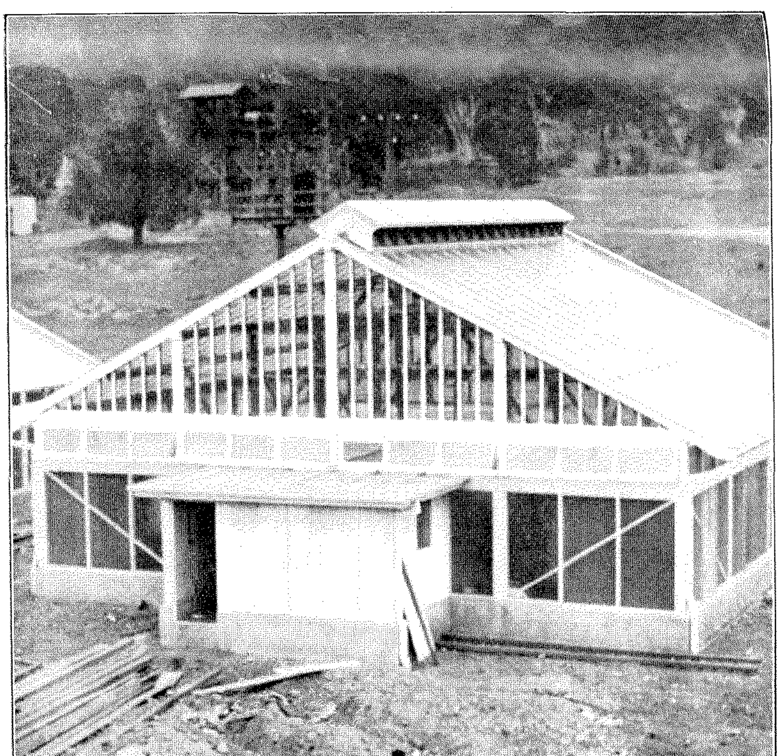
Central Laboratory of the Prickly Pear Board, Sherwood, near Brisbane, Queensland. In front, to left, a small insectary; in middle, rows of breeding cages.

Portion of The Wood, Nelson, New Zealand, with harbour in background, showing in foreground the Biological Control Laboratory and Insectary of the Cawthron Institute. Photo. taken from the grounds of the Cawthron Institute.

(Photo. by W. C. Davies.)

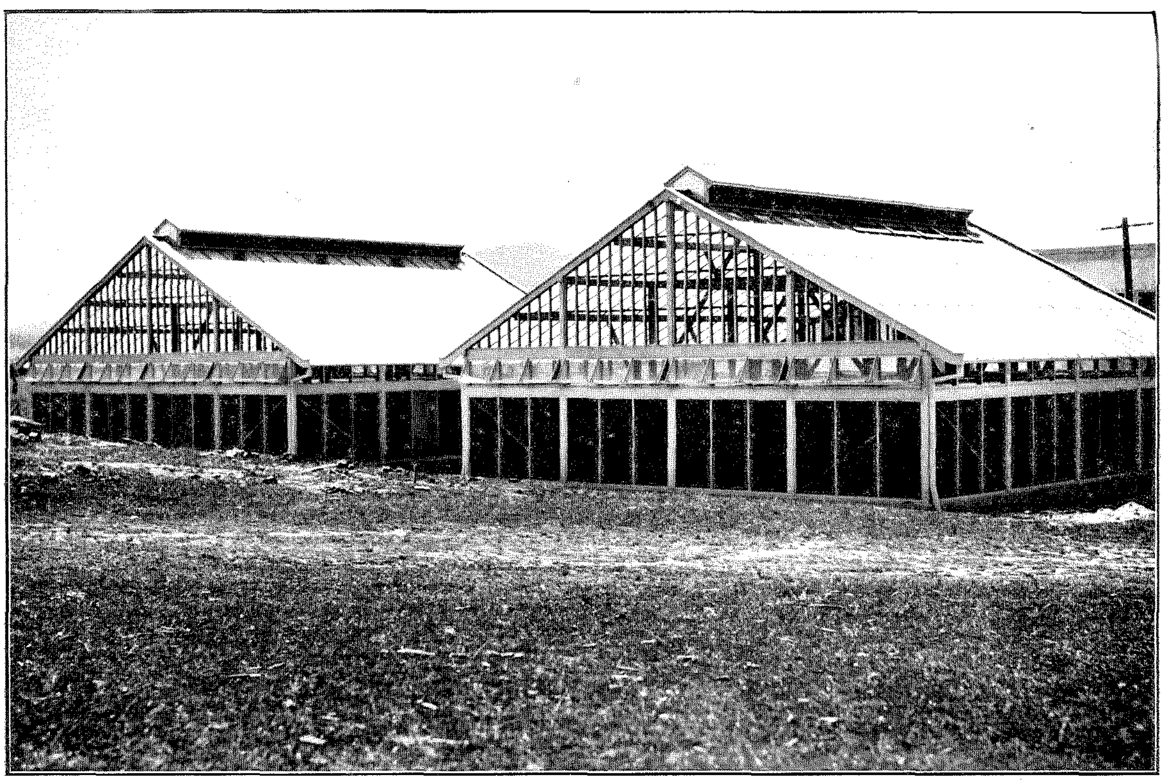


The large Quarantine Insectary of the Biological Control Station at the Cawthron Institute, Nelson, New Zealand. Note the raised roof with side ventilation between middle and side portions.



No. 1 Quarantine Insectary of the Division of Economic Entomology, C.S.I.R., Canberra, F.C.T., Australia, showing Baffle Chamber with door open to left; the quarantine store-room is the chamber with small window attached to right of baffle chamber. Note the roof-ventilation.

(Photo. by J. Mildenhall.)



Nos. 1 and 2 Quarantine Insectaries of the Division of Economic Entomology, C.S.I.R., Canberra, F.C.T., Australia, viewed from the back, showing complete roof and side ventilation.

(Photo. by J. Mildenhall.)

Interior of No. 1 Quarantine Insectary, Division of Economic Entomology, C.S.I.R., Canberra, F.C.T., Australia. In foreground, tubs containing fruit-trees for feeding tests on imported insects; in background, plots of St. John's Wort (*Hypericum perforatum*).

(Photo. by J. Mildenhall.)