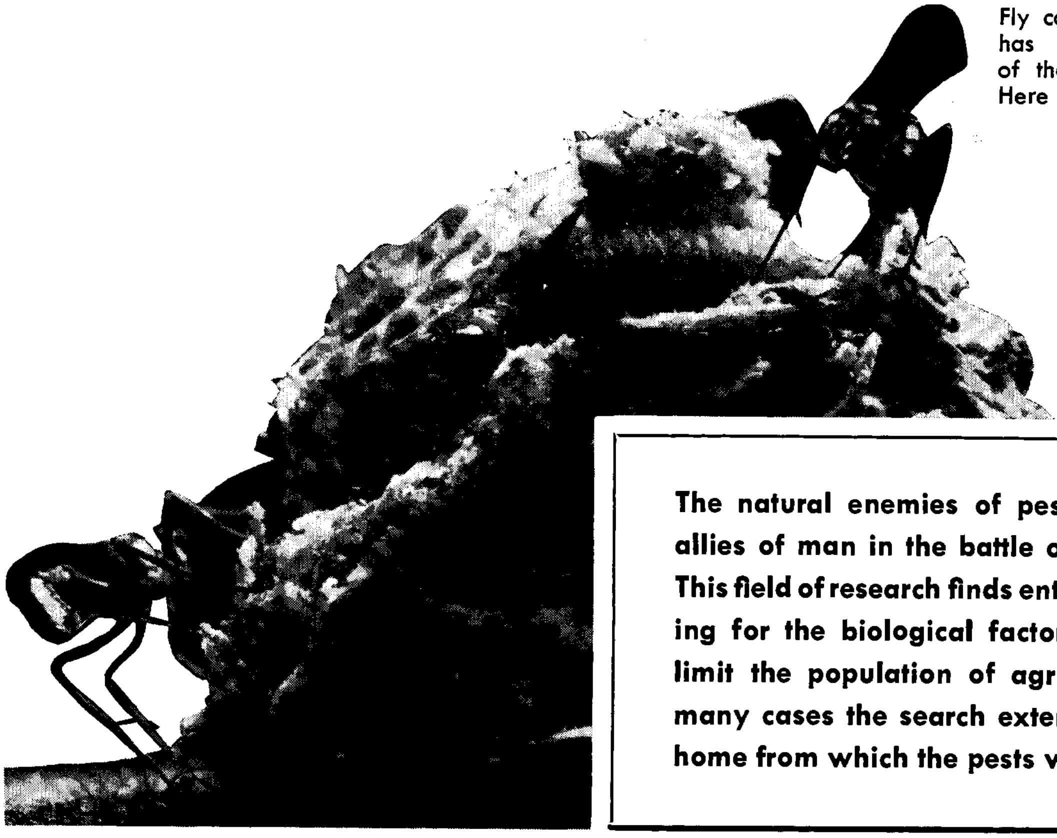


Fly commonly found in the U. S. has proved to be a predator of the Mediterranean flour moth. Here it attacks the larval stage

The natural enemies of pests are the natural allies of man in the battle of food production. This field of research finds entomologists searching for the biological factors which naturally limit the population of agricultural pests. In many cases the search extends to the original home from which the pests were imported

BIOLOGICAL ANTAGONISTS *in the future of* Insect Control

C. P. CLAUSEN, Chairman, Department of Biological Control, University of California, Riverside, Calif.

One of the most difficult problems in biological control is that of evaluating the field effectiveness of the parasites and predators introduced and established for pest control. In the past, workers in this field have been criticized, and perhaps rightly so, because of their failure to provide adequate proof that the natural enemies have been responsible for the reductions in pest infestations that have taken place following their establishment and general distribution. In some few cases, where control has been immediate, complete, and consistent year after year, as in the case of the cottony cushion scale, citrophilus mealybug, sugar cane leafhopper, etc., this question does not arise, because the answer is obvious. However, where control is only partial, as in the gypsy moth, European corn borer, and many others, there is a real question as to the extent of benefits obtained, and the estimates vary greatly.

Evaluation Is Complex

The exact evaluation of results from the introduction of natural enemies is much more complicated than in tests of insecticidal materials. First, the studies must usually cover a period of years, as the natural enemies may require that time in which to exert their full effect upon the host; second, suitable check plots are exceedingly difficult to maintain, as natural dispersion from test areas may quickly contaminate plots many miles away. In fact, the whole infested area may be covered so quickly that the maintenance of check areas becomes impossible. Third, the pest insect under consideration, usually an introduced species, may maintain a peak population for a period of years and then subside to a much lower level from causes other than the introduction of natural enemies. Where these are introduced and become abundant, at the peak of the infestation, and a sharp decline in pest population then takes place, it is often asserted that the course of events would have been the same, even had the parasites not been introduced. This argument is impossible to refute unless adequate check areas have been maintained throughout the test period. The decline in pest populations independent of introduced natural enemies unquestionably occurs in some instances but by no means in all, as is demonstrated by the European corn borer, cotton boll weevil, citrus blackfly, oriental fruit moth, and many others. In any case, whenever parasite introduction is followed by a consistent decline in the pest population, the result is often attributed by the critically minded to a natural decline rather than to biological control.

The fact that these declines do occur in some instances makes it highly desirable that methods be developed that will give a reasonably accurate evaluation of parasite introduction. One difficulty in previous efforts along this line has been that needs for personnel, time and funds are so great as to be almost prohibitive. The cost of such a program would in many instances exceed that incurred in foreign exploration and rearing and colonization of the imported parasites. It is, therefore, understandable why exact evaluation has not been more frequently attempted. Furthermore, exact evaluation does not serve the same purpose in a biological control project as one in chemical control. If all available natural enemies are imported and established, nothing further can be done to increase their effectiveness, regardless of the conclusions reached. In chemical control, if the evaluation reveals an unsatisfactory degree of control, the search for new and better materials can be continued, changes made in formulations, etc.

One serious defect in many biological control projects in the past has been that plans for evaluation of effectiveness have been laid only after the natural enemies have been introduced, established, and widely distributed. It seems essential that these plans be developed and the program fully outlined before any of the parasites are released. This has been one weakness in practically all attempts at evaluation in the past. The whole problem of evaluation is an exceedingly difficult one, but definite progress is being made in the development of methods whereby the field effectiveness of introduced natural enemies may be determined. Obviously, however, this cannot be on as exact a basis as the field testing of insecticides, or changes in cultural practices.

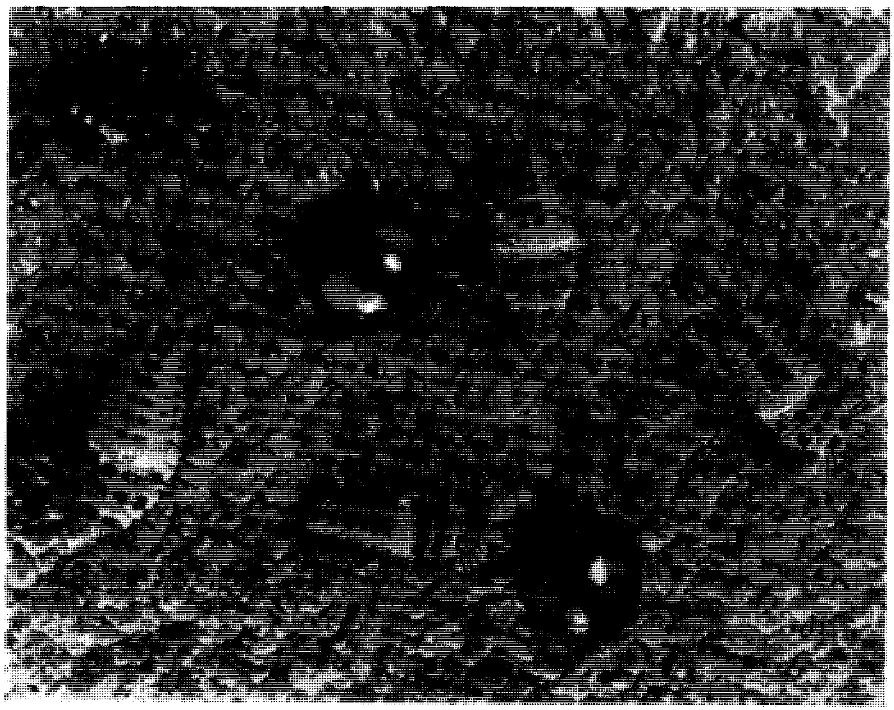
In most cases, our early conclusions will continue to be based on general field observations, but if these field observations are sufficient in scope and accuracy, a conclusion as to spread and effectiveness of the introduced parasites may often be established quite firmly by circumstantial evidence well in advance of experimental confirmation.

Environmental Knowledge Necessary

The present day field of biological control covers two distinct phases. The first is the importation and establishment of natural control agencies from abroad mainly for control of pests of foreign origin. For a long period the various biological control organizations were concerned almost entirely with this phase. The second, which has come sharply into the picture in recent years, is really applied ecology. We need to know the intimate relationships between all elements of the pest complex, including their natural enemies, and their environment in the field or orchard, in order to make full use of the potentialities of these natural enemies. The various control programs now under way have a wide influence on the insect population as a whole. In order to make the fullest use of the natural enemies present in the field or orchard, we must know how they react, not only to insecticidal applications but to other elements in the environment that may have an influence, one way or another, upon them. With our present great concern regarding the fate of native parasites and predators of the so-called minor pests I feel that we can anticipate a marked expansion in work on this fundamental subject.

C. P. Clausen **has been chairman of the Department of Biological Control at the University of California since 1951. His training in entomology was also at the University of California and his first position in entomology was at the university's citrus experiment station, 1914 and 1915. In 1916 and 1917, he was assistant superintendent of the California State Insectary and during that time made an expedition to Japan and China in search of parasities of black scale, of citrus, and others. After World War I, he went to work with the USDA Bureau of Entomology and Plant Quarantine and remained there until 1951. During his time with BEPQ, Dr. Clausen was again in the Far East, this time to collect natural enemies of the Japanese Beetle and citrus black fly. He was in charge of BEPQ's Division of Foreign Parasite Introductions and later of the Division of Control Investigations.**

Close-up of a Twice-Stabbed lady beetle feeding on scale insects attached to the skin of an orange. The three stages are: the pupae (upper left), the larvae, and two adults. These predators were imported to feed on scale insects attacking citrus in southern California



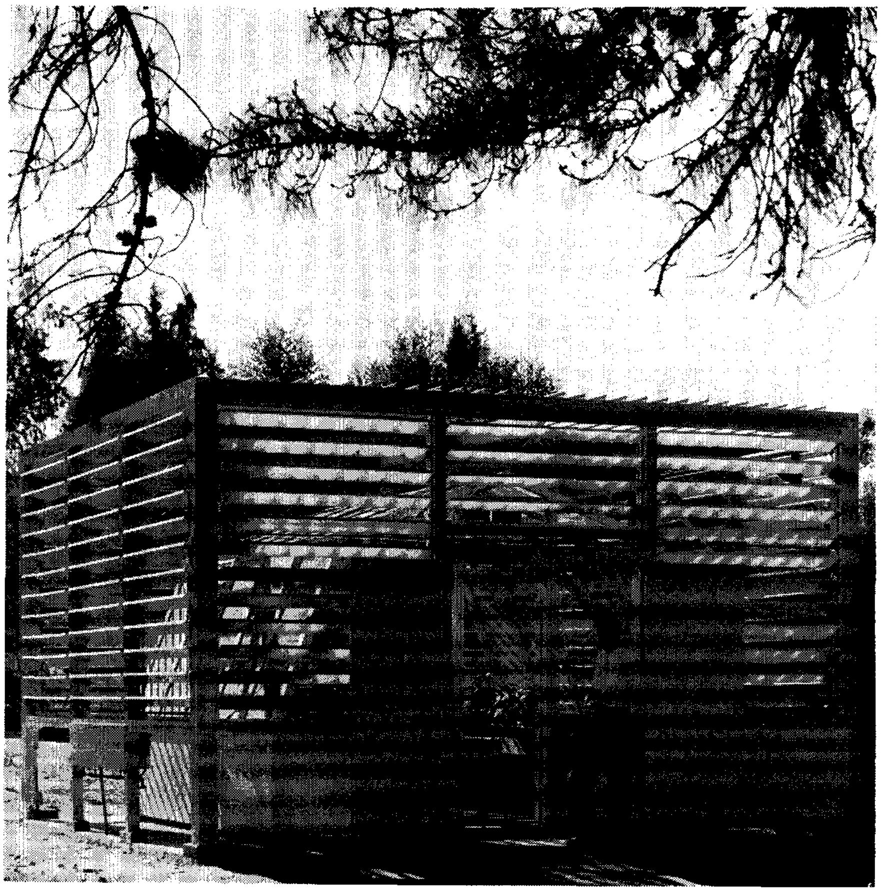
Need for Taxonomic Study

The need for thorough and basic taxonomic studies on the insects involved in biological control projects is becoming more and more apparent. Initially, an exact identification of the host insect is, of course, essential, otherwise the search for natural enemies abroad may be centered in the wrong part of the world. Several instances of incorrect identification of the pest insect have resulted in prolonged search for natural enemies in parts of the world where the true host did not occur.

This difficulty is relatively minor as compared with those relating to the parasite species themselves, as is well demonstrated by the parasitic wasp complex known under the name *Aphytis maculicornis* recently introduced into California for control of the olive scale. Stocks were obtained from four geographic areas and these proved to be distinct biologically, having different life cycles and reproductive capacities. Two were unisexual and two bisexual, and the bisexual forms do not interbreed. These so-called races or strains surely justify species status except for the apparent complete lack of morphological characters in the adults to distinguish them. A similar situation exists with respect to another species of *Aphytis* attacking red scale in the Orient and also with species of *Casca* and *Comperiella*, minute wasps, parasitic in the same and related hosts.

The absence of recognition characters in the adult very much complicates the field recovery program if all races are released. If the areas of dispersion have overlapped, only very careful and time-consuming breeding tests will reveal which form or forms have persisted and are most effective.

In the future, it is quite possible that morphological characters not yet detected will be found that will enable us to distinguish between these races, but, on the other hand, these characters may well be recognizable only by the specialist and will not be usable by the field worker. The more intensive our biological studies become the more numerous are the taxonomic problems that arise. Certainly, an expansion of taxonomic work on the parasitic insects is basic to continued progress in biological control. It requires either that the taxonomic worker shall deal not only with dead specimens, but also with the living insects, in all their stages, or that the taxonomist and the biologist work closely together in the solution of their problems.



Charles A. Fleschner standing in front of the University of California's biotrone, a structure which automatically maintains constant temperatures by opening and closing the aluminum louvers. It was designed to facilitate studies on the effects of plant changes on the vital balance between harmful and beneficial insects

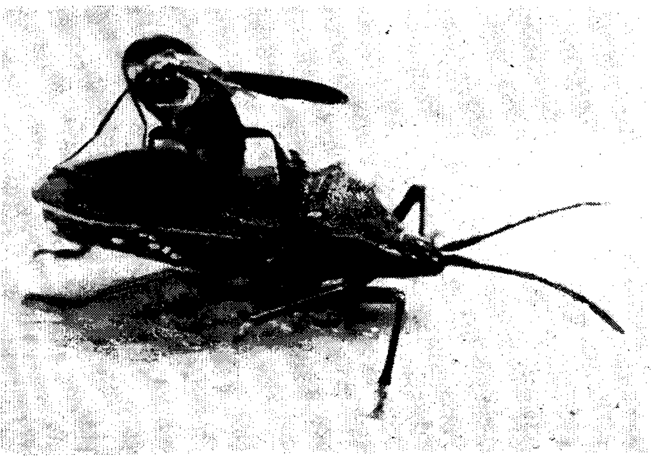
Adaptive Strains Looked for

We may look forward to considerable work on the development or selection of races or strains of parasitic insects especially adapted for use under special conditions. An example of this is the work by Pielou and Glasser in Canada on the development of a strain of *Macrocentrus ancylivorus*, the oriental fruit moth parasite that is more tolerant to the new insecticides than is the present field population. Such a strain would be of value in areas where the insecticides are coming into use for the first time, but in other areas, where their use has been consistent over a period of years, a resistant strain should evolve in nature, in the same way as has occurred in various pest species. One difficulty in this type of work is that the insecticide picture is constantly changing, so that before a tolerant or resistant strain of parasite can be developed, an entirely different chemical may come into general use against the pest insect involved, and to which the newly developed parasite strain may or may not be equally tolerant.

In the case of parasite species having a wide geographic range, it is well known that stocks from colder areas are often able to develop and increase to their maximum extent at lower temperature levels than those from more temperate areas. This is one reason why, in parasite introduction programs, it is coming to be realized that stocks should be obtained from all geographic areas inhabited by the species.

Another phase of this problem is the development by breeding of the so-called temperature strains of parasite species. Considerable progress in this line of research has been made by Wilkes in Canada in his work with *Dahlbominus fuscipennis* (Zett.), a pupal parasite of the European spruce sawfly, in an effort to produce a strain capable of survival at lower temperatures than is the present field population of the parasite. This line of research appears to have considerable promise of practical results, though of course we have at present no basis on which to judge its limitations, and no field tests have been made with such laboratory-produced strains. Many examples might be cited of serious differences in temperature responses between host and parasite. A conspicuous illustration is the green bug, *Toxoptera graminum* (Rond.), and its principal parasite, *Lysiphlebus testaceipes* (Cress.). The development of a low-temperature race of the parasite having a threshhold of development more nearly approaching that of the host would contribute greatly to its effectiveness in checking the pest early in the season. Other examples are *Metaphycus helvolus* on the black scale and *Aphytis* spp. on the red scale, both introduced into southern California. Both of these species suffer serious mortality during colder than average winters. *Chaetexorista javana*, the highly effective fly parasite of the oriental moth introduced from Japan into Massachusetts, suffers very high mortality of its early larval stages within the host body during exceptionally cold winters.

Close-up of a fly imported from New England to California. Fly lays its eggs, fairly visible in the photo, on the under side of the squash bug. Larvae burrow inside the squash bug and destroy its reproductive organs



At first thought, the simplest solution to problems such as these would be to import stocks from a region having winters at least as cold as those in the area in which they will be colonized. Certainly more attention will be paid to this factor in the future but in many instances the range of distribution of host and parasite does not extend into a comparable climatic zone.

Native Parasites and Predators

One phase of biological control activities that has not received the attention it deserves is the distribution of native parasites and predators. It has generally been taken for granted that these natural enemies are as widely distributed in nature as their adaptability permits and if restricted to only one part of the country the climatic and other conditions elsewhere are probably adverse to them. It has been demonstrated, however, that this certainly is not always the case. The squash bug parasite, *Trichopoda pennipes*, and the asparagus beetle parasite, *Tetrastichus asparagi*, both from the Northeastern states, proved fully as effective in the Pacific Northwest when colonized there some years ago as they are in the area of origin. A study needs to be made of the distribution of the principal parasites and predators of all of our major pests of widespread occurrence, both native and of foreign origin, with the objective of colonizing and establishing them in all sections of the country where they do not now occur. Such a program would call for close cooperation between the U. S. Department of Agriculture and many state agencies, first in making the preliminary surveys and next in assembling, shipping, and colonizing the parasite stocks. It would involve work over a considerable period of years, though at much less cost than foreign explorations, and the net results may compare favorably with the results of many of our programs based on foreign importations for use against introduced pests.

Microbial Control Promising

From the point of view of future developments in biological control, one of the most promising fields is the utilization of disease-producing microorganisms in field control of insect pests. The idea of microbial control is not new, as is shown by the attempt to control chinch bugs in several north central states during the decade from 1888, grasshoppers in 1900, the brown-tail moth during 1908–11, and the citrus white fly from 1915 onward. Looking backward, it is perhaps unfortunate that all of these early efforts in the United States, and others in several foreign countries as well, should have been with fungi, which are most intimately tied up with weather conditions and experimentally are most difficult to evaluate in the field. The fact remains that these failures discouraged further tests of this means of control and a period of years elapsed before interest in the subject revived, but with other classes of microorganisms.

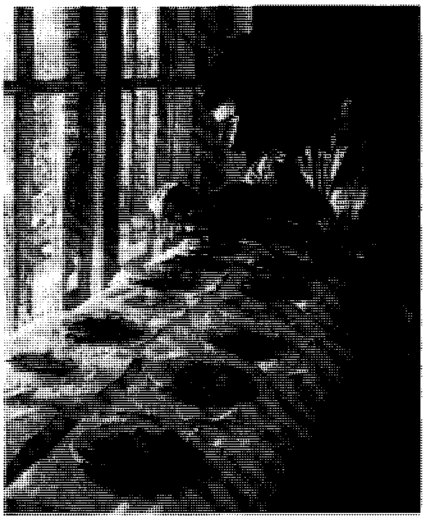
The work on the milky diseases of the Japanese beetle by G. F. White and S. R. Dutky and their associates in the Bureau of Entomology and Plant Quarantine from 1933 onward provided the impetus for a revival of interest in microbial control. It was demonstrated that the principal pathogen, *Bacillus popillae,* could be produced in quantity and utilized effectively in reducing Japanese beetle infestations. Grub populations have consistently been reduced 80% or more and build-up in the treated areas is prevented thereafter.

Disease Research On Sound Basis

The work on diseases of insects and their utilization in control of pest species may be said to have been placed on a sound and substantial basis with the establishment of the Laboratories of Insect Pathology at the University of California, under E. A. Steinhaus, in 1945; at the Canadian Department of Agriculture at Sault Ste. Marie, in 1946; and now with the setting up of a similar unit in the U. S. Department of Agriculture at Beltsville, under the leadership of C. G. Thompson. With the sustained researches of these three groups and, it is hoped, of others that may be organized in the future, we can look forward to a comprehensive program based on adequate fundamental research on the different groups of pathogenic microorganisms, that will yield substantial returns in crop pest control.

Looking ahead, there seems to be good reason to expect that these disease-producing organisms, and especially the bacteria, viruses, and fungi will prove useful in controlling a number of crop pests, and that the number of successes may well equal that attained with the insect parasites and predators. The examples of the use of *Bacillus popillae* against the Japanese beetle, *B. thuringiensis* against the alfalfa caterpillar, and the virus *Borrelina campeoles* Steinh., also against the alfalfa caterpillar, the latter two by Steinhaus and his associates, have demonstrated what can be done. There are a number of other native insect pests that are known to show frequent and heavy attack by bacterial and virus diseases and special attention perhaps should be given to those affecting insects attacking food crops, especially the leafy vegetables, as insecticidal residues are now a serious problem on these commodities. Another promising field is in control of incipient outbreaks of foliage-feeding forest insects.

The utilization of these various microorganisms in field control presents several differences from that of insect parasites and predators. So far as we can judge now, applications for control of foliage feeders are effective only during the one season, though possibly required only once, rather than several times each season, as with the insecticides. The cost of application of a disease-producing organism, therefore, is approximately the same as for the insecticide, whereas that of the material used for control will range from virtually nothing, as in the case of the virus of the alfalfa caterpillar, to a figure which, in some cases, may be economically prohibitive. This is due to our present lack of knowledge of methods of laboratory production of the organisms involved. Dead or dying alfalfa caterpillars can be collected in quantity with very little labor and the virus material stored almost indefinitely, but this procedure is not practicable with many other insects.



Stanley E. Flanders uses a mouth aspirator to remove tiny parasites from rearing cultures

Many parasitic fungi and some bacteria can be grown in the laboratory at very low cost. Examples of the first are the cinch bug fungus so widely distributed during the 1890's and the green muscardine fungus that attacks many soil-inhabiting insects in many parts of the world and several species widely distributed for white fly and scale insect control in Florida.

Among the parasitic bacteria the *Bacillus* attacking the alfalfa caterpillar which was referred to previously can be produced in quantity in the insectary, but the instances of such production with other bacteria are few. The most extensive utilization of a bacterium in insect control has been with *Bacillus popillae* against the Japanese beetle, extending over a period of 20 years; yet many years of study have failed to yield a method whereby an artificial cultural medium can be substituted for the living insect.

The production of the virus pathogens

First Insect Pathology Lab at U. of California

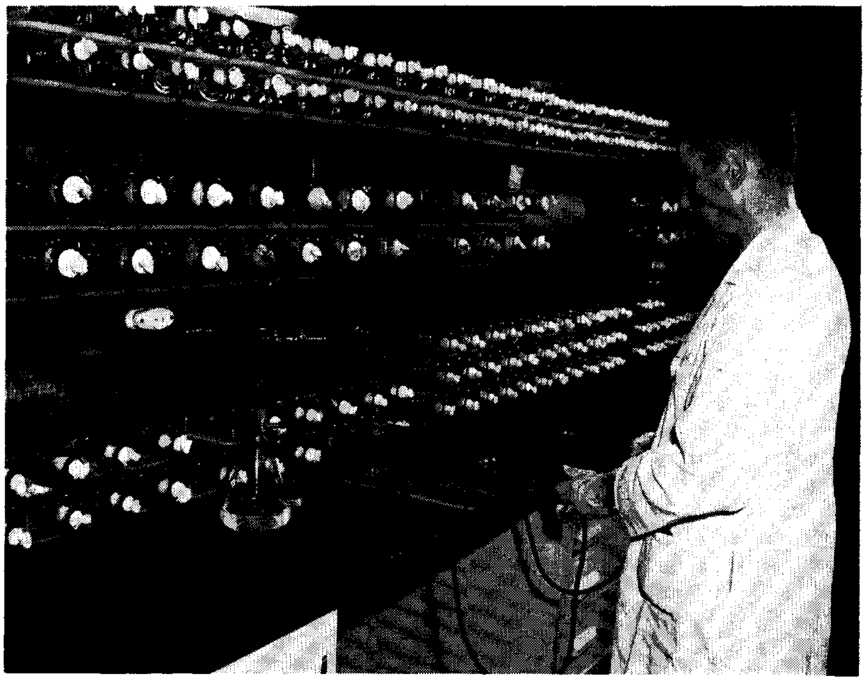
THE LABORATORY OF INSECT PATHOLOGY, a unit of the department of biological control at the University of California, is the first of its kind in the world. It concerns itself with the long-neglected question of insect diseases. Aristotle took note of the diseases of the honeybee more than 2000 years ago and Louis Pasteur, studied the diseases of the silkworm during the last century. But it was usually the useful insect that attracted the attention of science. Few seemed to care how the billions of useless, and often harmful, insects became ill and died.

The laboratory on the Berkeley campus, under the direction of Edward A. Steinhaus, is pioneering the way. A list of outstanding accomplishments in entomology during the past 100 years, being compiled by a leading entomological society, contains 10 with which the laboratory has been directly concerned. They include the first regular course in the subject given anywhere; the first isolation from insects of about 25 important disease-causing organisms; the first control of a field crop pest by spreading an artificial epidemic among the insects; the first use of aircraft in spreading such an epidemic; the first comprehensive classification of insect viruses; the establishment of a service for diagnosing insect diseases; and, of course, the setting up of the laboratory itself.

Laboratory Functions

The laboratory has five main functions. First, it does basic research on the diseases of insects and the organisms that cause them. Several hundred different insect diseases have been diagnosed, and more than two dozen studied comprehensively. The organisms that kill insects are the same general type that kill higher animals, including man: viruses, bacteria, fungi, protozoa, and nematodes. Fortunately they attack only a narrow range of victims. Higher animals are completely safe even when wading knee-deep in fields swarming with infected insects. This makes application safe for the farmer and his livestock.

The second function of the laboratory is to study the effects of diseases on insect populations in nature. Sometimes spectacular outbreaks eliminate pests from wide areas; then the disease disappears for years, giving the pests a chance to build up their populations to harmful proportions. Knowledge of the factors responsible for these cycles makes it possible for entomologists to use natural outbreaks in crop pest control.



Irving Hall inoculates Povitsky culture bottles with insect-killing bacteria. Water rinses remove the surface-growing bacteria; water is evaporated and the dry bacteria used in field and laboratory tests

The third function of the laboratory is to assist nature in killing off crop pests. The most striking example the laboratory has produced is the control of the alfalfa caterpillar by a virus artificially spread in the field. After five years of university tests, this type of pest control has now reached the commercial stage: one of the biggest alfalfa growers in California scooped up virus-killed caterpillars with a bulldozer, squashed them, and gained a virus concentrate which was diluted and used as a spray. With this university-developed method he rid 2500 acres of the alfalfa caterpillar. The laboratory is investigating virus, bacteria, and other organisms to control crop pests.

The fourth function of the laboratory is its diagnostic service. Packed in bottles, envelopes, pill jars, and other containers, several hundred packages of dying or dead insects arrive at Berkeley every year. They come from all parts of the country and from abroad. Beekeepers want to find a cure for an epidemic in their hives. Entomologists want to know the cause of death of an insect because its diseases are just as much part of a complete study as any other part of insect life. Manufacturers of insecticides rush in test insects threatened by an epidemic. Raisers of parasites look for help to the laboratory when their stock is attacked by a disease. Private and government scientists send in pests to find out whether ways can be found to control them by epidemics. And then there are private requests for help, such as that from the owner of a cricket farm whose crickets (presumably raised as fish bait) were being wiped out by some unknown sickness.

The fifth, and very important, function of the staff in insect pathology is concerned with the teaching of students and the training of visiting scientists. Courses in insect pathology are presented through the curriculum in the department of entomology and parasitology. Graduate students from all over the United States and many foreign countries have attended the university primarily to avail themselves of the special teaching program offered.

The laboratory, through its teaching and research, makes its contribution to at least three fields of science: to biology, because many of the basic principles of insect diseases, the relationships between microorganisms and insects, and knowledge concerning the fundamentals of insect life, are applicable to animals generally; to medicine, because the nature of infectious agents, disease resistance, and methods of infection can often be studied more penetratingly in simple organisms such as insects; and to agriculture, because pest control by artificial epidemics may save crops where chemicals are too expensive, cannot be used because of residue dangers, or where they might kill beneficial insects.

The first successful tests in microbial control of a California crop pest had their beginning in this laboratory. Subsequent field tests indicated that insect disease epidemics can be started artificially and may be capable of controlling potentially destructive populations of pests.

"What started out to be a research service to university entomologists has developed into a project of world-wide proportions, and one of direct benefit to California agriculture," Steinhaus says.

The cooperation between inquiring scientists and the laboratory has already led to the discovery of about 30 new insect diseases, to a better understanding of the dynamics of natural outbreaks of diseases, and to development of promising new methods of control.

During the past three years about 400 unsolicited shipments of sick and dead insects sent to the laboratory have been diagnosed. Most shipments come from California research institutes, insectaries, farm advisors, and farmers. About 60 shipments have been received from 16 other states, as well as from Hawaii, Puerto Rico, and Washington, D. C. And over 25 shipments have come from Canada, China, Burma, India, Australia, South Africa, New Zealand, Israel, Great Britain, and France.

A culture of a spore forming bacillus, sent from Maryland, was originally brought from Germany before the last war. This bacterium was tested on a number of California crop pests, and has shown promise in the control of such insects as the alfalfa caterpillar.

Insect shipments are welcomed by the laboratory. "Any shipment that arrives may bring material that might supply the missing knowledge of a still uncontrolled crops pest," Steinhaus says.

This service is of particular value to manufacturers of insecticides and to research laboratories.

When a shipment of diseased insects is received the university supplies the shipper a full diagnostic report after laboratory work is completed. The period of time involved varies from a few days to several months. Persons or organizations desiring the service should first obtain shipment instructions by writing to the Laboratory of Insect Pathology, Division of Biological Control, University of California, Berkeley 4, Calif.

of insects presents a still more difficult problem and very little progress has been made along this line. In general, it may be said that the widespread use of the great majority of insect pathogens in field control will be dependent upon the development of methods for mass production in the laboratory. The ground work on these production problems is being laid, however, and we may expect substantial progress in the years to come. It may be expected that research will be centered mainly on those species that appear to offer the greatest possibilities in field use, and each of the production problems that is solved will open the way to the economical field use of that particular organism.

Insecticide Influence On Biological Control

The advent of the new insecticides since the war period, beginning with DDT and now including a long series of new chemicals that has appeared since that time, some of them with a very much higher toxicity than DDT, has had a profound influence on biological control and field practices. It is reasonable to expect that even more highly toxic materials will enter the picture in the years to come, so that the present difficult situation not only will continue but will be accentuated. It is therefore essential that we should anticipate these developments and at least lay the groundwork as soon as possible of methods whereby their destructiveness to natural enemies may be alleviated as much as possible.

The whole viewpoint of workers in the biological control field and to a considerable extent the program of research has changed as a result of these recent developments in the insecticide field. Instead of being concerned primarily with the importation and colonization of parasites and predators of pests of foreign origin, the emphasis has shifted to a much broader field. We are now directly concerned with practically all insect pests of economic importance, both native and of foreign origin, and also even with those pests which, in the past, have been of no economic importance. The effect of the new insecticides upon the natural enemies of our major crop pests is, of course, a matter of concern but possibly of secondary importance as compared with that upon associated insects on the same crop which previously had been of no economic importance. The insecticides will not be generally used against the major pest unless they are highly efficient in control, so that their effect upon the natural enemies of that particular pest alone does not lead necessarily to serious consequences.

If, however, these same applications bring about a high or total mortality of the natural enemies of another insect pest of the same crop, creating a situation whereby a pest normally of no economic consequence assumes major status, the problem is compounded. The grower then may be in greater difficulty than before. The use of DDT for control of the citricola scale in Tulare County, Calif., a few years ago resulted in the virtual eradication of the vedalia beetle. This was followed by outbreaks of the cottony cushion scale such as had not been since the 1880's before the beetle was imported and established. The occurrence of such a situation is today almost commonplace. Everyone knows of instances where heavy outbreaks of red mites, aphids, and other insects have followed the use of the new insecticides on a wide variety of orchard and field crops, and the list will multiply as time goes on. These developments have impressed upon us one particular fact, which is that the parasites and predators are much more important in maintaining our minor native pests at noneconomic levels than has been generally realized in the past. Frequently, with a series of pests attacking a single crop, the biological control of one is the key to the whole problem. For example, the citrus growers of Tulare County believe, with considerable justification, that if the citricola scale could be controlled by the biological method, their need for chemical control of yellow scale and red mites would disappear. The codling moth on apple is in many parts of the country a similar instance, though here it must be admitted that there appears to be little hope of biological control, and other approaches to the problem are necessary.

The solution of these different problems will not be easy and no single remedial measure will suffice for all of them. Fortunately, entomologists in all fields are fully aware of the situation. The entomologists concerned with developing methods for insecticidal control, the chemists, and even many of the insecticide salesmen are now seriously concerned about the effect of their products upon the biological balance in the orchards and fields where they are being used. Biological control, therefore, receives more general and sympathetic consideration than before.

Post-DDT Research

Fortunately, the need for intensive study of the effects of insecticides on natural enemies was realized as an outstanding problem very soon after DDT came into general use, and two Bureau of Entomology and Plant Quarantine stations have been engaged in its study for a number of years. At the University of California this phase of biological control has been emphasized on all projects since the effect of DDT on the vedalia beetle and cottony cushion scale was so strikingly brought out in 1946 and follow ing years. Many research projects on pest control, both state and federal, now include provision for study of this phase of the problem, so that we can feel confident of substantial future progress.

There are a number of things that can be done now to lessen the seriousness of the situation. The first is the elimination of unnecessary spraying and a reduction in frequency of applications. This excessive use of insecticides is perhaps more prevalent here in California than elsewhere, because of the greater range of insect problems and a higher per acre value of crops, which allows a greater margin for insect control. There is often a tendency to spray by calendar, regardless of the need for it, and if the grower himself is not in a position to judge the need for treatment, he succumbs to bad advice and sprays regardless of the real need or the consequences.

In any plan for the modification of an insecticide use program it is essential that a study be made of the biology and habits of the parasites and predators that may be affected. These insects show just as wide a range of susceptibility to the different insecticides as do the pest insects themselves, and one stage in the life cycle may be highly susceptible to a given insecticide and another stage highly tolerant. It has been shown, for example, that the larvae of the lacewings, *Chrysopa* spp., tolerate the DDT dosage customarily applied in apple and pear orchards, whereas the adults suffer almost total mortality. Knowledge of these facts might contribute substantially to the development and timing of a control program that will do a minimum of damage to these beneficial insects.

In general, it may be said that the degree of harmfulness of an insecticide to natural enemies is in direct relation to its period of residual toxicity. Because of this factor, DDT is still the most destructive of all the new chemicals, though greatly exceeded in toxicity by a number of the more recently developed materials. It is hoped that the insecticides of the future, which presumably will be of even greater toxicity, will not possess longlasting residual effects.

Systemic Insecticides Encouraging

From the point of view of conserving the populations of natural enemies on agricultural crops subject to treatment with insecticides, the advent of systemic insecticides is one of the most encouraging developments of recent years. When applied to the soil and taken up by the roots of the plants, these materials appear to cause little or no harm to parasites or predators. If applied as a spray to the foliage they may cause high mortality to the natural enemies for a very few days but the loss from the total population considering all stages during this short period is not great. A relatively high population remains alive to prey upon the small pest population that survives the treatment.

Reports on field tests with the systemic insecticides thus far have dealt mainly with sap feeding insects, such as aphids, red mites, and scale insects, so that the full range of pests against which they may be successfully utilized is not yet known. We can only hope that these insecticides will find in the future a broad field of usefulness in pest control. It is quite possible that their use, even when only partially effective in destroying the pest insect, may yet result in a net gain to the grower, as compared with the present more generally used chemicals.

The present-day situation that has developed with respect to insecticides emphasizes the importance and necessity for close cooperation between chemical and biological control workers. The day of mutual exclusiveness in these fields of research has ended, and we can already count this as a substantial gain.

What has been termed supervised control, mentioned earlier, is a field of service that will undoubtedly expand greatly in years to come. Under the guidance mainly of Ray Smith and his associates it has been developed extensively in California, especially in the control of pests of alfalfa and cotton, and has likewise been adopted in recent years in several other states.

The employment by the growers themselves of a competent entomologist to supervise the pest control program on an acreage of such size that he is fully familiar with the pest situation in each field or orchard ensures first that the proper insecticide is applied in the lowest practicable dosage at the proper time, and only when there is actual need for it. In addition, proper consideration is given to the existing natural control agencies, so that, if control by any one of these agencies is imminent, the insecticide treatments can be withheld. Supervised control of the alfalfa caterpillar and other pests in California has resulted in a substantial reduction in insecticide applications and consequent savings to growers. Often it was found that the pest population was not sufficiently high to justify treatment and in other instances the abundance of natural enemies gave assurance of rapid control if not interfered with by insecticide applications.

On The Cover

The Biological Control Of Insects

The imported lady beetle shown on the cover attacking black scale on a citrus twig is one of many parasites which may be used to control insect populations. In the feature article of this issue, C. P. Clausen indicates that insect control by means of parasites and other biological factors has a promising future. Not only can predator insect enemies be cultivated, but fungus and bacterial disease organisms can be used very effectively against pests. Such techniques need further study of optimum conditions, ecology, and other factors. Biological control is a field where good research should produce valuable returns.

Programs such as this ensure the most efficient and economical pest control for the grower, in that the insecticides are used only when actually needed, and full consideration is given not only to the natural enemies of the pest being treated but to those of associated insects as well. While supervised control has thus far been developed only for field crops, even greater benefits may be expected if and when such programs are extended to the orchard crops. Certainly, the complex problems that face us in apple production, to name only one, emphasize the need for competent and unbiased advice to the growers, such as is provided by a properly organized program of supervised control.

Needs and Trends

In summing up this evaluation of trends in biological control, and the emphasis that may be placed upon the different phases of the subject in the future, the utilization of disease-producing organisms in control programs should probably be placed first in respect to anticipated progress in the near future. Second would be a marked expansion in the cooperative programs dealing with the effect of insecticide applications upon natural enemies and the development of materials and methods whereby these natural enemies may be conserved. Third will probably be a greater participation of state organizations in biological control work. California and Hawaii have the only government organizations that have maintained a long term program, yet there is a real opportunity for many other states to participate in a substantial way. This could be either by assuming responsibility for the rearing and colonization within the state of natural enemies already imported by the Federal Agricultural Research Service or, on smaller projects, assuming full responsibility for all phases following importation and clearing through quarantine by the federal agency. This latter procedure has already been followed in several instances in Texas, Oregon, and North Dakota, but more general state participation in all phases except importation will greatly advance progress in the future.

Based on an address delivered before Entomological Society of America, Los Angeles, Calif., Dec. 7 to 10, 1953.