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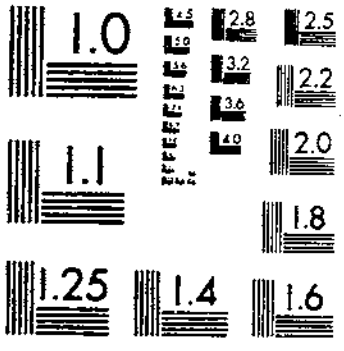
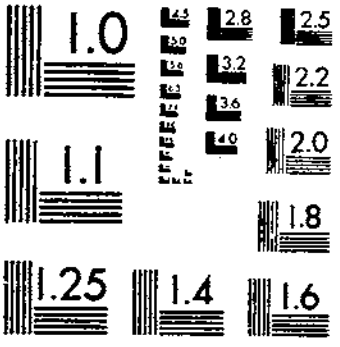


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CONTENTS

Biological Control of INSECT PESTS in the Continental United States[1]

By C. P. Clausen[2]

Most of our major insect pests of agricultural crops today are of foreign origin, having entered the United States through various trade channels since colonial days. The great expansion of international trade in recent times and the greater speed of transportation have increased the opportunity for insect pests to move from one country to another. Once they are established these pests are generally more destructive in the new environment than in the countries of origin. This condition may be attributed to several factors, one of which is the absence of natural enemies. Often the natural enemies did not enter the country with their hosts, and consequently the latter were able to increase to a far greater extent than in the countries of origin.

The objective of the biological control work herein reported was to import parasites and predators from abroad, establish them throughout the range of each insect pest in the United States, and thus reduce the hosts to the approximate level that occurs in the countries of origin. Often this level is not below that at which injury to crops is inflicted and then other methods of control may be required, though possibly on a reduced scale. Occasionally the results of these parasite introductions are so great as to reduce the insect pests below the level of economic injury, and thus large savings may be effected each year through completely eliminating the need for spraying, fumigation, or other chemical control measures.

The first intentional importation of an insect enemy of a crop pest into the United States was that of *Apanteles glomeratus*, a parasite of the larvae of the imported cabbageworm, which became established as a result of shipments received from England in 1884. However, the real beginning of sustained biological control work dates from 1888, when Albert Koebele was sent to Australia by the United States Department of Agriculture to obtain natural enemies of the cottony-cushion scale. The spectacular success of this venture was followed by almost continuous work to the present day in the importation of beneficial insects for use against many crop pests.

[1] Submitted for publication August 5, 1955.

[2] Formerly entomologist in charge, Division of Foreign Parasite Introduction, Bureau of Entomology and Plant Quarantine, Agricultural Research Administration, United States Department of Agriculture; now chairman, Department of Biological Control, University of California.

This account of biological control efforts in the continental United States is believed to be reasonably complete up to 1950 insofar as the record of importations and establishments is concerned. The final results on a number of field projects cannot be given at this time because the parasite-distribution and the importation programs have not been completed.

WORLDWIDE SEARCH FOR EFFECTIVE NATURAL ENEMIES

The entomological explorers for over 60 years have combed practically every country in the Temperate, Subtropical, and Tropical Zones for effective parasites and predators to control the pests attacking our agricultural crops. The 95 species of imported parasites and predators now established in the continental United States have come from many parts of the world, as shown in figure 1. They and their hosts are listed in table 1.

As expected, most of the successful importations have been from temperate areas, and by far the largest number have been from continental Europe. Many of our major pests have come from there. The 42 species of established parasites from that region are used mainly in large-scale and prolonged work to combat the gypsy moth, the browntail moth, and other forest insects, the European corn borer, and the alfalfa weevil. Australia is represented by 13 species and South Africa by 10, all being parasites or predators of scale insects and mealybugs for use in California. It is noteworthy that relatively few have come from South America, and as of 1953 none have come from India or the Malayan region.

Among the 95 species that are here recorded as established, 81 are parasitic in habit and 14 predaceous. Of the parasites, 32 species belong to the hymenopterous families Encyrtidae and Eulophidae (Aphelininae), and they are used mainly for scale insect and mealybug control in California. Of the 15 species of Tachinidae, 9 are utilized in the control of forest and shade-tree insects.

Any list, such as that given in table 1, cannot be considered complete on any particular date, as species believed to be well established have disappeared after a period of years; on the other hand, some species not believed established have persisted and appeared in recovery collections many years later.

For example, *Rodolia koebelei* (Ol.) from Australia was colonized in infestations of cottony-cushion scale in California in 1891, and was distributed through field-collected material during the following 6 years; yet it later disappeared. *Chilocorus similis* Rossi, the predator of the white peach scale (*Pseudaulacaspis pentagona* (Targ.)) and of the San Jose scale (*Aspidiotus perniciosus* Comst.), imported from Japan in 1901 and 1902 and extensively colonized in Georgia, showed a marked increase the following year and was still common in 1905, but eventually died out. Likewise *Lixophaga diatraeae*, the parasite of the sugarcane borer, persisted in Louisiana for at least 5 years after completion of the colonization program, but each year the number of recoveries declined and it finally disappeared. It is therefore possible that some of the species included in the present list, particularly those

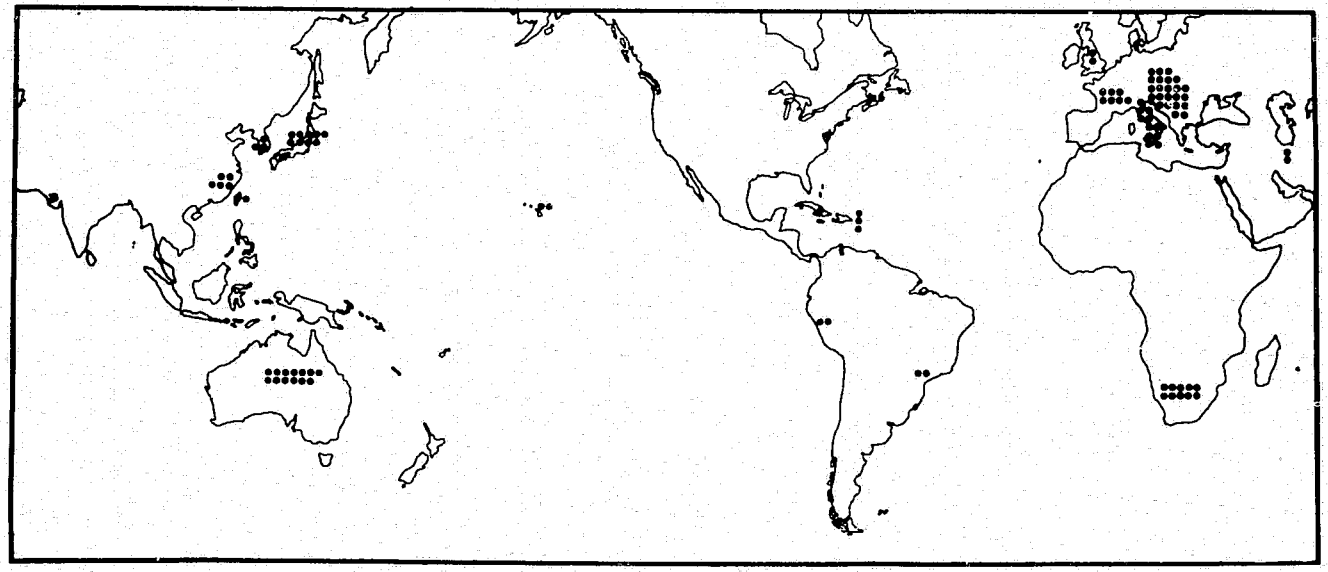


FIGURE 1.—Areas of origin of the 95 species of imported parasites and predators established in the continental United States. *Scutellista cyanea* Mots. and *Comperiella bifasciata* How., introduced at different times and from different areas against several pests, are represented by two dots each.

TABLE 1.—*Imported parasites and predators (listed under host) successfully established in the continental United States, country of origin, and date of importation, 1875–1951*

Host and parasite or predator	Country of origin	Date of importation
Antonina graminis (Mask.) (Rhodes-grass scale):		
Anagyrus antoninae Timb	Hawaii	1949.
Aonidiella aurantii (Mask.) (California red scale):		
Aphytis "A"[1]	South China	1947.
Comperiella bifasciata How. (red scale strain)	do	1941.
Cybocephalus sp	do	1932–33.
Habrolepis rouxi Comp	South Africa	1937.
Lindorus lophantae (Blaisd.)	Australia	1891–92.
Orcus chalybeus (Boisd.)	do	1892.
Prospaltella perniciosi Tower (red scale strain)	Formosa	1949.
Aonidiella citrina (Coq.) (yellow scale):		
Comperiella bifasciata How	Japan	1916–17, 1922–24.
Aphididae:		
Leis dimidiata 15-spilota (Hope)	South China	1924.
Aspidiotus destructor Sign. (coconut scale):		
Azya trinitatis Mshll	Puerto Rico	1938.
Cryptognatha nodiceps Mshll	Trinidad	1936.
	Puerto Rico	1938.
Autoserica castanea (Arrow) (Asiatic garden beetle):		
Tiphia asericae A. & J	Korea	1927–32.
Ceroplastes cirripediformis Comst. (barnacle scale):		
Scutellista cyanea Mots	Italy	1895–98.
Cnidocampa flavescens (Wlkr.) (oriental moth):		
Chaetexorista javana B. & B	Japan	1929–30.
Coleophora laricella (Hbn.) (larch casebearer):		
Agathis pumilis (Ratz.)	Austria, England, Holland	1932–37.
Chrysocharis laricinellae (Ratz.)	Austria	1932–35.
	England	1936.
Diatraea saccharalis (F.) (sugarcane borer):		
Agathis stigmaterus (Cress.)	Argentina	1929–30.
	Peru (?)	1932.

Lixophaga diatraeae (Tns.)	Cuba, Puerto Rico	1915, 1918–20, 1926–27, 1936–40.
Paratheresia claripalpis (v. d. W.)	Argentina	1929.
	Peru	1929–31, 1932, 1936.
Diprion (Gilpinia) hercyniae (Htg.) (European spruce sawfly):		
Dahlbominus fuscipennis (Zett.)	Europe (via Canada)	1935–39.
Etiella zinckenella (Treit.) (lima-bean pod borer):		
Bracon piger Wesm	France	1936–38.
Chelonus inanitus (L.)	do	1938.
Phaneratoma planifrons (Nees)	Hungary	1936–38.
Forficula auricularia L. (European earwig):		
Bigonicheta setipennis (Fall.)	France, England, Italy	1924–29, 1931, 1938–39.
Galerucella xanthomelaena (Schr.) (elm leaf beetle):		
Erynnia nitida R.-D	Italy	1909, 1911.
	France	1924–25, 1932–35, 1939.
Grapholitha molesta (Busck) (oriental fruit moth):		
Agathis diversus (Mues.)	Japan	1933–36.
Heterarthrus nemoratus (Fall.) (birch leaf-mining sawfly.):		
Chrysocharis laricinellae (Ratz.)	Austria	1930–34.
Phanomeris phyllotomae Mues	do	1930–35.
Hypera postica (Gyll.) (alfalfa weevil):		
Bathyplectes curculionis (Thoms.)	Italy	1911–13.
Mymar pratensis (Foerst.)	do	1911–13, 1925–28.
Hypera punctata (F.) (clover leaf weevil):		
Biolysia tristis (Grav.)	do	1912.
Icerya purchasi Mask. (cottony-cushion scale):		
Cryptochaetum iceryae (Will.)	Australia	1888–89.
Rodolia cardinalis (Muls.)	do	1888–89.
Lecaniine Coccidae:		
Exochomus quadripustulatus (L.)	France	1905–6.
	Italy	1915, 1927.
Lepidosaphes beckii (Newm.) (purple scale):		
Aphytis "X" [1]	China	Prior to 1916.
	South China, Formosa	1948–49.
Physcus "B" [1]	Formosa	1950–51.
Neodiprion sertifer (Geoff.) (pine sawfly):		
Aptesis basizonia (Grav.)	Europe (via Canada)	1935, 1938, 1940.
Dahlbominus fuscipennis (Zett.)	do	1935–36.

[1] Species designation by Department of Biological Control, University of California.

TABLE 1.—*Imported parasites and predators (listed under host) successfully established in the continental United States, country of origin, and date of importation, 1875–1951*—Continued

Host and parasite or predator	Country of origin	Date of importation
Nygmia phaeorrhoea (Donov.) (brown-tail moth):		
Apanteles lacteicolor Vier	Austria, Italy	1906–10.
Carabus auratus L.	Europe	1907.
Carcelia laxifrons Vill.	do	1906–10.
Eupteromalus nidulans (Thoms.)	Central Europe	1906–8.
Exorista larvarum (L.)	Italy	1905.
	Europe	1906–11, 1923–32.
Meteorus versicolor (Wesm.)	Central Europe	1906–11.
Monodontomerus aereus Wlkr.	Europe	1905–10.
Townsendiellomyia nidicola (Tns.)	do	1905–11.
Parlatoria oleae (Colvée) (olive scale):		
Aphytis maculicornis (Masi):		
(Egyptian strain)	Egypt	1948–49, 1951.
(Indian strain)	India	1951.
(Persian strain)	Iran	1951.
(Spanish strain)	Spain	1951.
Aspidiotiphagus sp.	Iran	1951.
Phytophaga destructor (Say) (hessian fly):		
Pleurotropis metallica (Nees)	England	1890–94.
Pieris rapae (L.) (imported cabbageworm):		
Apanteles glomeratus (L.)	England	1875, 1883–84, 1891.
	Germany	1881.
Popillia japonica Newm. (Japanese beetle):		
Dexilla ventralis (Ald.)	Korea	1925–27, 1929–31.
Hyperecteina aldrichi Mesnil	Japan	1920–24, 1927–30, 1933.
Prosena sibirita (F.)	do	1921–30.
Tiphia popilliavora Roh.	Japan	1920–22.
	Korea, China	1925–27, 1930–31, 1934–36.
Tiphia vernalis Roh.	Korea, South China	1924–33.
Porthetria dispar (L.) (gypsy moth):		
Anastatus disparis Ruschka	Central Europe, Japan	1908–10.

Apanteles melanoscelus (Ratz.)	Sicily	1911–12.
Blepharipoda scutellata R.-D	Europe	1905–11, 1924–27.
Calosoma sycophanta (L.)	Switzerland, Italy	1905–10.
Carabus auratus L	Europe	1907.
Compsilura concinnata (Meig.)	Central Europe	1906–11.
Exorista larvarum (L.)	Italy	1905.
	Europe	1906–11, 1923–32.
Monodontomerus aereus Wlkr	Europe	1905–10.
Ooencyrtus kuwanai (How.)	Japan	1907–9.
Paraseligena silvestris R.-D	Central Europe	1906–11, 1924–33.
Phobocampe disparis (Vier.)	do	1907–12, 1924–31.
Pseudococcus adonidum (L.) (long-tailed mealybug):		
Anagyrus fusciventris (Gir.)	Hawaii	1936.
Anarhopus sydneyensis Timb	Australia	1933.
Tetracnemus peregrinus Comp	South Africa	1924, 1926.
	Brazil	1934.
Pseudococcus brevipes (Ckll.) (pineapple mealybug):		
Hambletonia pseudococcina Comp	Brazil (via Puerto Rico)	1943–44.
Pseudococcus citri (Risso) (citrus mealybug):		
Cryptolaemus montrouzieri Muls	Australia	1891–92.
Leptomastidea abnormis (Gir.)	Sicily	1914.
Pseudococcus comstocki (Kuw.) (Comstock mealybug):		
Allotropa burrelli Mues	Japan	1939–41.
Pseudaphycus malinus Gahan	do	1941.
Pseudococcus gahani Green (citrophilus mealybug):		
Cleodiplosis koebelei (Felt)	Australia	1928.
Coccophagus gurneyi Comp	do	1928.
Scymnus binaevatus (Muls.)	South Africa	1921.
Tetracnemus pretiosus Timb	Australia	1928.
Pyrausta nubilalis (Hbn.) (European corn borer):		
Chelonus annulipes Wesm	Italy	1929–37.
Horogenes punctorius (Roman)	France, Italy	1921–23, 1925–37.
	Manchuria	1930–32.
Lydella stabulans grisescens R.-D	France, Italy	1920–35.
	Japan, Korea	1929–36.
Macrocentrus gifuensis Ashm	France	1926–33.
	Japan, Korea	1929–32.
Phaeogenes nigridens Wesm	Italy	1924–32, 1937–38.
	Japan	1931.
Sympiesis viridula (Thoms.)	Italy	1930–34.

TABLE 1.—*Imported parasites and predators (listed under host) successfully established in the continental United States, country of origin, and date of importation, 1875–1951*—Continued

Host and parasite or predator	Country of origin	Date of importation
Rhyacionia buoliana (Schiff.) (European pine shoot moth):		
Cremastus interruptor Grav	Austria	1931–35.
	England	1936.
	Holland	1937.
Orgilus obscurator (Nees)	Austria	1931, 1933–35.
	England	1936.
	Holland	1937.
Tetrastichus turionum (Htg.)	Austria	1931–35.
Saissetia nigra (Nietn.) (nigra scale):		
Aphycus helvolus Comp	South Africa	1938.
Saissetia oleae (Bern.) (black scale):		
Aphycus helvolus Comp	South Africa	1924, 1937.
Aphycus lounsburyi How	South Africa	1900, 1914.
	Australia	1916.
Aphycus stanleyi (Comp.)	South Africa	1937.
Coccophagus capensis Comp	South Africa	1914–15, 1921–23.
	Australia	1918.
Coccophagus cowperi Gir	South Africa	1937.
Coccophagus pulvinariae Comp	do	1937.
Coccophagus rusti Comp	Transvaal	1937.
Coccophagus trifasciatus Comp	South Africa	1924–25.
Lecaniobius utilis Comp	Argentina, Brazil	1934–35.
Quaylea whittieri (Gir.)	Australia	1900–1901.
Rhizobius debilis Blackb	do	1891–92.
Rhizobius ventralis (Er.)	Australia, Tasmania	1888–89, 1891–92.
Scutellista cyanea Mots	South Africa	1900–1901.
Stilpnotia salicis (L.) (satin moth):		
Apanteles solitarius (Ratz.)	Hungary	1927.
	Austria	1932–33.
Meteorus versicolor (Wesm.)	Central Europe	1932–34.

of comparatively recent establishment, may not persist even though their present status is promising. Conversely, some of those not believed to be established may be found after a period of years, as was the case with *Agathis diversus*, an oriental fruit moth parasite.

The species that were imported but did not become established represent a much larger number and came from practically every country or geographic area. Approximately 390 species were imported and colonized in varying numbers, but failed to establish themselves. Many of them were available and were colonized in only very small numbers or were by necessity released under unfavorable conditions. Among them, however, were a considerable number of species that were released in very large numbers and under all possible environmental conditions and even then failed of establishment. In some instances adverse climatic conditions were believed responsible, whereas in others the apparent lack of suitable alternate hosts to carry the parasite through the winter served as an effective bar to their persistence year after year.

At least 175 additional species were imported, but were not released. This was due to various reasons, such as insufficient numbers for satisfactory colonization, arrival of the shipments at the wrong season for release, failure of the stock in hibernation, inability to rear the species in the insectary, or doubt as to the exact host relationships.

ORGANIZATIONS CONDUCTING BIOLOGICAL CONTROL WORK

The Federal Entomology Research Branch, formerly the Bureau of Entomology and Plant Quarantine, is responsible for controlling the importation of living insect material into the United States, and has largely restricted to itself the privilege of importing parasites and predators into the continental United States. This restriction is based on the need for handling the imported material under strict quarantine conditions in order to eliminate the possibility of escape of insect pests and hyperparasites. Many importations comprise enormous quantities of living host stages, which represent a real risk unless they are handled with extreme care.

Until 1934 all phases of the biological control work of the Bureau were conducted independently by the several divisions concerned with research on the different insect pests. In that year the Division of Foreign Parasite Introduction was organized, with responsibility for the foreign investigations and for the quarantine handling of the imported material. After passing through quarantine, the pure colonies of approved parasites and predators were released to field stations of the respective divisions, which were then responsible for the rearing, colonization, and recovery programs.

In 1940 the facilities for the quarantine reception of imported material were greatly improved through the construction and utilization of a specially designed parasite receiving station at Hoboken, N. J. This occupied an entire floor in the Plant Quarantine Building, and provided insectproof rooms with independent air-conditioning controls in each, as well as cool-storage facilities, for the safe handling of any type of material that might be received. Unfortunately, this station

had to be closed in 1944, and imported material is now received in improvised quarantine rooms at several field stations.

The one exception to the restriction of importation activities to the Entomology Research Branch is the State of California, which began importations on an independent basis in 1899. Prior to this date the explorations of Albert Koebele in Austria, New Zealand, and Fiji during 1891–92 were on a cooperative basis with the United States Department of Agriculture, whereas those of George Compere in 1899–1901 were sponsored by the State. In 1913 the biological control work of the State, then under the State Commission of Horticulture, was reorganized under the direction of Harry S. Smith, and this unit was transferred to the University of California in 1923. In 1931 the parasite-importation program in California was formalized under a three-way memorandum of understanding between the Bureau of Entomology and Plant Quarantine, the University of California, and the State Department of Agriculture. Excellent quarantine facilities are provided at the two main stations of the Department of Biological Control at Riverside and Albany, and the scale of work for the State is now about equal to that of the Federal organization. Approximately one-third of the species of parasites and predators established in the continental United States have been imported by the California organizations.

The early investigations on natural enemies of the gypsy moth and brown-tail moth that were conducted in Europe during 1905–11 were on a cooperative basis between the Bureau and the Massachusetts State Board of Agriculture, whereby the State defrayed the costs of the foreign explorations by Bureau personnel.

Although the State organizations, with the one exception mentioned, do not conduct importation activities, they are now participating substantially in the overall biological control program, especially the colonization and recovery phases. In general, the Entomology Research Branch is responsible for the initial colonization and establishment of imported parasites and predators in each State, whereas the State conducts the general distribution program. However, this has been a variable practice, as the entire distribution program on gypsy moth and a large portion of that on the Japanese beetle and European corn borer were handled by the Federal organization alone.

In recent years the States have been participating much more actively. An example is the cooperative project developed in 1943 for the wide distribution of corn borer parasites, mainly in the Middle West, and for the later recovery and evaluation studies.

More and more the State organizations are being called on to handle the entire domestic program, with the Entomology Research Branch making the importations, passing the material through quarantine, and then forwarding the pure colonies of parasites to the State organizations. Examples of this participation are the projects on biological control of the sweetclover weevil (*Sitona cylindricollis* Fahr.) in North Dakota, the omnivorous leaf tier (*Cnephasia longana* (Haw.)) in Oregon, and the Rhodes-grass scale in Texas. The Branch also forwards direct to the University of California many consignments of parasites for use against miscellaneous pests in that State. The Maine Forest Service and the New Jersey Department of Agriculture have conducted large-scale rearing and colonization pro-

grams with sawfly parasites of European origin provided by the Canadian Department of Agriculture.

This participation of the State organizations in biological control projects is encouraging and offers possibilities of a substantial contribution to progress in this line of work. In the case of an insect pest of wide distribution, such as the corn borer, it is obviously impracticable even for the Federal organization to maintain a staff of sufficient size to rear and colonize the imported parasites over the entire infested area, not to mention the followup recovery and evaluation studies that are required in each section. The program as a whole would undoubtedly be much further advanced today if the cooperative plan of work developed about 1943 could have been undertaken many years earlier.

MICROBIAL CONTROL OF INSECT PESTS

Microbial control is that part of general biological control in which disease-producing micro-organisms rather than insect parasites and predators are utilized in the control of insect pests. The micro-organisms may be viruses, bacteria, fungi, protozoa, or nematodes. All these groups play an important and often dominant part in the natural control of many insects, though their utilization in biological control has lagged far behind that of the insect parasites and predators (*137*).[3]

Results thus far from utilizing several fungi, bacteria, viruses, and nematodes for the control of crop pests in the United States have been sufficiently successful with only two organisms, in that their use may be considered practical for control in the field. Other organisms have been used successfully in small-scale field experiments, but for various reasons the work has not advanced beyond that point. The two successful micro-organisms are the bacterium *Bacillus popilliae* Dutky, which is widely employed to control Japanese beetle grubs in the soil in the Northeastern States, and the virus *Borrelina campeoles* Steinhaus, which has proved highly effective in the control of the alfalfa caterpillar (*Colias philodice eurytheme* Bdvl.) in California.

Unfortunately the early attempts at microbial control were with organisms not adaptable for such use, and their overexploitation hampered further development in this field. It became the general opinion that insect diseases were strictly dependent on climate for the development of outbreaks and that if climatic conditions were not favorable nothing could be done to increase their effectiveness in the field.

Steinhaus (*138*) not only thoroughly analyzed past efforts in the utilization of disease-producing organisms in insect control but discussed the disadvantages as well as the advantages of this method. He emphasized that microbial control of certain insects is being constantly maintained in nature without the help or interference of man, and that these micro-organisms contribute substantially more to natural control than is generally recognized.

Perhaps the outstanding disadvantage in the use of micro-organisms in insect control is the need for accurate timing of the applications.

[3] Italic numbers in parentheses refer to Literature Cited, p. 135.

This is especially true when dealing with foliage-feeding insects as compared with those inhabiting the soil. The fungi especially need to be distributed when moisture and temperature are high. Under certain circumstances the pathogenic organisms may have a definitely adverse effect on the insect parasites and predators of the pest, and the net effect may be detrimental. Microbial control, even if fully effective, may not be so lasting as that attained with insect parasites and predators and may necessitate reapplications annually or at such intervals as the pest buildup may require. As yet there has been no demonstration of microbial control comparable in completeness and permanence to that of the cottony-cushion scale by the vedalia (*Rodolia cardinalis*).

Microbial control has the following advantages: (1) Many of the micro-organisms can be cultivated and produced at low cost as compared to insect parasites and predators, (2) application in the field as a spray or dust costs approximately the same as that of an insecticide, (3) micro-organisms are harmless to man and plants, and (4) they are not affected by most insecticides.

One of the most important points demonstrated by Steinhaus and his associates in recent work in California with several viruses and bacteria is that outbreaks of disease can be induced at practically any level of host density (*140*). This possibility and a fuller understanding of the interrelationships of the organisms, climatic conditions, and the host will permit much greater utilization of these controlling agencies than in the past. It is quite possible that their successful use may yield results equal to those already attained with the insect parasites and predators.

UTILIZATION OF NATIVE PARASITES AND PREDATORS

The wide range of climatic conditions in the continental United States has a direct bearing on the distribution of native insect pests and their natural enemies. Areas of comparable climate may be widely separated by geographic barriers such as mountain ranges and deserts. Originally these barriers, in conjunction with the discontinuous occurrence of the food plants, served as effective checks against the spread of both pests and natural enemies. The advent of rapid transportation facilities and the large-scale movement of plants and commodities throughout the country have been the means whereby many pest species have been able to extend their range. This has been facilitated also by changed agricultural practices, which have greatly extended the areas in which each crop is grown, and which many times have reduced the extent and effectiveness of the natural barriers.

An excellent example is the woolly apple aphid (*Eriosoma lanigerum* (Hausm.)), which is native to the northeastern portion of the continent. With the extension of apple culture to all parts of the country, this pest spread rapidly and reached the Pacific coast about a hundred years ago. However, its parasite, *Aphelinus mali* (Hald.), was left behind. The colonization and establishment of *Aphelinus* in these new sections has resulted usually in satisfactory control.

The squash bug (*Anasa tristis* (Deg.)) occurs throughout the United States, whereas its principal parasite, *Trichopoda pennipes* (F.), or more exactly the strain of that species, was limited to the eastern region. The latter has now been colonized successfully in the Pacific Northwest.

In a slightly different category are the pests of foreign origin that have become widely established and which have been attacked by native parasites. The outstanding example in this group is the oriental fruit moth. A native parasite, *Macrocentrus ancylivorus* Rob., the normal host of which is the strawberry leaf roller (*Ancylis comptana fragariae* (W. & R.)), quickly adapted itself to the new host, and has been utilized effectively in the biological control of the fruit moth. Originally, the parasite's distribution was limited, centering about New Jersey and Delaware, but its effective range on the new host has now been greatly extended through a large-scale distribution program.

Other similar examples may be cited. The asparagus beetle (*Crioceris asparagi* (L.)) is attacked in the Eastern States by a native egg-larval parasite, *Tetrastichus asparagi* Cwfd., which was of limited distribution. Its introduction into the Pacific Northwest was highly beneficial. Likewise *T. brevistigma* Gahan, a pupal parasite of the elm leaf beetle in the Eastern States, proved of value after its introduction into California.

There is some question as to whether the more effective parasites of the San Jose scale are of foreign or domestic origin, but in any case their natural distribution has not covered the entire range of the pest in the United States. The introduction of *Prospaltella perniciosi* from Georgia into California aided greatly in the control of the pest in that State.

These few examples indicate the need for and benefits to be gained from the distribution of native parasites throughout the country when it is found that they do not occur throughout the range of the host insect. It has been demonstrated that many native parasites are well adapted to conditions that prevail in some, if not in all, areas in which they do not occur naturally.

EFFECT OF INSECTICIDES ON NATURAL ENEMIES

The discovery and widespread use of many new and extremely toxic insecticides during and following World War II have had a pronounced effect on the biological control of several major pests and on the natural control of many other pests that previously had been of only minor importance. Many of the insecticides used prior to 1945 remained in toxic form as residues on the foliage for only a short time after application, and consequently were destructive to parasites and predators for only a few days after application, rather than for a period of months (*21*). This was especially true of the insecticides of plant origin, such as rotenone, nicotine, and pyrethrum. The portion of the natural-enemy population affected by these materials was only that which was in the active stage for a short period after treatment, and thereafter the ratio of natural enemies to the pest insects was appreciably higher than before.

The first of the new insecticides to appear, DDT, quickly demonstrated its destructiveness, owing not only to its high toxicity to many entomophagous insects but even more to the persistence of a toxic residue on the foliage for as long as 6 months or more. A spectacular example of its capacity to upset the natural balance of an insect pest very soon appeared in the case of the cottony-cushion scale on citrus in California (*38*). The application of DDT for control of the citricola scale (*Coccus pseudomagnoliarum* (Kuw.)) and the citrus thrips (*Scirtothrips citri* (Moult.)) was quickly followed by heavy infestations of the scale, a situation that had not been seen since the introduction of vedalia more than 50 years before. Two applications, one during the winter or early spring and again in July, resulted in the scale remaining free from attack by the vedalia throughout the season. A single application prior to July weathered sufficiently before fall to permit reentrance of vedalia and consequent biological control. In localities where use of the insecticide has been general, the colonization of vedalia after a proper interval rather than waiting for the natural influx from some distance away expedited control. A similar course of events has been shown in the case of such insects as the black scale in California and the woolly apple aphid in the Northwest.

Another and possibly more serious effect of the new insecticides has been revealed through the upsurge of minor pests following these applications. Many of these pests had previously been of little economic importance and required no special measures for their control. Reports have come from all parts of the United States of heavy infestations of aphids, phytophagous mites, scale insects, and leaf miners following application of insecticides for control of other insect pests. This development is usually attributed to the destruction of the natural enemies. In some cases this obviously is true, but in others this supposed cause of outbreaks is only an assumption and is not supported by factual data. Much work is now being done to measure and evaluate the effect of the new insecticides on the complexes of insect pests on the different crops. As these data accumulate it may be possible to devise measures to eliminate or minimize the harmful effects of present chemical control practices.

Of the extensive number of new organic insecticides developed since DDT, some of which are vastly more toxic, none have as long a residual action and several lose their effectiveness very soon after application. A change in the chemical used, in its formulation, or in the timing of applications may contribute to the solution of the problem. These compounds differ markedly in their toxicity to entomophagous insects, and each one possesses qualities making it especially toxic to some species and relatively innocuous to others.

The use of the so-called selective insecticides (*120*) has been recommended to overcome the difficulties previously mentioned. These insecticides are stomach poisons, the particles of which are coated with substances that are digestible only by the plant-feeding insects, and are therefore harmless to the parasites and the more common groups of predators.

Another approach to the problem is the recently developed systemic insecticides, which at present appear to have a somewhat restricted usefulness. These compounds enter the sap stream of the plant either through the foliage or by way of the roots and are translocated.

The phytophagous insects are killed as a result of feeding on the sap or foliage, but parasites and predators attacking them are not harmed. Some of these compounds when applied to the foliage are toxic to parasites and predators, the extent varying with the species concerned, but this effect persists for only a short time.

The development of resistance to insecticides, which has been demonstrated in recent years to occur in many pest species, leads to the hope that a similar resistance may appear among the entomophagous insects. Confirmation of that development in the field is lacking, mainly because evaluation studies are less exact in biological control programs than in those dealing with insecticides. The attempts to produce resistant strains in the insectary have yielded a little success, though not sufficient to be of practical application.

ANTS IN RELATION TO BIOLOGICAL CONTROL

The ants have a wide range of food sources, including fungi, plant sap, exudations, and seeds, honeydew secreted by various insects, and the body fluids and tissues of other insects and higher organisms. As a whole the predaceous members of the family rank high as natural control agencies, which hold many insect pests of forest trees and agricultural crops below the level of economic injury. They feed extensively on many insects that pass all or part of their lives in the soil, and have been reported to destroy a high percentage of larvae of fruit flies and house flies (*Musca domestica* L.), which enter the soil for pupation. The driver and legionary ants of the Tropics when on the march destroy practically all insect life in their paths that is unable to escape by flight.

Ants were the first insects to be utilized in biological control. For many centuries the Chinese citrus growers made a regular practice of placing colonies of *Oecophylla smaragdina* F. in their orchards, and even provided runways from tree to tree. The ants were believed to feed on naked caterpillars and to drive away beetles and various bugs. At the present time ants of the genus *Formica* and related forms are colonized and protected for their aid in controlling insect pests in the forests of Europe.

The species that are harmful to agricultural crops are mainly those that feed on honeydew secreted by scale insects, mealybugs, whiteflies, aphids, and leafhoppers. The injury is mainly indirect, resulting from protection given these pests from their natural enemies. The predators are driven away and oviposition by parasites is prevented. The harmful effect is especially noticeable with parasite species that require considerable time for completion of oviposition or for host feeding (*72*).

In addition to their harmful effect through interference with the activities of natural enemies, ants have been shown to be directly harmful by performing a sanitary service for the insect pests—the removal of honeydew, which results in a reduction in mortality of the early stages and an acceleration in the rate of development.

There is a wide variation in attractiveness to ants of the honeydews of different species. That of the soft (brown) scale (*Coccus hesperidum* L.), black scale, and green scale (*Coccus viridis* (Green)) is much

sought after, whereas that of the citricola scale is almost entirely neglected. Some essential nutrient seems to be lacking in the honeydew of the last insect.

In the citrus groves of southern California it is essential to eliminate ants before biological control of any of the lecaniine scales can be accomplished by the introduced parasites, and this applies also to mealybug control through the use of the coccinellid beetle *Cryptolaemus montrouzieri*.

It has been generally assumed that the development of diaspine scale infestations would be little affected by ants, inasmuch as these scales do not produce honeydew. However, there are usually small colonies of aphids, soft scales, or mealybugs on the trees, and the ants in tending them incidentally protect the diaspine scales from attack by parasites and predators. Observations and tests on the California red scale in southern California (*39*) showed that infestations on ant-inhabitated trees increased as much as 24 times over those on ant-free trees, and that parasitization by *Aphytis* was much higher on the latter. Infestations of red mites also became much heavier on the ant-inhabited trees. In these tests the species involved was the Argentine ant (*Iridomyrmex humilis* Mayr).

It is becoming increasingly clear that the presence of honeydew feeding ants, regardless of the pest species that attracts them, may prevent entirely or greatly reduce the effectiveness of natural enemies that otherwise might be capable of controlling major pest species. Fortunately on tree crops at least ant control is economically practicable.

MASS CULTURE OF PARASITES AND PREDATORS

The development of methods for the mass culture of a wide range of parasites and predators has contributed substantially to progress in the biological control of pest species. When such methods are practicable, they not only make possible the early and complete distribution of a species over the entire geographic range of the host but also make stocks available at an economical figure for periodic or annual colonization and for inundative programs tied in with area control or eradication projects. The key requirement in all such programs is that the cost of producing the enormous numbers that are needed shall not exceed the benefits that will accrue from their large-scale use.

The periodic colonization of natural enemies is a device to increase the effectiveness of species that are already established but for various reasons do not attain their full or consistent effectiveness in the field. Examples of the practical application of this method of control are the mealybug predator *Cryptolaemus montrouzieri* in California, which often fails to survive the winter in sufficient numbers and is therefore recolonized each spring, and the oriental fruit moth parasite *Macrocentrus ancylivorus*, the effectiveness of which can often be greatly enhanced by supplementary spring releases. The value of *Aphytis* "A," a newly introduced parasite of the California red scale, is much increased in some areas of southern California by periodic colonization during the season to bridge the period during which the host scales are not in the proper stage for parasitization.

In the inundative method of control, which is practicable only under exceptional circumstances, a sufficient number of natural enemies are released at one time to control the pest by the first field generation. The numbers released per acre may exceed the host population, as frequently occurred when *M. ancylivorus* was used to control the outbreak of the oriental fruit moth in California during 1944–46.

The first and still one of the outstanding examples of mass production was that with *C. montrouzieri* in California (*127*). Since it was impracticable to use the growing host plants to produce the vast numbers of mealybugs that were required, sprouted potatoes were used instead. *Cryptolaemus* adults were then produced and distributed by the millions at a cost of approximately $2.50 per thousand.

At the peak of the program for control of mealybugs with *Cryptolaemus* in southern California during the 1920's, 15 county, cooperative, and private organizations were engaged in beetle production. The scale of operations may be judged by the Orange County establishment, constructed specifically for this purpose, which comprised 22 separate building units, in which millions of beetles per day were produced. The potatoes were grown in open trays about 18 inches square, the well-developed sprouts were infested with mealybugs, and the beetles were then released in the room after the mealybugs had matured and deposited eggs. Average production was about 400 beetles per tray.

The potato has proved exceedingly useful in other biological control projects. The sprouts have served exceptionally well for the production of black scale and related species, permitting the economical production of millions of a series of imported parasite species. The tuber itself is an excellent host on which to produce the red scale and other diaspine Coccidae for parasite production. Finally, it provided the means whereby the millions of *M. ancylivorus* were produced for the control of the oriental fruit moth outbreak in California (*58*). This production was possible because the potato tuberworm (*Gnorimoschema operculella* (Zell.)) proved to be an acceptable host for the parasite (*57*), although the latter is not known to attack it in the field.

The methods developed for the mass production of egg parasites of the genus *Trichogramma* represent an outstanding contribution to biological control techniques. The early work in California (*59*) utilized corn in open bins for the rearing of the host insect, the Angoumois grain moth (*Sitotroga cerealella* (Oliv.)). Modifications of this method were later developed by various workers, and a closed unit system (*135*), with wheat being used instead of corn, proved more economical and solved the problem of controlling troublesome mite infestations. The cost of production ranged from $5 to $10 per million *Trichogramma*, dependent on the scale of rearing.

Several varieties of melons of the genera *Cucurbita* and *Citrullus* have been highly satisfactory for mass production of a number of lecaniine and diaspine scale insects and their parasites. These, with potatoes and potato sprouts, now provide the means for mass rearing of practically every species of scale insect and mealybug that is of economic importance in California.

Several examples may be cited where the utilization of a substitute host has made possible the mass production of parasite species that

never attack it under natural conditions. The best known are the Angoumois grain moth and the Mediterranean flour moth (*Ephestia kühniella* Zell.) in the rearing of *Bracon* and *Chelonus* species that are parasites of the pink bollworm (*Pectinophora gossypiella* (Saund.)) and of the European corn borer, and the potato tuberworm, an excellent insectary host for *M. ancyliorus* and other parasites.

The recent development of an artificial food medium (*85*) for the mass production of the oriental fruit fly (*Dacus dorsalis* Hendel) in Hawaii has expedited greatly the parasite-production program. The use of fruit for this purpose was uneconomical and was impracticable for several other reasons. A preparation of squash, later replaced by carrot, supplemented with an enzymatic protein hydrolysate of soy to induce increased fecundity, proved highly satisfactory for large-scale production of the fly. The development and use of such media can greatly reduce the cost of large-scale parasite-production programs.

Mass production of parasites that attack inactive stages of the host and that are readily available in quantity in the field represents a much simpler problem, involving mainly the development of devices and procedures to reduce labor costs to a minimum. Many millions of *Dahlbominus fuscipennis*, a cocoon parasite of the European spruce sawfly, have been produced and distributed each year by the Canadian Department of Agriculture and several State organizations. In the same category are the egg parasites of the gypsy moth and the range caterpillar (*Hemileuca oliviae* Ckll.), which have been reared by the millions at very low cost.

RESULTS OF BIOLOGICAL CONTROL

In the following pages is given briefly the present status of the different insect pests against which biological control has been undertaken, either as a major project or incidental to other activities. These pests are grouped according to the kind of agricultural crop that they attack. All activities in biological control are represented, whether large or small, and include those in which native as well as imported natural enemies have been utilized.

A total of 91 insect pests are dealt with in this account. Importations of natural enemies from abroad have been made against 77 of them, and the remaining 14 are species against which attempts were made either to extend the distribution of natural enemies already present in the country or to increase their effectiveness by mass colonization or by other means.

The results of biological control work in the continental United States for more than 60 years indicate that only a small portion of our most important agricultural pests can be fully controlled by this method and that with a substantial number of them no reduction whatever can be attained. However, most of the biological control projects may be expected to yield a partial control, the benefits derived therefrom being in the form of reduced injury to crops and a lower total cost for chemical and other means of control that still need to be practiced.

FRUIT INSECTS

On the basis of the number of insect pests involved, the greatest portion of the biological control work in the continental United States has been devoted to insects attacking fruit trees. This is partly explained by the efforts of the California State organizations, which for many years were centered almost entirely on a rather large number of scale insects and mealybugs attacking citrus. Several outstanding results have been obtained there, and their great success is partly attributed to the more favorable climatic conditions in California and to the fact that the scale insects and mealybugs appear, in general, to be especially susceptible to control by the biological method.

The fruit insects with which commercial control has been effected by this means, or a measurable reduction in infestation has been attained, are as follows: Of the citrus insects, black scale, citrus mealybug, citrophilus mealybug, cottony-cushion scale, long-tailed mealybug, and yellow scale; of the deciduous fruit insects, Comstock mealybug, Japanese beetle, oriental fruit moth, and woolly apple aphid.

Oriental Fruit Moth

(*Grapholitha molesta* (Busck))

Because of the great destructiveness of the oriental fruit moth to the peach crop of the Eastern United States and the lack of success in controlling it with insecticide applications, an extended program for the importation of its natural enemies was undertaken in 1930 (*2*). Most of the collections were made in Japan and Korea (*82*), though some consignments were received from France, Italy, and Australia. However, the moth was of only recent establishment in the last three countries, and consequently the natural enemies attacking it were native species having other normal hosts. These few native species were not abundant in comparison with the parasite complex attacking the pest in its native home in the Far East.

Total importations from all sources from 1930 through 1939 comprised approximately 440,000 field-collected fruit moth larvae with a variable percentage of parasitization, 211,500 parasite cocoons and puparia, and 20,000 adult parasites. These importations included more than 20 parasite species. With the exception of 1 or 2 species, they were all colonized in the infested areas of the Eastern States, some in very large numbers and at many points. Several species, notably *Horogenes molestae* (Uchida), reproduced well in the field during the season of release and showed considerable promise. Unfortunately the colonies declined sharply after the first season and eventually disappeared. The principal obstacle to establishment appears to have been the lack of a suitable alternate host to carry the parasites over the winter. The very extensive importation program, covering a period of 10 years, resulted in the establishment of only a single species, *Agathis diversus*, in the United States, and even now, over 20 years after the initial releases, it is found at only a very few points and is of no value in control.

In 1950 the University of California imported a small amount of parasite material from Shantung Province, China, from which was reared *Phanerotoma molestae* Mues. and *Agathis festiva* Mues. Rearing

stocks of these two species were forwarded to the Bureau of Entomology and Plant Quarantine laboratory at Moorestown, N. J., where insectary production was undertaken. Releases of both of these and of *A. diversus* as well were made in light infestations in southern California in 1951. None of them are known to be established in that State.

Despite the very disappointing outcome of the foreign importation program, a very substantial degree of control has still been attained by the biological method through the use of *Macrocentrus ancylivorus*, a native parasite previously reared only from the strawberry leaf roller (*Ancylis comptana fragariae* (W. & R.)). This is one of the few examples of a parasite of a native pest proving effective against an introduced pest attacking another crop.

Prior to the appearance of the fruit moth in the United States *Macrocentrus* was known to be common only in New Jersey, Delaware, and Maryland. It quickly adapted itself to the new pest and attained a high degree of parasitization. A large-scale production and colonization program was undertaken in 1929 and continued to 1935, during which period colonies were released in all infested sections. Infested orchards frequently showed 50-percent or more fruit injury, yet often this loss was reduced to less than 10 percent the season following release of the parasite. Satisfactory methods of chemical control were not then known, and the parasite releases therefore prevented serious and otherwise unavoidable losses. These benefits were obtained in many of the most important peach-producing States, yet there are some sections, such as southern Ohio, where *Macrocentrus* releases have consistently failed to effect any appreciable reduction in the fruit infestations. The reasons for this condition are not well understood, but it may be associated with a scarcity or absence of the strawberry leaf roller, which is a superior overwintering host, or to adverse climatic conditions, particularly low winter temperatures. Even in the sections where the parasite is most effective there are occasional seasons when the pest is able to build up to destructive levels, so that the parasite, although generally effective, cannot be depended on to control the fruit moth every year.

A further development in the utilization of *Macrocentrus*, which greatly increases its effectiveness, is mass colonization early each season (*10*). Even in orchards that already have a considerable parasite population, the release of 500 additional adults per acre at the proper time results in an appreciable reduction in the proportion of fruit that becomes infested. In New Jersey such liberations have brought about a reduction of 50 to 80 percent in fruit injury. This practice may also be of special benefit during the occasional seasons when outbreaks occur in sections where control is usually satisfactory.

The most intensive utilization of *Macrocentrus*, however, was in connection with the outbreak of the oriental fruit moth in California, which was discovered in 1942. Here the releases were not for direct protection of the fruit crop but for suppression of incipient infestations and prevention of spread. Methods were developed by the University of California (*58*) for the production of the parasite in enormous numbers and at low cost, with the potato tuberworm as the host. Fifteen million or more were colonized annually from 1944 through 1946. The colonies were placed in every infested orchard,

irrespective of the degree of infestation, and in adjoining orchards also. It is, of course, impossible to evaluate the part this program played in control of the pest. Many of the incipient infestations disappeared, and in no area of the State has the fruit moth attained a pest status comparable with that held in the Eastern States. In spite of the millions of *M. ancylivorus* that were released, this parasite failed to become established in California, though recoveries were made the season of release.

Codling Moth

(*Carpocapsa pomonella* (L.))

The codling moth is the most destructive pest of apples in the United States, and all possible means of control need to be fully explored. The first attempt along biological control lines was in 1904–5, when *Ephialtes caudatus* (Ratz.) was imported from Spain under the name of *Calliephialtes messor* (Grav.) by the California State Commission of Horticulture for release in that State. It was reported to be established and abundant at several points of release, but eventually disappeared. Later, in 1935–36, it was introduced from France for colonization in the Eastern States, but this effort likewise was unsuccessful. *Perisierola emigrata* Roh. was imported from Hawaii and released by the University of California in 1947, but did not become established.

The penetration of the codling moth larvae deep within the pulp of fruit for almost the entire larval period provides almost complete protection from parasite attack, except by the species that oviposit in the host eggs. Consequently, control by larval parasites appears to offer little promise.

Extensive tests were made to utilize the native egg parasite *Trichogramma minutum* Riley of various strains and possibly different species of the genus, wherein large numbers were released in the orchards early in the season. They were not sufficiently beneficial to warrant recommendation of the practice commercially (*1*). These tests were conducted in Georgia and in several other principal apple-producing sections of the United States.

A series of tests were conducted in an apple orchard at Kearneysville, W. Va., in 1936–40 to evaluate the effectiveness of native natural enemies in the absence of insecticidal treatments. During a 3-year period the percentage of sound fruit in the commercially-treated plots was 56–75, whereas in the biological control plots it was 28–38 (*96*). None of the parasites or predators increased their efficiency sufficiently in the absence of insecticides to justify discontinuation of the standard spray practices.

Peach Twig Borer

(*Anarsia lineatella* Zell.)

The peach twig borer is of foreign origin and is now distributed throughout the United States, being most abundant and injurious in California. In 1931 the importation of natural enemies was undertaken, when the Bureau of Entomology and Plant Quarantine station

in France forwarded seven shipments of *Paralitomastix pyralidis* (Ashm.) to the University of California, which undertook the rearing and colonization work.

The shipments from France comprised more than 2,300 field-collected and reared twig-borer larvae, from which more than 62,000 *pyralidis* adults were obtained for field release. Several large colonies were placed in infested orchards in the Chino area in southern California and near Yuba City in the Sacramento Valley during June to August 1931. Field recoveries of parasitized larvae were made shortly after the releases at Chino in 1931, and in 1932 the parasitization ranged up to 35 percent. Additional releases were made with domestic material during 1932. Recoveries were made in Yuba County in 1940–41 at the sites of the 1932 releases. The parasite is well established in California, but detailed information is lacking on its effectiveness in control.

At the time this introduction was made it was known that *P. pyralidis* was already present as a parasite of the twig borer in the Eastern States, but stocks for use in California were more readily available in Europe.

This parasite deposits its egg in that of the host, and development is polyembryonic. Thirty or more individuals are produced in each host larva, which is killed when it attains full growth. Dead parasitized larvae are larger than healthy individuals. The number of generations is the same as for the host.

Western Grape Leaf Skeletonizer

(*Harrisina brillians* B. & McD.)

The western grape leaf skeletonizer, a pest of wild and cultivated grapes, is native to the Southwest and Mexico, and an infestation appeared in San Diego County, Calif., in 1941. Eradication efforts were undertaken to eliminate the risk of its spread to the important grape-growing sections of the State, but they have not been successful and the program is now centered on prevention of spread. To aid in the attainment of this objective, the importation of natural enemies was begun in 1950, when the search was started in Arizona, followed by surveys in Mexico, the eastern half of the United States, and Utah. The collections in the Eastern States were from other species of *Harrisina* and related genera. Fifteen species of primary parasites were found (*132*), of which 6 have been reared and colonized in the infested area. Three of them are established—*Apanteles harrisinae* Mues. and *Sturmia* sp. from Arizona and *Pelecystoma harrisinae* (Ashm.), the stock of which was reared from *Harrisina americana* (Guer.) and *Acoloithus* sp. collected in Florida.

Total releases during 1951–53 comprised approximately 91,000 parasites representing 6 species. In addition, 4,790 adults of *Compsilura concinnata*, obtained through the Bureau of Entomology and Plant Quarantine laboratory at New Haven, Conn., were released in 1952 in infestations of the skeletonizer and other lepidopterous pests in San Diego County.

The *Sturmia* from Arizona and Mexico, originally believed to be *S. harrisinae* (Coq.), is now thought to comprise several closely

related species. *Apanteles* and *Sturmia* quickly attained a high parasitization, ranging up to 75 percent in the colonized areas, but evaluation of their effectiveness has been complicated by the appearance of a virus disease of the skeletonizer larvae, which has greatly reduced the field infestations.

Orange Worms

Several species of Lepidoptera are known as orange worms in California, the more important being *Argyrotaenia citrana* (Fern.), *Pyroderces rileyi* (Wlsm.), *Holcocera iceryaeella* Riley, and *Myelois venipars* Dyar. Several thousand adults of a larval parasite, *Perisierola emigrata*, as well as a small number of *Cremastus* sp., obtained from Hawaii, were colonized in Orange County in 1947, but failed to become established. Small quantities of parasite material, mostly of *Myelois*, were forwarded from France to the University of California in 1948 and the following years. Several colonies of *Campoplex xanthostomus* Grav. were released in infestations of *M. venipars* on walnut in Orange County, but did not become established.

Pecan Nut Casebearer

(*Acrobasis caryae* Grote)

Investigations on the biological control of the pecan nut casebearer through the utilization of egg parasites of the genus *Trichogramma* were initiated in Georgia in 1931 and extended over a 5-year period (*136*). Five strains of *T. minutum*, derived from various hosts and reared on eggs of the Angoumois grain moth, were used in the tests. Releases were variable in number and were distributed over the oviposition periods of the host. They ranged up to 200,000 adult parasites per tree. On some plots small but definite reductions in infestation were obtained, but they were not sufficient to offset the cost of parasite production. This method of control therefore cannot be recommended on a commercial basis.

Similar field tests were made during the same period on two other pecan insects, the pecan leaf casebearer (*Acrobasis juglandis* (LeB.)) and the hickory shuckworm (*Laspeyresia caryana* (Fitch)). Results in the various plots were inconsistent, and no substantial reduction in infestation was attained.

Japanese Beetle

(*Popillia japonica* Newm.)

The large-scale importation of natural enemies of the Japanese beetle from Japan, Korea, China, and India (*23*, *24*, *79*) from 1920 until 1933 totaled 15 species, of which 4 were dipterous parasites of the adult beetle, 2 were tachinid internal parasites of the grubs, 8 were hymenopterous external parasites of the grubs, and 1 was a carabid predator. Five of them became established in the infested areas in the Northeastern United States—*Hyperecteina aldrichi* (=*Centeter cinerea* Ald.), a parasite of the adult beetles, and *Dexilla ventralis*, *Prosena sibirita*, *Tiphia popilliavora*, and *T. vernalis*, which are parasites in or on the grubs in the soil. Of these, only the 2 species of *Tiphia* have adapted

themselves to local conditions and are now generally distributed. *T. vernalis* emerges in the spring when the host grubs are nearly full-grown and is, accordingly, the most valuable of the 2. *T. popilliavora*, however, emerges during the late summer, and during its oviposition period most of the host grubs are still small. As a result, the progeny of the parasite are largely of the male sex, and increase and effectiveness in control are therefore reduced.

It has been exceedingly difficult to evaluate the effect of *Tiphia* on the Japanese beetle infestations. One reason is that the beetle populations have not maintained a consistent level. In every locality the pest builds up to a high peak quickly after establishment, and then after a period of years subsides to a much lower level. As a result the zone of heaviest infestation is not the area of initial infestation but is at the periphery, which increases each year in distance from the original center of establishment. However, even in the older and less dense infestations *T. vernalis* often parasitizes up to 65 percent of the grubs. It is believed that this parasite contributes substantially to suppressing the grub population in spite of certain habits that cause it to be much less effective in some localities than in others. Heavy parasitization of grubs takes place most frequently in the immediate vicinity of an adequate food supply for the adult wasps. *T. vernalis* feeds mainly on aphid honeydew, whereas *T. popilliavora* feeds at the blossoms and nectar glands of certain plants.

Extended field tests have been conducted in New Jersey to determine the effectiveness of a parasitic nematode, *Neoaplectana glaseri* Steiner, in controlling grub infestations (*81*). Methods were developed by the State Department of Agriculture in cooperation with the Rockefeller Institute of Medical Research and the Federal Bureau of Entomology and Plant Quarantine, whereby the nematodes could be economically reared in culture media in the laboratory. Enormous numbers were produced and utilized in large-scale field experiments throughout the State. The results were not encouraging, and this parasite does not seem capable of aiding in the biological control of the pest.

The greatest possibilities in biological control of the Japanese beetle now appear to be the bacterial diseases of the grubs (*7*, *151*), which are known as milky diseases. They are caused by species of *Bacillus*, the most common being *B. popilliae* and *B. lentimorbus* Dutky. The origin of these bacteria is not known, but diseased grubs were first found in New Jersey, where the beetle first became established, and they may either be native to the United States or have entered with the original beetle stock from which the infestation arose or have been contained in the large quantities of soil accompanying some of the early parasite shipments from Japan.

Methods have been developed whereby grubs can be infected artificially and the bacteria grown in quantity under insectary conditions. After the required period of incubation, the diseased grubs are macerated and mixed with talc or other material at a predetermined dosage (*52*), and it is usually in this dry form that the bacteria are distributed in the field. This spore dust is available from commercial sources.

Large-scale colonization programs have been conducted in New Jersey, Delaware, and Maryland and to a lesser extent in other States.

They have been effective in preventing turf injury by the grubs and serious defoliation by the beetles in parks and gardens. Experimental plots have shown a grub mortality in excess of 90 percent within 2 months after application, and equally high mortalities have been noted in areas where the organisms had become established by natural means. The present distribution program is directed principally to the areas representing the periphery of the main beetle infestation to prevent buildup of the population to the peaks attained in the older infested areas. In city and suburban areas it is desirable that any program for control should be on a community basis so that the treated areas will not be subjected to a constant influx of adult beetles. The cost of the spore dust and of its application is too high to permit general utilization for protection of agricultural crops, but its use is practicable for protection of turf in city parks, golf courses, and lawns of private homes. Spot treatment in agricultural areas is followed by a gradual, though somewhat slow spread of the disease by natural means.

Cherry Fruit Flies

(*Rhagoletis cingulata* (Loew) and *R. fausta* (O. S.))

Fruit flies of the genus *Rhagoletis* are serious pests of cherry in the Pacific Northwest, and apparently are spreading southward into California. In 1952 four species of *Opius*, including *O. formosanus* Fullaway and *O. compensans* (Silv.), all parasites of the oriental fruit fly, were imported from Hawaii, and 835 adults were colonized by State agencies in Oregon and 692 in Idaho. The following year 31,830 adults of the same species were colonized in infestations at 2 sites in Washington and 1 each in Oregon and Montana. The release in Montana was on *R. fausta*, whereas in the other 3 States it was on *R. cingulata*.

These efforts were experimental, as the normal host of the parasites is the oriental fruit fly, a tropical or subtropical species. It is not known whether the parasites will develop in any species of *Rhagoletis* or whether they will be able to bridge the winter on a one-generation host.

Walnut Husk Fly

(*Rhagoletis completa* Cress.)

The walnut husk fly was first reported in southern California in 1927. It is an accidental introduction from the eastern part of the continent, and attacks several deciduous fruits in addition to the walnut.

In 1931–32 three parasites of the Mediterranean fruit fly (*Ceratitis capitata* Wied.) in Hawaii—*Opius tryoni* Cam., *O. humilis* Silv., and *Tetrastichus giffardianus* Silv.—were imported and colonized by the University of California, but failed to become established. In 1937 the next attempt was made to establish parasites of this pest, when several small colonies of *Opius melleus* Gahan, a parasite of the apple maggot (*Rhagoletis pomonella* (Walsh)) obtained from New York, were released in the Pomona district. No recoveries were made. In 1951 *Opius formosanus* was imported, and several colonies were

released in groves at Pomona. This parasite had originally been imported into Hawaii from Formosa and was established on the oriental fruit fly. It was thought that it might be adapted to the husk fly because of an obligatory winter diapause, inasmuch as the husk fly has only a single generation each year. Establishment was not attained.

Black Scale

(*Saissetia oleae* (Bern.))

The search by the California State organizations for natural enemies of the black scale, a major pest of citrus in that State, has covered a period of 60 years, in the course of which practically every subtropical and tropical region of the world has been combed for parasites and predators that might aid in control (*131*). The scope of this work may be judged by the fact that more than 70 species of Chalcidoidea have been reared from this one scale insect in various parts of the world. Many of these species belong to the aphelinine genus *Coccophagus*. The occurrence of sex differentiation in the host relationships of species of this genus and other genera of the family, discovered by Flanders (*61*), is the probable reason for failure of establishment of a number of species colonized in the early years, and has provided the knowledge essential for successful rearing and colonization of species of the genus that have been imported in recent years.

Of the approximately 30 species of parasites and predators imported and colonized during the 60-year period, 8 internal parasites, 1 of which later proved to be a secondary parasite, 2 chalcidoid egg predators, and 3 coccinellid predators have become established. The first importations from Australia were mainly coccinellid beetles, and of these, *Rhizobius ventralis*, colonized in 1891 and 1892, showed the greatest promise. It increased enormously, and expectations were high that field control would be accomplished. This result was not attained, though the beetle has persisted in large numbers in the citrus groves, especially in the coastal sections. Commercial control of the scale on olive has been attained by this beetle a number of times, and it is probably of greater value against the pest on that crop than on citrus. Other imported coccinellid predators that have become established are *R. debilis* and *Lindorus lophantae*, though the latter has proved to be better adapted to other pests.

Scutellista cyanea is the more abundant of the two introduced egg predators, and attains a high population in the uneven hatch areas along the coast. Its contribution toward control is relatively little, even when a very high percentage of scales is attacked, as a sufficient number of eggs to maintain a maximum infestation remain unconsumed under each female scale. The second of the established egg predators is *Lecaniobius utilis*.

Prior to 1900, when *Scutellista* was introduced into California, a native egg predator, *Tomocera californica* How., was abundant on the black scale, often attacking up to 75 percent of the adult females. It declined rapidly thereafter and is now seldom seen. Its place apparently has been permanently usurped by *Scutellista*.

Of the 8 species of internal parasites that have become established, the 2 that have been valuable in control are *Aphycus helvolus* and *A. lounsburyi*. The colonization of *A. lounsburyi* in the coastal sections of southern California in 1918 and thereafter gave great promise, and commercial control was effected in a considerable number of groves from 1920 to 1924. It declined thereafter as a result of its own activities in bringing the scale to more of an "even hatch" condition and through the attack of *Quaylea whittieri*, a secondary parasite. The reduction of the off-hatch brood of the scale permitted more effective control by a single annual chemical treatment. The permanent cleanup of the infestations on pepper trees, which are widely grown along streets and for shade and which served as a source of reinfestation for citrus groves that had been sprayed or fumigated, is credited mainly to *A. lounsburyi*.

A. stanleyi, *Coccophagus rusti*, and *C. capensis* have shown their ability to control the scale only under special conditions. The first appears to prefer the soft scale as a host, though occasionally it becomes sufficiently abundant on the black scale to cause an appreciable reduction in the infestations. *C. rusti* and *C. capensis* have been effective in infestations on citrus in only a few localities and are of most value against the scale on oleander and pepper trees.

The remaining three species—*C. cowperi*, *C. pulvinariae*, and *C. trifasciatus*—are still of very limited distribution and of no value in control of the black scale on citrus or olive.

The long search for fully effective parasites of the black scale finally appeared successful when *A. helvolus* was obtained from South Africa in 1937 (*64*). After an extensive rearing and distribution program during the next few years, the pest infestations subsided greatly, and there was little or no need for insecticidal treatment. The savings effected by this control amounted to millions of dollars each year. However, this highly favorable situation did not persist in all sections, as it developed later that the parasite was not fully adapted to the full range of climatic conditions prevailing in the citrus-growing sections of the State. In recent years the protracted periods of low winter temperatures that occur periodically in the interior valleys have had a serious effect on the efficiency of the parasite. The cold winter of 1949–50, for example, was followed by heavy and extensive outbreaks of the scale in many groves, and chemical control again became necessary.

Apart from its greater effectiveness in areas having a mild winter climate, *A. helvolus* attains its most consistent control of the black scale in sections where there is a certain overlapping of generations of the host, such as occurs in some coastal areas rather than in the interior, where there is a single sharply defined brood annually. This situation has led to an interesting series of experiments, which are still under way, to increase the effectiveness of the parasite under the latter conditions. These tests provided for the infestation of a portion of the infested trees with off-hatch scale crawlers during the spring; thus the parasite was provided with hosts of a stage suitable for attack during several months in which the normal field population is too far advanced in development to be suitable for parasite reproduction. Instead of dying because of lack of hosts, the parasite would then be

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able to survive and reproduce in sufficient numbers to control the new brood of scale that appears in the late summer and the autumn.

After the introduction of *A. lounsburyi* and the severe attack on it by the secondary parasite *Q. whittieri*, it had been thought that this introduced hyperparasite might prevent for all time the attainment of biological control of the black scale (*131*). For that reason its activities after establishment of *A. helvolus* were watched with much interest. Fortunately the habits of the latter are such that it is never attacked by *Quayiea*, and the early apprehensions regarding this hyperparasite have proved unfounded. In the groves where *A. helvolus* is most abundant and effective there has been no extensive increase of any hyperparasite.

Citricola Scale

(*Coccus pseudomagnoliarum* (Kuw.))

Consignments of field-collected citricola scale material were forwarded from Japan to the University of California in 1922–23 and 1936–37, from which 4 or more chalcidoid parasites and 1 coccinellid predator were obtained. One parasite, *Coccophagus japonicus* Comp., was released in small numbers in California, but did not become established. Importations were resumed in 1951 and 1953, and releases have been made of *Coccophagus yoshidae* Nakay., *Coccophagus* sp. not yet described, and *Aphycus orientalis* Comp. in Tulare County. The outcome of these releases is not yet known.

European Fruit Lecanium

(*Lecanium corni* Bouché)

The European fruit lecanium is a serious pest of apricot and several other fruit trees and ornamentals in central California. In 1939 the University of California undertook a survey of the pest and its natural enemies in Europe, especially in France and Italy. A large number of shipments of this and related species were sent to California during that year, and they were supplemented by additional consignments from the parasite station of the Bureau of Entomology and Plant Quarantine at St. Cloud, France.

A large number of parasites were reared from this material, mainly from other species of the genus, and colonies of 10 parasite species were released on infested apricot and other host plants in the San Jose, Calif., area. However, these were small colonies, with the exception of *Aphycus maculipennis* Timb., and none became established.

H. S. Smith concluded as a result of his survey in Europe that in most of the records of parasites on this host, the hosts are incorrectly identified, and that no important parasites attack the European fruit lecanium in that region. The heavy infestations of the pest in Europe, in conjunction with the absence of parasites, led to the conclusion that the species is native to North America and that it has been introduced into Europe.

Kuno Scale

(*Lecanium kunoensis* (Kuw.))

The kuno scale is of Japanese origin and has become established in Contra Costa and Santa Clara Counties in California as a pest of deciduous fruit trees, especially plum and apricot. It is spreading slowly, but infestations are sufficiently heavy to require chemical control measures.

In 1953 the University of California imported several of the parasites of this pest from Japan and colonized them in the infested area. The principal ones were *Encyrtus* sp., which has two generations each year, the first emerging from half-grown scales and the second from the mature females, and *Brachytarsus kuwanai* Yuasa. The latter is an anthribid beetle that attacks the ovipositing females, the larvae being predaceous on the eggs in the egg chamber. Field releases of both species were made in 1953, but there is as yet no evidence of establishment.

California Red Scale (*Aonidiella aurantii* (Mask.)) and Yellow Scale (*Aonidiella citrina* (Coq.))

These two pests of citrus, which in the United States are most destructive in California, will be discussed together because the yellow scale was long considered to be merely a strain of the red scale and because the imported natural enemies have been from various species of the genus and have been utilized against both. This effort in control by the biological method has been under way by the California organizations for 60 years; thus it rivals that of the black scale in duration but does not yet equal it in results.

The early introductions were mainly from the Australian region and comprised a number of predaceous coccinellids, of which only *Orcus chalybeus* and *Lindorus lophantae* became established. Later importations were from India, China, South America, and most recently from South Africa. At least 30 species of parasites and predators have been imported and colonized. In addition to *Orcus* and *Lindorus*, 1 other predator—*Cybocephalus* sp.—and 4 parasites—*Comperiella bifasciata, Habrolepis rouxi, Aphytis* "A," and the red scale strain of *Prospaltella perniciosi*—are now established in southern California.

Coccidophilus citricola Bréthes, a promising predator imported from Brazil in 1934, persisted in the field for several years but finally disappeared.

From the point of view of effectiveness in control the predators may be disregarded, as they have persisted in only very limited areas and are not abundant. The same is true of the South African parasite *H. rouxi*, which is primarily a red scale parasite and is established only in San Diego County. Only *Comperiella* and *Aphytis* "A" are of appreciable value in control, the first on the yellow scale and the second on the red scale. Effective natural enemies of the red scale appear to be conspicuously lacking in all parts of the world where it occurs. Although a strain of *C. bifasciata* adaptable to the red scale

has become established and abundant in some orchards, it has shown no indication thus far of accomplishing any degree of control. The two most recently established parasites *Aphytis* "A" and the red scale strain of *Prospaltella perniciosi*, obtained from China and Formosa, show considerable promise, but their final status is yet to be determined.

Intensive field tests have been undertaken to determine the practicability of periodic heavy colonization of *Aphytis* "A" and *A. chrysomphali* (Mercet), the latter probably accidentally introduced with its host many years ago, as a means of controlling the red scale (*40*). Such a practice would compensate for the delay in buildup of the field parasite population owing to the unsuitability of the successive host broods at certain stages of development for parasite oviposition. Preliminary field tests have given satisfactory control, and the practicability of this method in the areas suitable for the parasite is now dependent on the development of methods of mass production of the parasite and of its release at a cost not in excess of the amount expended for chemical control.

The results obtained with the yellow scale strain of *Comperiella* have been much better than those with the red scale strain. In the Redlands area especially it has shown up well, particularly under city conditions, where the environment and the variety of vegetation are most suitable because of overlapping of the different host stages. Infestations in parks and similar areas have been completely controlled, and high populations of the parasite are frequently found in the field. At the present time the yellow scale is of little commercial importance on citrus except in the San Joaquin Valley (*69*), where its seasonal cycle is much more uniform than elsewhere and stages suitable for parasitization may be lacking for long periods. The original strain of *C. bifasciata* from Japan appears not to be adapted to these conditions, whereas stocks imported from China during the last part of 1948 and widely distributed in the San Joaquin Valley in 1949 have effected control in a number of orchards.

Purple Scale

(*Lepidosaphes beckii* (Newm.))

The purple scale has long been one of the most destructive pests of citrus in certain of the coastal sections of southern California and is also a serious problem in Florida. Since the 1890's the California organizations have searched in many parts of the world for effective natural enemies, but with little success. The imported coccinellid beetles *Orcus chalybeus* and *Lindorus lophantae* are often found feeding on it, but with no appreciable effect in control. The external parasite *Aphytis* "X," obtained from South China and Formosa in 1948–49, and *Physcus* "B," imported from Formosa in 1950–51 (*71*), are established in several localities in the coastal area, but their final value in control of the scale is not yet known.

Fig Scale

(*Lepidosaphes ficus* (Sign.))

A considerable number of shipments of fig scale, oystershell scale (*Lepidosaphes ulmi* (L.)), and *L. conchiformis* (Gmel.) were made from

Italy and France to the University of California during 1939–40 and 1949–50 for control of the fig scale in the San Joaquin Valley. The principal parasites obtained from this material were *Physcus testaceous* Masi, *Archenomus* sp., and *Aphytis mytilaspidis* (LeB.). All three species were colonized extensively, but *Physcus* and *Archenomus* did not become established. Releases were made in mixed infestations of the fig scale and oystershell scale, as the parasites were known to attack both species. Other releases against the fig scale comprised *Aspidiotiphagus* sp. and *Telsimia* sp. from South China and several coccinellid beetles from South Africa. *A. mytilaspidis*, which is known to be already widely established in the United States, was colonized at Merced, Calif., in March 1949 in an area where the domestic form of that species was absent.

Field observations in the San Joaquin Valley revealed that the *Aphytis* originally obtained from *L. conchiformis* in France had established itself and attained a high rate of parasitization, ranging up to nearly 100 percent. As a result the infestations under observation have been very greatly reduced (*48*).

Glover Scale

(*Lepidosaphes gloverii* (Pack.))

The Glover scale is a minor pest of citrus in a very limited area in California. During 1948–49 shipments of miscellaneous scale material received from South China by the University of California yielded hundreds of specimens of *Prospaltella elongata* Doz. (*76*). It was reared in the insectary, and the first field release, consisting of only five mated females, was made in Orange County in May 1948. The parasite was recovered from this colony site through collections made in December 1949. Releases were made at other points in the following years and establishment was attained. *P. elongata* had previously been reared from Glover scale collected in Texas and Florida, so that this effort cannot be considered as an original introduction into the United States, though the species had not previously been found in California.

San Jose Scale

(*Aspidiotus perniciosus* Comst.)

The San Jose scale, which originated in Asia and was first observed in the United States about 1870, quickly spread over the entire country and caused serious injury to apple and other fruit trees and to ornamentals. In the Eastern and Southern States it is attacked by a number of parasites that may have adapted themselves to it or were of foreign origin and had been brought in with the host. For many years these enemies appear to have kept the pest under reasonable control in many sections except in orchards receiving frequent spray treatments. Certainly it is now much less destructive than during the period immediately following its establishment in this country.

A coccinellid beetle, *Chilocorus similis*, is an abundant enemy of the scale in Japan, and efforts were made to import and establish it from 1895 to 1923, but without success.

Since the important parasites of the scale were not present in California, the Bureau of Entomology and Plant Quarantine and the

University of California undertook cooperatively to establish one or more of the effective species in that State. The material was obtained from Georgia, where the dominant parasite is *Prospaltella perniciosi*. Approximately 200,000 *Prospaltella* adults were released in 5 central and southern California counties in 1943–44. The parasite is now known to be established in San Bernardino, San Diego, and Santa Cruz Counties. Parasitization is high and the scale infestations have been much reduced in severity.

Coconut Scale

(*Aspidiotus destructor* Sign.)

The coconut scale is a minor pest of ornamentals in Florida, and the importation of its natural enemies was incident to a larger project under way in Puerto Rico in 1936 and the following years. The 2 coccinellid beetles *Azya trinitatis* and *Cryptognatha nodiceps*, which had been exceptionally successful in controlling the pest in other countries, were established in southern Florida as a result of releases made in 1938–39. No further information is available regarding their progress and effectiveness in control. Two additional coccinellid predators, both of the genus *Delphastus*, were obtained from Puerto Rico in 1936 and 1938, but neither species persisted in the field in Florida.

White Peach Scale

(*Pseudaulacaspis pentagona* (Targ.))

The white peach scale is an abundant and at times injurious pest of peach and related deciduous fruit and ornamental trees in the Southeastern States. In connection with a project in the Far East in 1901 (*103*) it was observed that the scale in Japan was heavily attacked by a coccinellid beetle, *Chilocorus similis*, an enemy of the San Jose scale. Several shipments were made to the United States, but only two individuals survived. However, they proved sufficient for rearing purposes, and large numbers were produced in the insectary at Washington, D. C., for release in several States. The field colonies appeared to thrive, especially those in Georgia, where recoveries were made for several years, but the species did not persist beyond 1905. Several attempts have been made to establish this predator on various other scale insects in California, but they likewise were not successful.

Olive Scale

(*Parlatoria oleae* (Colvée))

The olive scale is a relatively recent introduction into California, having first been observed abundantly on olive in the San Joaquin Valley in 1931. Since that time it has become widely spread over the State, and is destructive not only to olive but to a wide range of other fruit and ornamental trees. The importation of natural enemies was initiated by the University of California in 1939, when two shipments of material from Italy were received. They yielded a small number of *Aphytis* sp., but no field releases were made.

In 1948–49 several consignments of scale material were received from Egypt, and yielded large numbers of a strain of *Aphytis maculicornis* adapted to the olive scale. In March 1949, 5,000 adults were released on olive at 4 points in the San Joaquin Valley, and recoveries were made in 1951 at 2 of these colony sites.

The foreign survey of this pest and its natural enemies was extended by the University of California in 1951 to include India, Pakistan, the countries of the Middle East, and the Mediterranean region. The scale is at times a serious pest on deciduous fruit trees in some countries of the Near East, but is rather rare in northwest India, Pakistan, and the Mediterranean region. The presence of one or more apparently effective parasites led to the belief that they might hold the pest in check there. Small importations of parasitized material from many countries were made into California during the summer of 1951. From this material were obtained four strains of *A. maculicornis*, which have been designated the Indian, Persian, Egyptian, and Spanish strains.

The first field release was of the Indian strain in 1951 followed by the other three early the next year, and they quickly became established. The distribution program, which included also *Aspidiotiphagus* sp. from Iran and *Chilocorus bipustulatus* (L.) from Israel, was largely completed early in 1953, when a total of approximately 6½ million parasites and predators, most of which were the Persian and Indian strains of *A. maculicornis*, had been released throughout the infested areas of the State.

Results of the field tests with these strains of *A. maculicornis* have been especially promising (*44*). Releases in field plots in Fresno County in January 1952 and the following months resulted in parasitization of the spring brood of the scale, which approached 100 percent in June. The second host generation during the late summer showed relatively low parasitization. The scale population in the spring of 1953 was less than 5 percent of that of the preceding year, and parasitization again approached 100 percent. There are indications that the same course of events is taking place in the commercial olive orchards throughout the State, where the releases were made later.

Field recoveries have also been made of *Aspidiotiphagus* sp. at many points, mainly on dooryard trees, and of *C. bipustulatus*, a coccinellid predator, but the latter is not known to be established.

Cottony-Cushion Scale

(*Icerya purchasi* Mask.)

The biological control of the cottony-cushion scale in California through the importation of its natural enemies from Australia is well known. Within less than 2 years after the arrival of the first small consignments of the vedalia (*Rodolia cardinalis*) from Australia in 1888, the pest, which had threatened to destroy the citrus industry, was under complete control throughout southern California and has remained so to this day. The pest is held at such a low level that several days may be spent in search for it before a single small colony is found. From time to time a small infestation may appear on one or

a few trees in an orchard or on ornamentals, but the beetle soon appears and quickly brings it under control.

The expenditure of less than $5,000 to defray the costs of the expedition to Australia thus brought benefits to the citrus industry of the United States amounting to millions of dollars annually. This beetle has since been colonized and established in about 50 citrus-producing countries in different parts of the world, and in most of them the same thorough control of the pest has been attained. It has also been equally effective against related pests, notably *Icerya aegyptiaca* (Doug.) and *I. seychellarum* (Westw.), which are destructive to citrus and other plants in other countries.

The rapidity with which commercial control was effected in southern California from an original stock of 514 beetles received between November 1888 and March 1889 is shown by the following extract from a letter from D. W. Coquillett to C. W. Riley dated October 21, 1889:

> The first half of the year I devoted nearly the whole of my time to propagating and distributing the Australia Lady-bird (*Vedalia cardinalis*) recently introduced by this Division. At the present time it is very difficult to find a living Fluted Scale (*Icerya purchasi* Maskell) in the vicinity of this city (Los Angeles), so thoroughly has the Lady-bird done its work; and, indeed, the same is true of nearly the entire Southern part of the state, as well as of many localities in the Northern part.

That complete control by the vedalia has continued to the present day requires some qualification in the light of certain developments during the last few years. The widespread use of DDT and other even more toxic chlorinated hydrocarbons and organic phosphates in the control of crop pests has upset the natural balance of many associated insects and has raised them to the status of major pests. These insecticides, especially DDT, persist on the foliage for months and practically eradicate the parasite and predator populations. The general use of DDT against the citricola scale and citrus thrips in certain areas in California eliminated the vedalia beetle in those areas. As a result heavy and destructive infestations of the cottony-cushion scale quickly appeared (*38*) such as had not been seen for more than 50 years. Consequently, it was necessary to recolonize the vedalia after the toxic residues on the foliage had been dissipated.

Certain of the host plants of the cottony-cushion scale are not, for some reason, suitable for feeding and reproduction of vedalia. Repeated efforts have been made to establish the beetle in infestations of the scale on Scotch broom (*Cytisus scoparius*) and maple in central California, but without success.

The spectacular success with the vedalia overshadowed completely the value of the parasitic fly *Cryptochaetum iceryae*, which was established in California at the same time. The latter is most abundant in the coastal sections and, in the absence of the vedalia, would effect an appreciable degree of control alone. However, it has not been given this opportunity in any of the citrus-producing areas, but its value in control of the pest on ornamentals in the San Francisco Bay area, where climatic conditions are not suitable for the vedalia, has been fully demonstrated.

A second coccinellid beetle, *Rodolia koebelei*, was imported from

Australia in 1891 and persisted in abundance in the citrus orchards of southern California for many years, but eventually disappeared.

Citrophilus Mealybug

(*Pseudococcus gahani* Green)

The first infestations of the citrophilus mealybug on citrus trees were observed in southern California in 1913, and in the following years it spread rapidly and soon became one of the major pests not only of citrus but of ornamentals in that State. For a considerable period it was adequately controlled by annual mass releases of the coccinellid beetle *Cryptolaemus montrouzieri*, which had originally been imported from Australia for control of the citrus mealybug. Another species, *Scymnus binaevatus*, was imported from South Africa by the California Department of Agriculture in 1921. It became established and rather widely distributed, but contributed little to control.

It became recognized as time went on that more efficient control might be possible with internal parasites, if such could be found, than with the predaceous beetles. The search for these was undertaken by the University of California in 1927–28. The country of origin of the mealybug was not known, but a study of its distribution pointed toward the Australian region. Investigations were therefore started in that country, though the species had never been reported to occur there. However, it was quickly found, and with it were several parasites. The importations made during early 1928 resulted in the establishment in California of *Coccophagus gurneyi* and *Tetracnemus pretiosus* as well as a predaceous itonidid fly, *Cleodiplosis koebelei* (*29*). The predator proved to be of little value in control, but the 2 parasites increased and spread so rapidly that satisfactory control was effected throughout all the infested areas of California within 2 years. There have been no outbreaks since that time, and the pest is consistently held at an exceptionally low level. In completeness and consistency of control the success of this project equals that attained 40 years previously by the vedalia beetle on the cottony-cushion scale.

Immediately following initial releases of the parasites, *Coccophagus* was generally the most effective in reducing the heavy existing infestations. However, observations in recent years have shown a preponderance of *Tetracnemus*, indicating that this species may be the most effective under conditions of low host density.

It is somewhat surprising that outbreaks of citrophilus mealybug have not occurred following the general use of the new organic insecticides since 1945, as infestations of other mealybug species on citrus in southern California have increased greatly after application of sprays or dusts to the trees.

Citrus Mealybug

(*Pseudococcus citri* (Risso))

The first effort in the biological control of the citrus mealybug in California was in 1891–92, when the coccinellid beetle *Cryptolaemus montrouzieri* was imported from Australia. It increased rapidly for

several years and showed promise of effecting control, but then subsided to relatively little importance. Later investigations demonstrated that this was due mainly to the inability of the beetle to survive the winter in sufficient numbers to prevent mealybug buildup in the spring. The development of mass culture methods, with releases in the infested groves each spring, solved this problem, and for many years the pest was satisfactorily controlled by this means.

The use of *Cryptolaemus* constituted an annually recurring cost to the growers, in which respect it differs from the requirements of other biological control projects, and for that reason the search for effective internal parasites was continued. *Leptomastidea abnormis* was obtained from Sicily in 1914. Although it was not consistently effective in reducing the pest infestations, in some sections it held them to a low level between outbreaks and possibly also lengthened the intervals between these outbreaks. Certainly the citrus mealybug has been much less destructive since the introduction of the parasite.

In Ventura County, however, the mealybug has persisted in many groves in sufficient numbers to necessitate control measures. About 50 million *Cryptolaemus* beetles and many millions of *Leptomastix dactylopii* How. and *Pauridia peregrina* Timb. are produced and colonized each year for its control. *L. dactylopii*, which previously had been recorded from Washington, D. C., and Louisiana, was imported from Brazil in 1934 and *P. peregrina* from South China in 1949. These two species are not yet known to be established, as survival over the winter is uncertain. When colonized in the spring and early summer, however, they increase rapidly and are often effective in controlling the pest.

Extensive experiments were conducted in Massachusetts (*150*) during 1933–35 to determine the possibilities for the effective use of *Cryptolaemus* in controlling heavy infestations of the citrus mealybug on gardenias and chrysanthemums in greenhouses. The releases were on the basis of about one beetle per plant. Control was usually accomplished by the second brood of larvae and in 9 to 10 weeks after the initial releases.

Cryptolaemus reproduces satisfactorily only at 70° F. or above. Greenhouse temperatures are usually below that during the winter, and therefore the beetles can be utilized successfully only when releases are made during April through June. The beetle does not reproduce extensively in light infestations, yet if they are too heavy at the time of beetle release there will be serious injury to the crop before control is accomplished by the second brood of larvae. Thus there are definite limitations to the use of *Cryptolaemus* in greenhouses under commercial conditions.

The inability of *Cryptolaemus* to reduce light infestations in greenhouses or to hold them consistently at a low level once the heavy infestations are controlled suggests the use of *L. abnormis*, *L. dactylopii*, and *P. peregrina* as a supplementary measure. A recent study of this problem in California (*42*), where gardenias are often heavily infested with this mealybug, showed that initial heavy infestations could be reduced and then maintained at a low level by the use of several natural enemies, the most important of those used in the tests being *Chrysopa californica* Coq., *Scymnus binaevatus*, and *Anagyrus kivuensis* Comp.

Comstock Mealybug

(*Pseudococcus comstocki* (Kuw.))

During the 1930's the Comstock mealybug increased to a destructive status in apple orchards in sections of Virginia, West Virginia, and several other Eastern States. Attempts at biological control through the importation of its parasites from Japan were begun in 1939 and continued through 1941 (*83*). Five species of internal parasites were imported and colonized, and 2 of them became well established—*Allotropa burrelli* and *Pseudaphycus malinus*. In addition, *A. convexifrons* Mues. and *Clausenia purpurea* Ishii had apparently been accidentally introduced with the host some years previously, but the first was found to occur in only a few localities, whereas the latter was generally distributed.

A. burrelli, *P. malinus*, and *C. purpurea* have proved to be effective in the field in this country. The rearing and distribution program was continued until 1948, although the 3 species were well established in all the main infested areas by the end of 1945. Commercial control has been attained in most infested orchards mainly by the first 2 species. Their release early in the season generally results in control by the end of the year, but if made later in the season the control is not accomplished until the end of the following year. This delay is mainly attributed to competition with *C. purpurea*, which is especially effective against the third brood of mealybugs, but is very much hampered earlier in the season by the attack of secondary parasites.

In 1940–41, before the effectiveness of the imported parasites had been demonstrated, an attempt was made to utilize the Australian mealybug predator *Cryptolaemus montrouzieri* for control of heavy infestations. The Comstock mealybug has the same general habits as the citrophilus and citrus mealybugs on citrus, in that the infestations consist of large aggregations of adults and egg masses, a condition found to be essential for the full effectiveness of *Cryptolaemus*. Releases of large colonies of adult beetles were made in three orchards in Albemarle County, Va., under favorable conditions in 1941–42, but the experiment was unsuccessful. No feeding by the beetles was observed, and only a single larva was found after the releases. Apparently there was practically no reproduction.

Long-Tailed Mealybug

(*Pseudococcus adonidum* (L.))

The long-tailed mealybug is one of the minor pests attacking citrus in California, but occasional outbreaks have occurred in recent years, and in some areas it has become a major pest of avocado. The importation of natural enemies was begun in 1933, when *Anarhopus sydneyensis* was obtained from Australia, where it had been observed several years before. *Tetracnemus peregrinus*, which had been imported from South Africa in 1924 and 1926 but not established, was brought in from Brazil in 1934, followed by *Anagyrus fusciventris* from Hawaii in 1936. All three species have become established (*62*).

A. fusciventris has proved to be of little value in control, whereas *A. sydneyensis* and *T. peregrinus* have been highly effective in con-

trolling infestations on citrus and avocado as well as on *Dracaena*, an ornamental plant that is a preferred host. *A. sydneyensis* is the dominant species, though either it or *T. peregrinus* alone is able to bring an infestation under control. Both of these species were colonized in heavily infested avocado orchards in San Diego County in 1941 (*66*). Observations 18 months later showed that both were established and the infestations reduced sufficiently so that further control measures were unnecessary. Since that time the parasites have become established throughout the coastal area of southern California. They have aided greatly in control of the pest, though occasional local outbreaks still occur on citrus.

Grape Mealybug

(*Pseudococcus maritimus* (Ehrh.))

The grape mealybug is presumably native to North America and is widely distributed. In California it is a pest of grape, citrus, walnut, apple, pear, and many other plants. The form that occurs on grape appears to represent a distinct strain, as it is unable to develop on the other plants mentioned, and it has only two generations each year. Also it is heavily attacked by several parasites that do not attack the form infesting the other plants.

Experiments have been conducted recently (*45*) in the control of this pest on pear trees through the utilization of a native predator, the well-known green lacewing (*Chrysopa californica*). These tests were undertaken mainly to restore in the orchards the natural populations of the lacewing that had been greatly reduced because of applications of DDT and other insecticides for control of the codling moth. The adults of *Chrysopa* are extremely susceptible to these insecticides, whereas the larvae are resistant. Accordingly, the colonies placed in the field consisted of eggs rather than adults.

It was found that 3 releases of 250 eggs per tree, properly timed over the spring and summer months, brought about a very substantial reduction in fruit infestation. There was also a "residual" effect, in that the orchards remained reasonably free of mealybugs the second year, even without further releases. This finding suggests that releases in alternate years will be sufficient to maintain control.

Pineapple Mealybug

(*Pseudococcus brevipes* (Ckll.))

The pineapple mealybug is a common though not destructive pest in small pineapple plantings in southern Florida. Although it is a minor pest, it was possible in 1943–44 to obtain parasite stocks from Puerto Rico incident to other activities. As a result *Hambletonia pseudococcina*, originally from Brazil, was obtained and established in plantings at Sebring from an initial release of 454 adults in June 1944. No information is available regarding its abundance or effectiveness; in fact, the general use of the new organic insecticides on this crop in recent years has probably reduced the parasite to a very low level.

Woolly Apple Aphid

(*Eriosoma lanigerum* (Hausm.))

The woolly apple aphid is native to the northeastern portion of the continent, as is also its internal parasite, *Aphelinus mali*. The pest is usually fairly well controlled by *Aphelinus*, though occasional minor outbreaks occur.

The opening of the West to agricultural development in the last century led to the establishment of a large apple industry in the Pacific Northwest. Apple cuttings and nursery plants from the East undoubtedly carried the aphid to the Northwest, but apparently the parasite was left behind. Because of this absence of an important natural-control agency the aphid increased and spread widely, and heavy infestations developed on the trees. The situation was further complicated by a fungus disease, perennial apple canker, which caused serious injury to the trees. The physical condition of the bark about wounds or pruning scars, induced by large colonies of aphids, provided optimum conditions for the development of the disease and resulted in large lesions at such points. The essential step in the control of the disease was therefore the elimination of the aphid infestations.

The introduction of *A. mali* into the Northwest was accomplished first in the Hood River Valley by the Oregon Agricultural Experiment Station in 1929 and by the Federal Bureau of Entomology in the Wenatchee and Yakima, Wash., areas in 1930–31. Its establishment and spread were rapid, and the aphid infestations soon subsided to a noninjurious level. A further consequence was the virtual disappearance of perennial apple canker as a serious orchard problem. This favorable situation persisted until the late 1940's, when the widespread use of DDT and related compounds for codling moth control practically eliminated the parasite from the orchards. This brought on once more the heavy aphid infestations and in their wake outbreaks of perennial apple canker. The solution of this problem lies in either the addition of an effective aphidicide to the codling moth sprays or a change in the insecticide to one less toxic to the parasite and less persistent on the foliage.

The parasite was also introduced into the apple-growing sections of California during 1935–39, but it is not so effective in some areas of the State as it is in the Northeast and Northwest.

The general effectiveness of *A. mali* in the United States has led to its introduction into the apple-growing areas of 50 countries or geographic areas during the last 30 years. It is known to be established in more than 40 of these countries, with varying degrees of success in control of the pest.

Recent observations in California (*105*) indicate that *Exochomus quadripustulatus*, a coccinellid beetle imported from Italy and established in 1928 to control certain lecaniine Coccidae, is capable of checking heavy infestations of the aphid in some parts of that State and is a valuable supplement to *A. mali*.

Citrus Blackfly

(*Aleurocanthus woglumi* Ashby)

Information on the biological control of the citrus blackfly is included in this account because this is the only project conducted in other countries and participated in by the United States Department of Agriculture with the direct objective of protecting an agricultural crop here. The purpose was to prevent or reduce the probability of entry of the pest into the United States as contrasted with control after entry.

This blackfly, which is of Asiatic origin, became a destructive pest of citrus and other plants in Cuba, the Bahamas, and Central America after its discovery in Jamaica in 1913. Its presence in these places, particularly on the islands near Florida, made imminent the danger of introduction into that State. It was felt that if the pest could be reduced to a low level by the biological method, the danger of entry into Florida and the Gulf States would be greatly reduced. Accordingly, the United States Department of Agriculture and the Cuban Department of Agriculture, Commerce, and Labor investigated the problem on a cooperative basis.

A parasitic wasp, *Eretmocerus serius* Silv., and a predaceous beetle, *Catana clauseni* Chapin, were introduced into Cuba from Malaya in 1930 (*22*) and widely colonized. Complete control was quickly brought about, mainly through the parasite, not only in Cuba but in Jamaica, Panama, Costa Rica, and, after some delay, in the Bahamas. The danger of entry of the pest into the United States from the West Indies has thus been greatly reduced. If it should appear in Florida, the parasite can be obtained immediately, and there is reasonable assurance that it will exercise the same degree of control that was attained in Cuba and elsewhere.

The discovery in 1935 of an infestation of the blackfly on the west coast of Mexico and its rapid spread to many parts of that country in the following years were of much concern to the citrus growers of the border States from Texas to California. The heavy infestations that developed during the following years in several areas of Mexico demonstrated that the pest might well be able to increase to a destructive status under the conditions that prevail in those semiarid States.

In 1943 a project was undertaken by the Mexican Department of Agriculture and the United States Department of Agriculture for the importation of *E. serius*, which had been so effective elsewhere. During the summer of that year 60 colonies of the parasite, obtained from the Canal Zone, were released in the infested area on the west coast from Colima northward beyond Los Mochis, to which area the pest at that time was restricted. Many of the colonies became established and, as the pest spread to other parts of the country, the parasite was distributed from these sources. In many sections it became very abundant, but in only a few small areas was it able to bring about control. This result was unexpected and disappointing, but climatic conditions during the winter apparently are markedly unfavorable to the parasite, causing its population to decline greatly.

The seriousness of the problem, accentuated by the close approach of the pest to the border and the almost complete failure of *Eretmocerus*,

made it necessary to renew the search in tropical Asia for more effective parasites. This was undertaken in 1948–50, with special attention to species that might be found in regions having a semiarid climate similar to that of Mexico. In western India and Pakistan a number of parasites were found that had not been encountered in the original investigations in Malaya. Four of them—*Prospaltella clypealis* Silv., *P. opulenta* Silv., *P. smithi* Silv., and *Amitus hesperidum* Silv.—are now established in Mexico and are being widely distributed. They have been collected and distributed by the hundreds of millions by the Mexican National Committee for the Combat and Control of the Citrus Blackfly, and satisfactory control has been obtained in the central and eastern parts of the country but not yet in the west coast areas. *A. hesperidum* is the most effective of the new importations.

Citrus Whitefly

(*Dialeurodes citri* (Ashm.))

The citrus whitefly is generally distributed as a pest of citrus and many ornamentals in Florida and the Gulf States, and infestations have developed from time to time in California. In 1910–11 a search was made in India for natural enemies of this pest and two were found (*152*), an internal parasite, *Prospaltella lahorensis* How., and a coccinellid predator, *Catana parcesetosa* (Sicard) (=*Cryptognatha flavescens* Mots.). Both of these were taken to Florida, but unfortunately during the early winter when facilities were not available for laboratory propagation. The stocks of both species died during the winter, and consequently no field releases were made.

For many years considerable interest has been shown in the parasitic fungi of the genera *Aschersonia* and *Aegerita*, which attack whiteflies in Florida. A study of these fungi (*106*) indicated that they are the most important of the natural-control agencies operating against the whiteflies in the State, but artificial dissemination of spore suspensions did not contribute appreciably to control if the fungi were already present in the groves. Methods were developed by State agencies for growing these fungi in quantity in the laboratory, and beginning in 1915 cultures were widely distributed. In recent years much doubt has arisen as to the actual relationship of the fungi to the whiteflies and the real value of the distribution program. It was discontinued in 1943.

Citrus Red Mite

(*Metatetranychus citri* (McG.))

Occasional efforts have been made to obtain natural enemies of the citrus red mite, which is a serious pest in southern California. As early as 1900 one or more species of predaceous Coccinellidae were imported from Australia, but did not become established. *Stethorus vagans* (Black.), which was colonized in 1900–1901, was recovered in 1902, but did not persist. *S. gilvifrons* Muls., obtained from South China in 1950, reproduced well in several localities during the seasons of release, but is not known to be established.

FIELD AND GARDEN INSECTS

The main efforts toward biological control of insect pests of field and garden crops have been directed against the alfalfa weevil, European corn borer, sugarcane borer, European earwig, and pink bollworm. Commercial control has not been attained throughout the range of any of these pests, although substantial results have been shown on the European corn borer, alfalfa weevil, and alfalfa caterpillar.

European Corn Borer

(*Pyrausta nubilalis* (Hbn.))

The discovery of the European corn borer in Massachusetts in 1917 and in other areas shortly thereafter led to an early realization of the importance of the problem facing the producers of one of the principal grain crops in the United States. As a result biological control investigations were initiated at an early date (4), studies being undertaken in France in 1919. The search for natural enemies in Europe was concentrated mainly in France and Italy. Importations from that region from 1920 to 1938 totaled nearly 24 million field-collected hibernating borers, a portion of which contained early stages of parasites, and a large number of cocoons, puparia, and pupae of several of the parasite species. Eighteen parasite species were obtained from these shipments.

The importations from Japan, Korea, and Manchuria from 1929 through 1936, totaled more than 3 million field-collected borers, with 13 parasite species represented. As certain of these species were identical with those from Europe, the combined total comprised 24 species. The total production of parasites obtained from the imported material was approximately 2,687,000 adults from Europe and 307,000 from the Orient. These numbers were supplemented later in the colonization program by 3,360,000 of 5 species, produced by domestic rearing, and field collections of 146,000. Additional field collections of several of the established species for extension of the colonization program have been made annually since 1939.

Although the large-scale importation program was completed in 1938, small collections of certain species occurring in Europe but not yet established in the United States were made during the following 10 years in the hope that they would be better adapted to some of the more newly infested areas.

Of the 24 species of parasites that were imported and colonized, 6 have become established—*Chelonus annulipes, Horogenes punctorius, Lydella stabulans grisescens, Macrocentrus gifuensis, Phaeogenes nigridens,* and *Sympiesis viridula.* The first species attacks the egg and develops in the larva, *Phaeogenes* is a parasite of the pupa, and the other 4 attack the larva. Only *Lydella* and *Macrocentrus* have become sufficiently abundant or widely distributed to be considered as of appreciable value in field control. Each species appears to be rather definitely limited in its ecological requirements, and none are able to increase to effective numbers throughout the entire area of infestation of the host.

L. stabulans grisescens, the most effective of the introduced species, is now widely established over the Eastern and Middle Atlantic

States, where it effects a parasitization of 10–45 percent. Extensive colonization in the North Central States since 1944 has resulted in its general establishment and rapid spread in that area, with field parasitization ranging from 45 to 75 percent in Illinois, Indiana, Iowa, Kentucky, and southwestern Ohio.

M. gifuensis has been widely distributed, but thus far has not persisted in appreciable numbers except in certain areas of southern New England, where it is the dominant species and where parasitization up to 52 percent has been observed.

H. punctorius has been established and widely distributed for many years in southern New England and New Jersey, but field parasitization has declined in recent years. It has been widely distributed, especially since 1944, in the North Central States, but has not persisted in appreciable numbers at any point beyond the generally inhabited area in the Eastern States.

Several other species have been colonized on a very wide basis but without success. Releases of *Exeristes roborator* (F.) totaled 314,796 adults, which were distributed over 6 States. Although recoveries frequently were made, permanent establishment was not attained. *Bracon brevicornis* (Wesm.) was colonized on an even greater scale, with 2,820,403 adults released in 11 States. No recoveries have ever been made.

The extensive Federal-State cooperative program initiated in 1943 and covering mainly the North Central States has permitted much more intensive colonization and recovery studies than had previously been possible. The entire biological control program, which has now been under way for more than 30 years, shows much more promise than was thought possible 15 years ago. The figures for field parasitization, especially in the North Central States, indicate the possibility of substantial results in control of the pest. Definite decline in the infestations in several areas appears to be correlated directly with the establishment and increase of the introduced parasites.

In 1931–33, experiments were undertaken in the utilization of a fungus disease in supplementing the insect parasites for control of the corn borer (*5*). The fungus was *Beauveria bassiana* (Bals.) Vuill., which was contained in a consignment of corn borer larvae imported from Manchuria. A mortality of 80–90 percent of the larvae occurred while they were being held for parasite emergence. The field plots were treated with spore dust applied with a hand duster, at first 1 week after the peak of oviposition and again after all the eggs had hatched. Other plots received weekly applications.

As expected the mortality varied with the dosage of spores applied. The best results, representing a kill averaging 71.3 percent, were secured with 2 applications of 20 gm. of spores each per acre. However, it was concluded that the annual application of spore dust for field control would be impracticable because of difficulties of production and application.

Although the fungus persisted in the field for some time after the applications, the natural spread in succeeding generations was very limited. This condition is understandable with this and other insects of similar habit, as the infected caterpillars die in their burrows in the plant, and there is little opportunity for dispersion of the spores from these confined spaces.

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Sugarcane Borer

(*Diatraea saccharalis* (F.))

The early attempts at the biological control of the sugarcane borer, beginning in 1915, consisted of the colonization in Louisiana of large numbers of a tachinid fly, *Lixophaga diatraeae*, which is native to Cuba and other West Indian islands. It persisted in the field for several years, but finally disappeared.

In 1928 a large-scale program was started for the importation of parasites from Argentina and Peru. The search revealed at least 9 species, 2 of which were very abundant. During a 4-year period 5 of these parasites were shipped to Louisiana (*93*), the consignments of *Paratheresia claripalpis* consisting of 637,000 puparia and of *Iphiaulax rimac* (Wolc.), 59,600 adults. The other 3 species were forwarded in only small numbers. Most of this material came from Peru. The field releases were mainly in Louisiana, though a small portion of the stock was utilized in southern Florida. Additional supplies of the 2 abundant species were obtained in 1936 and of *Lixophaga* as well in that and later years for release in Florida. In 1938–41 it was possible to obtain colonies of the Amazon fly (*Metagonistylum minense* Tns.), a very promising species originating in Brazil and previously imported into Puerto Rico by the Federal Agricultural Experimental Station there. Adequate numbers were released during several years in both Louisiana and Florida.

None of these natural enemies of South American origin became established in Louisiana. There appear to be two reasons for the consistently unsuccessful attempts to establish parasites of the borer in that State. Cane is an annual crop and its complete removal in the autumn of each year creates conditions unfavorable for overwintering of the parasites. Further, the winter temperatures, with a minimum of 15°–20° F., are too severe to permit survival of the parasites. There appears to be little prospect of the successful utilization in the State of any of the more common parasites of the pest that are known to occur in the West Indies and Central and South America. It may be possible to find others that are adaptable to lower winter temperatures, but even if such are eventually found the cultural methods employed may prevent their increase.

The climate and cultural practices in southern Florida are much more favorable for parasite survival than those in Louisiana. *L. diatraeae* is now well established in the State, as is also *Agathis stigmaterus* (*122*), which had been included in small numbers in the shipments from Peru in the early 1930's. *Lixophaga* is the more abundant and effective. In 1941 the combined parasitization ranged up to 83 percent in a number of fields at Fellsmere.

The distribution of *Lixophaga* and *Agathis* in Florida is not yet complete, but the fields receiving the earlier releases have shown a marked reduction in the percentage of stalks injured by the borer. However, even in southern Florida the occasional frosty winter periods result in high mortality of the parasites and low parasitization the following season.

The outcome with *P. claripalpis*, the most promising of the Peruvian parasites imported and colonized in great numbers, was especially disappointing. Repeated recoveries were made in Florida, some up

to 50 miles from the nearest point of release, and samples showed 30 percent or more parasitization. It undoubtedly is established, though no observations on its field status have been made since 1945.

Repeated releases of the Amazon fly were made during several years, and field recoveries were made at a number of colonization sites during the season of release. Establishment was not effected.

During 1950 a rearing stock of an egg parasite of the genus *Telenomus* was imported from Trinidad. The releases totaled 6,220 in Louisiana and 2,000 in Florida. Field recoveries have not yet been made.

Importations of additional species are still being made in the hope of finding one or more that will be better adapted to conditions prevailing in the cane-growing areas of the United States than those that have been tested thus far.

For many years attempts have been made, not only in the United States but in several West Indian islands and South American countries, to control the sugarcane borer by the use of egg parasites of the genus *Trichogramma*. It was believed that their release early in the spring, when the pest population is low, and at the rate of about 5,000 to 10,000 per acre would give a high parasitization earlier in the season than would otherwise occur, and that this would prevent or reduce the buildup of the pest to destructive levels later in the season. Substantial reductions in infestations have resulted from this practice in Barbados and Peru. It may be mentioned that the methods of production of sugarcane in the continental United States differ from those of tropical countries. The cane is harvested at the end of each growing season, whereas in the Tropics the crop is permitted to grow for 18 to 24 months before cutting. This cultural practice obviously has a definite influence on parasite abundance. Large-scale field experiments (*95*) have shown that releases of as high as 45,000 *Trichogramma* adults per acre have no appreciable effect in reducing borer injury to cane under conditions prevailing in Louisiana. Very little difference was observed in the parasitization of the eggs in the release plots as compared with the check plots.

Alfalfa Caterpillar

(*Colias philodice eurytheme* Bdvl.)

The attempts to control the alfalfa caterpillar in California by the biological method represent the first effort in the United States to utilize and disseminate artificially a disease-producing virus. This virus, *Borrelina campeoles*, occurs in nature in California and is transmitted from larva to larva in several ways. Natural outbreaks of the disease occur sporadically, initiated by high population densities and other factors, and play an important part in controlling some infestations, but they cannot be depended on to occur with sufficient frequency to give satisfactory economic control.

Field tests were undertaken during 1948–51 (*141*) to determine whether outbreaks of the disease could be induced by the distribution of the virus material. Methods had been developed for obtaining the virus material, either by infecting and rearing larvae in the laboratory or by collecting dead and dying larvae in the field. The dead diseased larvae were blended into a thick homogeneous solution,

which, when applied in the field, was diluted sufficiently to give a polyhedral count of 50–100 million per milliliter. Application was by conventional ground equipment and by airplane.

Rapid and substantial reductions of the caterpillar populations were obtained as a result of these applications, and it was concluded that 5 gallons of virus suspension containing 10 million polyhedra per milliliter per acre was adequate to insure infection and to reduce the field population below economically injurious levels. One of the chief obstacles to general use of this method of control is the necessity for exact timing of the applications. Light infestations can be controlled by treatment when the larvae are in the third instar, whereas the heaviest infestations must be treated while the pest is still mostly in the egg stage.

Preliminary experiments have shown that *Bacillus thuringiensis* Berliner, originally obtained from larvae of the Mediterranean flour moth in Europe, may also be utilized in initiating outbreaks of disease in infestations of the alfalfa caterpillar (*139*). The suspension used in the early field tests contained 1 to 2 million spores per milliliter of diluent. Within 24 to 48 hours after application infection was general enough to kill large numbers of caterpillars. The test plots showed a reduction in population below an economic level. The bacillus is more rapid in its action than the virus, which requires 5 or 6 days, though the action does not appear to be quite so consistent. An added advantage in heavy infestations is that the integument of the diseased caterpillar is left intact; thus the dead insect drops to the ground without fouling the foliage. However, one disadvantage is that the foliage does not become contaminated with the bacterium, and consequently the later broods of larvae do not become generally infected. The effects of a single treatment are therefore not so long-lasting as those of the virus.

Since *B. thuringensis* can be grown on artificial media, its culture is more simple than that of the virus, which must be grown in the living insect. The bacillus can possibly be produced on a commercial basis at a cost approximating that of a chemical insecticide. The cost of application is the same, whether a bacillus, virus, or chemical is used.

The alfalfa caterpillar is also often heavily parasitized in the field by *Apanteles medicaginis* Mues. The existence of these three natural-control agencies, each of which is capable of controlling the pest under favorable conditions, has led to the development of an effective and economical program for control in the Dos Palos area of central California. This supervised program has two main objectives—the application of insecticides at the proper time and the withholding of such insecticide treatments when control by natural agencies is expected with some certainty. *Apanteles* often attains a high degree of parasitization, and its buildup in relation to the host population and stage of development usually can be predicted at the time of examination. The parasite is not adversely affected by the virus disease, as it matures in the young stages; whereas the host is killed by the disease mainly when nearly full grown.

In order to put this program into effect in the Dos Palos area, a cooperative pest-control association was organized and a field ento-

mologist employed. The area to be supervised was limited to approximately 9,000 acres, as it was essential that each field be examined at least once each week. In 1947, 30.5 and 11.4 percent of the fields at the fourth and fifth cuttings, respectively, were withheld from chemical treatment because of high parasitization. Fourteen percent of the fields were saved from injury without treatment during the third to fifth cutting periods and an additional 50 percent by high parasitization plus other factors.

Until recent years *A. medicaginis* was considered to be identical with the eastern *A. flaviconchae* Riley. However, the former is a solitary parasite and attacks only the young host stages, completing its development when the host is still only partly grown. *A. flaviconchae* is gregarious and is able to attack the host in any stage. In 1951 and 1953 rearing stocks of the latter were obtained from Maryland, and field colonization on a small scale was begun in California. It is anticipated that because of its habits this species may be more effective than *A. medicaginis*.

Pink Bollworm

(*Pectinophora gossypiella* (Saund.))

The pink bollworm, a highly destructive pest of cotton, is now nearly worldwide in distribution. It reached the United States in 1917 by spreading from Mexico. The eradication program that was conducted for many years, followed by an intensive control program, made it impracticable to undertake the importation of natural enemies until 1934. In that year a rearing stock of *Bracon kirkpatricki* (Wilkn.), a larval parasite recorded as being abundant in East Africa, was received from Egypt, and in the following year 3 additional species were obtained from the same country. Two species were then obtained from Hawaii and 3 species in 1938–40 from Korea. The search for additional parasites was started in South America in 1940, and during a 3-year period small consignments of 2 larval parasites were forwarded from Brazil. The imported stocks of the most promising parasites, mainly species of the genera *Bracon* and *Chelonus*, were supplemented by large-scale laboratory rearing, and large numbers were released in the infested area in Texas and in nearby infestations in Mexico, where conditions were believed to be more favorable for the parasites. None of the 11 species became established. The search for effective parasites was renewed in India in 1952.

The failure of these parasites to establish themselves may be attributed to several causes. From necessity, because of the restricted distribution of the pest, the releases were made in semiarid sections where cotton is grown in irrigated fields and where very few alternate host plants are available. Further, the cleanup program and the cotton-free period enforced as control measures eliminated a large portion of the hosts that would normally hibernate and of the parasites as well. Active stages of the pink bollworm suitable for parasitization are available during only a few months of the year. In the absence of alternate hosts on which to bridge the intervening period, the parasite colonies died out.

Bollworm

(*Heliothis zea* (Boddie))

Importations of natural enemies of the bollworm from Peru were undertaken in 1941 incident to the work on parasites of the boll weevil (*Anthonomus grandis* Boh.). An anthocorid bug, *Paratriphleps laeviusculus* Champ., had been found in Peru to be highly effective against another species of *Heliothis* on cotton, and it consistently destroyed a high percentage of the eggs. A total of 1,450 nymphs and adults of *P. laeviusculus* were forwarded to the United States during 1941, of which about 1,200 were released in bollworm infestations in Texas. The species did not become established.

Lima-Bean Pod Borer

(*Etiella zinckenella* (Treit.))

The investigations on the natural enemies of the lima-bean pod borer were begun in France in 1936, and shipments of material from that country and Hungary were made during 1936–38. They comprised 7 species of parasites that attack the larvae, of which *Bracon piger*, *Phanerotoma planifrons*, and *Chelonus inanitus* were received in the largest numbers. Releases were made both in lima bean fields and in wild growth of the tree lupine (*Lupinus arboreus* Sims), a favored native host of the pod borer.

Recovery collections were made for several years after the initial release, and these three species were found to be established in southern California. The development of the colonies and their spread have not been followed since that time, but there is little reason to believe that they have had any appreciable effect on the pod borer infestations.

Pea Moth

(*Laspeyresia nigricana* (Steph.))

The pea moth is a destructive pest of field peas in the Northwestern States, and biological control measures were undertaken against it in 1936 and the following years by the Washington Agricultural Experiment Station. Field releases of *Macrocentrus ancylivorus*, the highly effective parasite of the oriental fruit moth, were made in 1936, 1943, and 1945, but establishment was not attained. In 1944 collections of adults of *Ascogaster quadridentata* Wesm., *Glypta haesitator* Grav., and *Glypta* sp. were made in British Columbia, and colonies were released in Whatcom and Skagit Counties. These parasites had previously been imported from England by the Canadian Department of Agriculture and established on the pea moth in British Columbia. *Ascogaster* is a well-known parasite of the codling moth in North America, but does not attack the pea moth; whereas the strain imported into Canada was obtained from the pea moth in England. The two species of *Glypta* did not become established in Washington, but the imported colonies of *Ascogaster* persisted, and there was also a natural spread from Canadian sources into adjacent counties of this State.

Fall Armyworm

(*Laphygma frugiperda* (J. E. Smith))

A small number of parasites of the fall armyworm and of related pests were obtained in Uruguay in 1944. During this year a total of 947 puparia and 381 adults of the tachinid fly *Archytas incertus* (Macq.) were forwarded to the Everglades Experiment Station in Florida. Approximately 700 were released in the field, but establishment was not accomplished. The importations also included several thousand adults of a carabid beetle, *Calosoma argentinense* Csiki, which likewise failed to establish itself.

Imported Cabbageworm

(*Pieris rapae* (L.))

The imported cabbageworm is an introduction from Europe and first appeared in Canada about a hundred years ago. It spread so rapidly that practically all sections of the United States were infested within 25 years. The imported larval parasite *Apanteles glomeratus*, which became established in 1884, is now generally distributed and often effects a high parasitization. The same is true of *Pteromalus puparum* L., a gregarious pupal parasite, which had been previously introduced accidentally. In spite of the abundance of these two parasites, this cabbageworm is still a serious pest of cruciferous plants, and the parasites apparently have contributed little to its control.

Omnivorous Leaf Tier

(*Cnephasia longana* (Haw.))

In recent years the omnivorous leaf tier has become a serious pest of strawberry and several other truck crops in the Pacific Northwest and has been observed as a pest of flax in California. A survey of its natural enemies in France in 1950 revealed the presence of several promising braconid and ichneumonid parasites of the larvae. Importations were started in the summer of 1951, the rearing and colonization program being conducted by the Oregon Agricultural Experiment Station.

Potato Tuberworm

(*Gnorimoschema operculella* (Zell.))

The potato tuberworm not only is a pest of stored tubers but is destructive to the crop in the field in several parts of the United States. The initial stock of a polyembryonic larval parasite, *Copidosoma koehleri* Blanch., was imported from Chile in 1945 by the Imperial Institute of Biological Control to its laboratory at Riverside, Calif., and stocks were later turned over to the University of California for rearing and colonization in the State. A total of 1,700,000 adult parasites were released in southern California and 360,000 in the area about Norfolk, Va., during 1946–47. Little attempt has been made to

determine the fate of these colonies in California, although it is known that establishment was not effected in Virginia.

Range Caterpillar

(*Hemileuca oliviae* Ckll.)

The range caterpillar is a serious pest of native grasses in northeastern New Mexico, where destructive outbreaks occur periodically. One of the chief factors in its natural control is an egg parasite, *Anastatus semiflavidus* Gahan. Another egg parasite, *Ooencyrtus kuwanai*, a larval parasite, *Compsilura concinnata*, and three species of carabid beetles of the genus *Calosoma*, including *C. sycophanta*, were introduced from New England and colonized in considerable numbers during 1913–16, but none of them became established.

In 1930 a program was undertaken for the mass production (*77*) of *Anastatus* for field colonization in the hope that large-scale releases might aid in the suppression of the periodic heavy infestations. A production rate of 2 million parasitized eggs per month was attained, and during the following 2 years 6 million of these eggs were placed in infested areas. The results were inconclusive, however, and the program was eventually discontinued.

Alfalfa Weevil

(*Hypera postica* (Gyll.))

The search for natural enemies of the alfalfa weevil began in Italy in 1911, and in that and the following 2 years a large number of natural enemies, comprising at least 5 species that attack the eggs and 4 that develop in the larvae and 1 on the pupae, were imported and released in Utah (*18*). The larval parasite *Bathyplectes curculionis* alone became established as a result of releases at this time. Additional importations were made from Italy and France during 1925–28, resulting in the establishment of the egg parasite *Mymar pratensis*.

Dibrachoides dynastes (Foerst.), an external parasite of the prepupa and pupa, which was included in the 1911–13 releases, has since been collected in Utah, Oregon, and Washington. Although no recoveries were made in the seasons following the early releases, these findings may indicate establishment at that time rather than accidental introduction at a later date.

After the alfalfa weevil became established in the central valleys of California, a third importation program was undertaken, with special emphasis on egg parasites and predators to supplement the already established *Bathyplectes*. During 1933–36 many shipments were made to the University of California. They contained mainly *Peridesmia phylonomi* Gahan and *Spintherus* sp., but included also several newly discovered larval parasites of promise. They were liberated in the infested areas in that State, but did not become established.

The benefits of the importation program are due to *B. curculionis* alone, as the second species to be established, *M. pratensis*, is so rare on this host as to be of no value in control. *Bathyplectes* increased very rapidly after its release in Utah, and in the field the parasitization of weevil larvae infesting the first crop often exceeded 90 percent, in

fact many samples showed 100-percent parasitization. Such a rate of parasitization would normally be decisive in control of a pest, but complicating factors intervened. The first cutting of the alfalfa was made at an earlier stage of growth than previously. Under both conditions a very high percentage of the immature stages of the weevil, whether parasitized or not, were removed from the field or were killed by heat or lack of food immediately after cutting of the crop. With early cutting, a much smaller proportion of the weevil larvae attained the cocoon stage and consequently the kill was higher. A detailed account has been recently published (*86*) dealing with the combined effects of early cutting and *Bathyplectes* parasitization on the weevil populations in Utah. The parasite is unquestionably an important factor in control in that and adjoining States.

B. curculionis was introduced into California in 1933–34 after the spread of the pest to that State (*54, 104*). Economic control was attained in lowland middle California, and the infestations were reduced to an exceedingly low level. The parasite has not been so effective in the San Joaquin Valley, but climatic conditions there are not so favorable to the pest itself.

Clover Leaf Weevil

(*Hypera punctata* (F.))

The importation of natural enemies of the clover leaf weevil from Italy was incidental to the biological control project on the alfalfa weevil, a species of the same genus. The larval parasite *Biolysia tristis* was presumably released at or near Washington, D. C., in 1912 and became established. Recoveries were made at widely separated points in Virginia in 1932 and the following years. No information is available as to its effectiveness.

Boll Weevil

(*Anthonomus grandis* Boh.)

The first attempt to control the boll weevil of cotton by the biological method was in 1904, when 4,000 adults of the predaceous ant *Ectatoma tuberculatum* (Ol.) were imported from Guatemala (*30*) and released in 89 colonies in Texas. This predator did not become established, and nothing further was done until 1941, when importation of 2 larval parasites, *Bracon vestiticida* (Vier.) and *Triaspis vestiticida* Vier., was begun from Peru. Large numbers were received during 1941–45, and supplemented by stocks from the rearing program they were released at many points in Texas and Louisiana. In spite of apparently ideal conditions neither species became established.

Pepper Weevil

(*Anthonomus eugenii* Cano)

Since the pepper weevil is of the same genus as the cotton boll weevil, any parasite of one is likely to attack the other. The large-scale importation and rearing of boll weevil parasites from Peru by the Federal Bureau of Entomology and Plant Quarantine made it

possible to provide the University of California with colonies for release against the pepper weevil in that State.

In 1942–43 approximately 7,000 females of *Bracon vestiticida* were released in several infested fields of San Diego and Orange Counties. In spite of very favorable conditions for establishment and increase no field recoveries have been made.

Sweetclover Weevil

(*Sitona cylindricollis* Fahr.)

Because of the damage to sweetclover by the sweetclover weevil in the North Central States the importation of its natural enemies from France was undertaken on a small scale in 1948. Since that time small shipments of *Microctonus aethiops* (Nees) and *Campogaster exigua* (Meig.), both of which attack the adult beetles, have been forwarded to the North Dakota Agricultural Experiment Station for rearing and field colonization. Recoveries have been made the season of release, but it is not yet known whether either species is permanently established.

Legume Weevils

Weevils of the family Bruchidae attack many legume crops. A project was undertaken in 1935 for the importation of natural enemies from Europe, especially for control of the pea weevil (*Bruchus pisorum* (L.)), the broadbean weevil (*B. rufimanus* Boh.), and the vetch bruchid (*B. brachialis* Fahr.). One internal parasite, *Triaspis thoracica* (Curt.), was found in abundance in France and Austria. Large numbers were shipped to the United States during 1935–39, and a rearing program, which continued until 1942, provided additional stocks for field use. Field releases to the end of that year comprised more than 66,000 adults in Idaho against pea weevil infestations, 17,200 in Oregon against that pest and the vetch bruchid, 19,000 in California against the broadbean weevil, and 20,700 in Pennsylvania and 21,200 in North Carolina against the vetch bruchid. In addition, 2,320 adults of *Tetrastichus bruchivorus* Gahan, also of European origin, were released in North Carolina in 1939 against the vetch bruchid.

No field recoveries of *T. thoracica* have been made at any of the large number of colonization sites. Specimens of *Tetrastichus* were recovered at two release points in North Carolina in 1940, but none have been taken since then.

Vegetable Weevil

(*Listroderes costirostris obliquus* Klug)

The search for natural enemies of the vegetable weevil in South America revealed 4 species that attack the larvae, and they were imported from Uruguay and Argentina during 1942–45 (*115*). The most promising was a tachinid fly, *Epiplagiops littoralis* Blanch. The parasite material was shipped to the University of California station at Riverside, and releases of that species and of *Porizon argentinensis* Blanch., *P. parkeri* Blanch., and *Triaspis* sp. were made in infested fields in Orange County. These releases (*27*) totaled 7,319 adults of *E. littoralis*, which had been reared in the insectary from imported

stock, 1,271 weevil larvae parasitized by the 2 species of *Porizon*, and a small number of adult *Triaspis*. Difficulty was experienced in handling these parasites because of the reversed seasons in South America and California. Material assembled in October and November, which is spring in Argentina, arrived in California in late autumn. The tachinid parasite had no true hibernation period, so that it was impossible to hold it in storage until the time most favorable for colonization. So far as known, none of the species became established.

Asparagus Beetle

(*Crioceris asparagi* (L.))

The asparagus beetle is of European origin and has, since its initial establishment, spread to all asparagus-growing sections of the United States. The search for natural enemies was begun in France in 1939, and during that season 9,500 puparia and 17,825 host larvae parasitized by *Meigenia mutabilis* (Fall.), a tachinid fly, were forwarded to the United States. A total of 11 colonies, comprising 6,556 adult parasites, were released in infestations at several points in southern New Jersey during 1939. Recoveries were made of the first field generation at 7 colony sites, and several showed a high percentage of parasitization in the area of release. However, the parasite failed to persist through the winter. There is some indication that an alternate host may be necessary for permanent establishment.

In 1936 a small number of adults of an egg-larval parasite, *Tetrastichus asparagi*, which is native to the Eastern United States, were shipped from Ohio to Washington and colonized at Sumner and Orting. Establishment was effected readily, and in 1937 field collections of parasitized larvae were utilized in distributing the parasite to other points in the State. Increase and spread were rapid at all points. According to B. J. Landis, the parasite has been responsible for a marked reduction in the severity of the beetle infestations, though not to the point of full commercial control. Two colonies of *T. asparagi* were released in Orange County, Calif., in 1940, but establishment was not effected.

Mexican Bean Beetle

(*Epilachna varivestis* Muls.)

The Mexican bean beetle has spread during the past 30 years over most of the eastern half of the United States. The search for its natural enemies in Mexico began in 1922, when a tachinid fly, *Paradexodes epilachnae* Ald., was found to attack the larvae in the central and southern portions of that country. The field parasitization was frequently very high, at times 80 percent or more. Importations during 1922–23 and 1929–30 totaled 62,400 parasite puparia. A large-scale rearing program during 1930–35 produced 145,500 adult parasites, of which 82,000 were released in 85 localities in 19 States (*101*). Reproduction was rapid in many of these field colonies, with the bean beetle populations showing parasitization up to 90 percent within 2 or 3 months after the initial release. The parasite spread several miles during this period. In spite of this promising situation it did not be-

come established; in fact, not a single individual was recovered during the season after colonization.

A study of the biology of the parasite and of the bean beetle revealed the reasons for this disappointing outcome. In the United States the beetle passes its inactive season, from about October to May, as an adult hidden away in sheltered places, and no larvae are present during this period. The parasite has no obligatory hibernation period, and even in the pupal stage cannot survive the winter. The species is able to persist in its native habitat in Mexico because a few beetle larvae, or those of an alternate host, are present in the fields during the winter. The parasite is consequently able to breed throughout the year, though development is much retarded during the winter.

In 1940 another tachinid fly, *Lydinolydella metallica* Tns., was found attacking native species of *Epilachna* in Brazil. Shipments to the United States during 1940–43 totaled 15,746 parasite puparia. One colony of 182 adults was released at Matawan, N. J., in 1942, and 7 colonies, comprising 3,300 adults, were liberated in that section of the State in 1943. One small release was made at Beltsville, Md., the same season. Extensive recovery collections indicate that the parasite failed to become established.

Field tests have been conducted on the microbial control of the Mexican bean beetle (*51*) with the fungus *Beauveria bassiana*, the same organism tested on the European corn borer. The infested bean plots were treated with 1-percent spore dust (wheat flour as the carrier) at the rate of 20 pounds per acre in 2 applications 2 days apart.

Examination of the plots 14 days after completion of treatment showed that 2 carried a very low population of living stages of the beetle, with no plant injury evident, a third had a larger number of feeding larvae causing up to 10 percent of plant injury, whereas the untreated control plot carried a high population of all stages, with the plant injury estimated at 90 percent. For comparative purposes an additional plot was treated with 1 application of rotenone at 20 pounds per acre. Surviving bean beetles in various stages were several times more numerous than in the fungus-treated plots, and plant injury was estimated at 25 percent. This unfavorable outcome is attributed to heavy and frequent rains, which, on the other hand, provided optimum conditions for fungus development.

All stages of the bean beetle are highly susceptible to fungus attack. Laboratory tests showed some liquefaction of egg clusters within 18 hours after dusting and 100 percent after 72 hours.

So far as known no attempt has yet been made to test or utilize this method of control on a commercial scale.

European Chafer

(*Amphimallon majalis* (Raz.))

The European chafer was first found in western New York in the 1930's and is still limited to that State. Because of the potential destructiveness of the grubs to turf, similar to that by the Japanese beetle, a program for the importation of its natural enemies from Europe was undertaken in 1948. Two species of tachinid parasites, *Dexilla rustica* (F.) and *Microphthalma europaea* Egger, that attack

the grubs have been received from France and colonized in small numbers. They are not yet known to be established, but their importation, as well as that of other European parasites, is being continued.

Asiatic Garden Beetle

(*Autoserica castanea* (Arrow))

Several parasites of sericine grubs were imported from Japan, Korea, and China during 1927–34 (*23*, *79*), incident to the search for natural enemies of the Japanese beetle, but only *Tiphia asericae* became established. It was released in infestations of the Asiatic garden beetle and of *Serica similis* Lewis in several States. It is known to be established at several points in Pennsylvania, but has not increased sufficiently to have any effect on the beetle infestations.

Oriental Beetle

(*Anomala orientalis* Waterh.)

The natural enemies of the oriental beetle were imported from Japan and Korea during 1925–26 and 1932. The shipments comprised 8,800 cocoons of 5 species of *Tiphia*, of which 3 were colonized in various infested areas in several Northeastern States. None became established.

Sugarcane Beetle

(*Euetheola rugiceps* (Lec.))

Small importations of natural enemies of the sugarcane beetle and several other sugarcane pests were made from Puerto Rico during 1934, 1936, and 1943. The shipments of the first 2 years consisted of a grub parasite, *Campsomeris dorsata* (F.), and the giant toad *Bufo marinus* L., whereas the 1943 efforts were centered on a predaceous elaterid beetle, *Pyrophorus luminosus* (Ill.). In 1944 the United States Sugar Corporation imported *Bufo arenarum* Hensel and *B. paracnemis* Lutz from Argentina for release in southern Florida against white grubs, mole crickets, and other soil-inhabiting pests. *Campsomeris* was colonized only in Louisiana, but *B. marinus* has been repeatedly released in both States and in Texas. The predaceous beetle was likewise released in Florida and Louisiana, though in rather small numbers. None of these natural enemies have become established. Observations on the giant toad have been sufficiently extensive to indicate quite definitely that although it may persist for several years in southern Florida, it is unable to withstand winters with even occasional light frosts.

Black Grain Stem Sawfly

(*Cephus* (*Trachelus*) *tabidus* (F.))

The several species of the sawfly genus *Cephus*, including *C. tabidus* and *C. pygmaeus* (L.), are at times serious pests of wheat in New York, Pennsylvania, and the North Central States, whereas *C. cinctus* Nort. is the dominant species in the Western States. In 1930 and

the following years the Canadian Department of Agriculture imported and established a larval parasite, *Collyria calcitrator* (Grav.), from England for use mainly against *C. cinctus* and *C. pygmaeus*. Through the courtesy of that Department stocks were obtained from field collections in Canada for release in the United States. In 1935 a total of 11,700 adults were released at 3 points in Ohio and 9 in Pennsylvania. The 1936 releases numbered 10,340, and were made at 1 point in Ohio, 3 in Pennsylvania, and 1 in New York. In 1937 a colony of 900 was placed at Carlisle, Pa., and the following year a colony of 1,830 at Dover, Ohio. A field recovery was made in April 1938 at Carlisle at the site of the release of the preceding year, but the parasite has not been taken since and is presumed not to have become established.

Grasshoppers

(Acrididae)

Little effort has been made to control grasshoppers by the biological method, mainly because these pests, being native to the North American Continent, already have a full complement of parasites and predators attacking them, and there was little possibility of benefit from the introduction of additional species. However, 2 abortive efforts appear to have been made to import 2 species of *Sarcophaga* from Australia, the first by Albert Koebele in 1893 and the second by George Compere in 1900. Shipments were made, and one small colony was released in Livermore Valley, Calif., in the latter year (*53*).

In 1900 field experiments were initiated by the United States Department of Agriculture to determine the possibilities of controlling grasshoppers by means of a fungus imported from South Africa (*88*). This was presumably *Empusa grylli* (Fres.), though probably contaminated by other species. During that year cultures were sent to 169 farmers in 24 States for field tests. Sometimes a very high mortality was reported, but in general the results were inconclusive and the investigation was abandoned.

Hessian Fly

(*Phytophaga destructor* (Say))

The first attempt to import natural enemies of the hessian fly was in 1890–94, when shipments of *Pleurotropis metallica* adults and parasitized fly puparia were obtained from England. This effort was successful, and the species became established and widely distributed, but it had no appreciable effect in control of the pest (*87*). No further work was done on the problem until 1934, when importations from France began. From that year until 1939 small shipments of *Platygaster pleuron* Wlkr. and *Trichacis remulus* (Wlkr.) were made annually from France and Morocco. They totaled 1,158 specimens of *P. pleuron* and 3,336 of *T. remulus*. The field releases of *P. pleuron* comprised 641 adults in Pennsylvania and 202 in New York, whereas those of *T. remulus* were 77 in Pennsylvania, 427 in Virginia, and 1,523 in North Carolina. So far as known neither species became established.

Releases of *Platygaster zosine* Wlkr., a species already present in the Eastern States, were made in central California in 1922 and 1925, but establishment was not attained.

Squash Bug

(*Anasa tristis* (Deg.))

The squash bug is a serious pest of cucurbits, particularly squashes and pumpkins, throughout the United States. In the Eastern States it is heavily parasitized by a tachinid fly, *Trichopoda pennipes*, which is also an effective parasite of the southern green stinkbug (*Nezara viridula* (L.)) in the Southeastern States. Since this parasite was absent in infestations of the squash bug in the Northwestern States, parasitized bugs were collected in New Jersey and Connecticut during 1943–44, and 4,123 parasite puparia were forwarded to Washington and Utah. Total releases of adult flies at Wapato, Wash., in 1943 were 912, with an additional but unknown number the following year.

Parasitized squash bugs were observed in some numbers in the field during the late summer and the fall of 1943, and the field parasitization over a considerable area the following year was approximately 50 percent. Observations by B. J. Landis in 1951 showed parasitization of about the same extent. The squash bug is now only a minor pest in central Washington, and this reduction in severity of attack may, in part at least, be attributed to the parasite.

This parasite occurs throughout the United States, but appears to comprise several host-determined strains, each of which is limited in distribution to a definite section of the country.

Harlequin Bug

(*Murgantia histrionica* (Hahn))

Biological control work on the harlequin bug, a well-known pest of cruciferous plants, was undertaken by the University of California during 1941–42, when stocks of the egg parasite *Trissolcus murgantiae* Ashm. were obtained from Mississippi for field release. A total of 780 adults were released at several points in Los Angeles and San Diego Counties during the 2 seasons. The species became established, though it did not attain the abundance of another egg parasite, *Ooencyrtus johnsoni* (How.), already present in the State.

Chinch Bug

(*Blissus leucopterus* (Say))

During 1865 the attention of entomologists was first drawn to severe outbreaks of fungus disease among chinch bug infestations. In 1888 the distribution of diseased bugs was undertaken on a small scale in Minnesota, and from 1888 through 1896 a large-scale program was developed in Kansas. In 1891 an experiment station was established for the specific purpose of developing methods for the mass production of the fungus and for its distribution without charge to the farmers of Kansas. During 1888–96 between 40 and 50 thousand packages

of fungus material were distributed. Other States likewise developed distribution programs, including Illinois, Nebraska, Missouri, Ohio, and Oklahoma, though on a smaller scale.

The fungus was *Beauveria globulifera* (Speg.). Many conflicting claims were made regarding the results of the work. The studies in Kansas were more prolonged and conclusive than elsewhere, and a critical analysis of the work was published in 1911 *(8)*. It was concluded that the fungus was present in all fields in the infested area and in such great abundance that artificial distribution could be of no practical use. Where the fungus was not in evidence, outbreaks of the disease could not be induced by artificial distribution. Climatic conditions played a dominant role, and when they were favorable the production of spores and their distribution by the wind provided, unaided, for the initiation and development of outbreaks of the disease.

The outcome of this work with the chinch bug is often cited to support the belief that little can be hoped for in the utilization of disease-producing organisms in the biological control of insect pests. However, as Steinhaus *(138)* pointed out the conclusions cited apply only to the chinch bug, to the particular fungus, and to the general area in which the work was done.

Potato Psyllid

(*Paratrioza cockerelli* (Sulc))

The discovery in 1942 of an encyrtid, *Aphycus psyllidis* (Comp.), heavily parasitizing the potato psyllid on tomato in Orange County, Calif., led to a small-scale effort to establish it in the potato-growing section of the North Platte Valley in Nebraska, where the pest is often destructive. In June and July 1943 the University of California forwarded 4 consignments of the parasite, comprising about 700 adults, to the Bureau of Entomology and Plant Quarantine laboratory at Scottsbluff, Nebr. The first 2 lots were released nearby and the other 2 at Torrington, Wyo. Unfortunately 1943 was a season of low psyllid infestations, so that conditions for parasite release were not favorable. Recovery collections in 1944 failed to show establishment.

Beet Leafhopper

(*Circulifer tenellus* (Baker))

The beet leafhopper is a serious pest of beet in the Western States and of tomato in California, on both of which plants it acts as a vector of disease. The first investigations on its biological control were in 1917–18, when the California State Commission of Horticulture undertook the importation of natural enemies from Australia *(146)*. The shipments during 1918 consisted of boxed stems of saltbush (*Atriplex muelleri*) containing large numbers of eggs of a native leafhopper. These eggs were about 90 percent parasitized by *Pterygogramma acuminatum* Perk. and a species of Mymaridae. These two species were reared in California and tested on the beet leafhopper in field cages. No reproduction took place, and it was concluded that they were not adapted to this host.

The second search for natural enemies was in 1926–28, when the Federal Bureau of Entomology and Plant Quarantine in cooperation with the University of California undertook a survey in Argentina, Uruguay, and Mexico. No parasite importations were made as the leafhopper was not found.

In later years taxonomists concluded that the beet leafhopper was of European origin. Its distribution is now known to extend from the Mediterranean region to the Near East. In a survey of the Mediterranean countries by the University of California during 1951, *C. tenellus* and several other species of that complex were found in Egypt, Algeria, Spain, and other countries. One shipment of parasite material was forwarded from Tripolitania. Two egg parasites were reared from this material, and a colony of *Aphelinoidea anatolia* Now. was released in the San Joaquin Valley in September 1951.

In 1952 a joint project was initiated between the Bureau of Entomology and Plant Quarantine and the University of California for an intensive parasite-collection program in Spain and the North African countries from French Morocco to Egypt. The shipments from these countries, supplemented by insectary rearings, provided 214,100 adult parasites of 4 species of Mymaridae and Trichogrammatidae, all of which attack the eggs, for release in California, and smaller numbers were distributed in Idaho, Utah, and Arizona (*90*).

Because of the success in Hawaii and elsewhere in controlling other leafhoppers through the introduction of egg predators of the genus *Cyrtorhinus*, it had been hoped that a species of this group might be found that would be equally effective against the beet leafhopper. However, such a predator adaptable to the beet leafhopper and its environment has not yet been discovered.

Greenbug

(*Toxoptera graminum* (Rond.))

One of the earliest large-scale attempts to utilize a native parasite in the control of a crop pest was that on the greenbug, a destructive pest of wheat in Kansas. This work was undertaken by the University of Kansas in 1907 (*91*), and may be regarded as the forerunner of the mass colonization practices employed later with *Cryptolaemus* for mealybug control, *Hippodamia* for aphid control in vegetable fields, and *Macrocentrus* for the oriental fruit moth.

It had been observed that the parasite *Aphidius testaceipes* (Cress.) (=*A. tritici* Ashm.) appeared in the fields in controlling numbers in the spring or early summer only after the greenbug infestations had built up to damaging proportions. This situation was attributed to the inability of the parasite to withstand winter conditions in sufficient numbers, and it was believed that if active colonies could be placed in the fields early in the season their increase would prevent development of destructive aphid infestations.

Infested wheat plants showing high aphid parasitization were collected in the field in southern Kansas and northern Oklahoma, where the season is slightly earlier than in the most seriously affected areas of central and northern Kansas. A total of 8,932 boxes of this parasite material were distributed to almost every county in Kansas from

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April 17 to June 16. Inasmuch as each shipment was estimated to contain from 20 to 30 thousand parasites, the total amounted to several hundred million.

None of this work was conducted on a strictly experimental basis, and reliance was apparently placed mainly on farmers' reports. Published testimonials were enthusiastic as to the outcome, and many farmers reported complete control within a few days or a week or two after receipt of the parasite colonies. These reports of course could not be true, but indicated instead that, with favorable conditions, the existing parasite populations in the field developed with startling rapidity, which they are capable of doing, and quickly brought the outbreaks under control.

Farmers in general are eager to believe in the efficiency of biological control, as it relieves them of using other more laborious and costly methods. However, this enthusiasm often leads them to overlook or ignore the evidence that is available. On other projects reports have repeatedly been received of complete control after the release of parasites or predators, even though thorough observations by competent entomologists showed that they had not even become established. The subsidence of the pest infestations had been due to other unrelated factors.

Studies on the influence of climate on the greenbug and its parasite have shown that temperature is one of the dominant factors and that the greenbug can reproduce at appreciably lower temperatures than are required by the parasite. It is thus inevitable that the infestations should build up in the spring well in advance of the parasite, especially during cool, damp seasons. The parasite, because of its temperature requirements, is not fully adapted to its host, and no means are available whereby this deficiency can be overcome or alleviated.

Yellow Sugarcane Aphid

(*Sipha flava* (Forbes))

The yellow sugarcane aphid is a minor pest in southern Florida and other Gulf Coast States. In Puerto Rico it is often heavily attacked by a coccinellid beetle, *Coelophora inaequalis* (F.), and this species was imported into the United States in 1939. Releases of 1,367 adults and larvae were made in Florida, Georgia, and Louisiana, but establishment was not attained.

Miscellaneous Aphids

A large though uncertain number of species of aphid-feeding Coccinellidae were imported by Koebele from Australia, New Zealand, and Tasmania into California during 1889–93, but none became established. The only species of foreign origin now established in the United States is *Leis dimidiata 15-spilota*, which was obtained from China in 1924. It failed to become established in California, but has done very well in Florida. It has shown a strong preference for the aphids and whiteflies occurring on papaya and citrus, and is

believed to contribute appreciably to the control of the citrus aphid in some localities.

For many years much attention was given to the control of aphids attacking truck crops by the release in infested fields, early in the season, of large numbers of native coccinellid beetles. The species utilized in this work has been almost entirely *Hippodamia convergens* Guér., which is the most common of the aphid-feeding species of the family in many parts of the United States. It hibernates in very compact and large colonies, some comprising 50 to 60 gallons of beetles, in mountain valleys and canyons, and consequently it can be collected in almost unlimited quantities at a low cost (*16*).

For many years, since about 1910, the California State Commission of Horticulture collected these beetles by the ton and distributed them free to vegetable-crop growers of the State, the greatest portion going to melon growers in the Imperial Valley. More recently several attempts have been made to utilize them on a large scale against the pea aphid (*Macrosiphum pisi* (Harris)) in the Eastern States and against the greenbug in the Middle West. However, in tests on the melon aphid (*Aphis gossypii* Glov.) in the Imperial Valley (*36*) little or no benefit resulted from this practice, as the beetles dispersed very widely immediately after release. Also, a native population was always present in all localities, and the beetles appeared in the fields as soon as the aphid infestation became sufficient to maintain them and to permit of extensive reproduction. For these reasons growers are advised against placing any reliance on them when released, even in large numbers, in the early spring, but to utilize the more dependable chemical control methods that are now available. Sometimes growers who have purchased quantities of beetles have failed to obtain the expected control and have delayed the use of other measures until serious damage has been done to the crop.

Rhodes-Grass Scale

(*Antonina graminis* (Mask.))

The Rhodes-grass scale, a pest of range grasses, has become exceedingly destructive in southeastern Texas in recent years and is spreading rapidly. It attacks not only Rhodes grass (*Chloris gayana*) but several other valuable grasses. Thousands of acres of excellent stands of Rhodes grass have been completely destroyed. Since it is improbable that this pest can be controlled economically with insecticides, it was especially urgent that the possibilities of biological control be investigated immediately. One internal parasite, *Anagyrus antoninae*, was known to occur in Hawaii, and in these islands the scale, although frequently seen, is a minor pest. Rearing stocks of the parasite were imported early in 1949, and since that time it has been reared and released in large numbers by the Texas Agricultural Experiment Station (*119*). Even though establishment has been attained at several points, it is not yet known to what extent it will be able to control the pest. Additional parasite species are being imported from other parts of the world.

Sugarcane Mealybug

(*Pseudococcus boninsis* (Kuw.))

The sugarcane mealybug is one of the less important pests of sugarcane in the Southern States, and is considered to be injurious principally in the sections where cane is grown for sirup production. The body fluids of the mealybugs cause a discoloration of the product. *Aphycus terryi* Full. was imported from Hawaii into Louisiana in 1932 and was thought to have become established during subsequent years. Colonies from Louisiana field collections were released in infested fields in Georgia and Florida. However, it developed later that the material distributed was of another but similar species, *Pseudaphycus mundus* Gahan, which presumably is native on another host or is an accidental introduction. It became established and abundant in a number of localities in which releases were made. The true *A. terryi* is not known to be established.

Two-Spotted Spider Mite

(*Tetranychus telarius* (L.) (=*T. bimaculatus* Harvey))

Field tests were conducted on the control of the two-spotted spider mite, a pest of bush beans, with the fungus *Beauveria bassiana* (*51*). A 0.5-percent spore dust was applied during a period of high temperature and relative humidity as well as some rainfall. A kill of 71.1 percent was observed in 5 days. The control plot showed a mortality of 25.5 percent, much of which may have been due to fungus contamination from the treated plots. The results of these tests suggest the desirability of similar experimental studies on other mite species that offer troublesome control problems, especially in areas having climatic conditions that are favorable to fungus development.

INSECTS AFFECTING FOREST, SHADE, AND ORNAMENTAL TREES AND SHRUBS

The most important projects for the biological control of forest- and shade-tree insects, in which some success has been attained, are those relating to the gypsy moth, brown-tail moth, and satin moth. Substantial benefit has resulted from the work on these three pests, though falling short of full control. On less important pest species, such as the oriental moth, definite benefit has likewise occurred.

Gypsy Moth

(*Porthetria dispar* (L.))

The project for the biological control of the gypsy moth, a destructive enemy of forest- and shade-trees, which became established in New England about 1869, has been one of the most extensive activities in this line in the United States. The large-scale importation of natural enemies from Europe and to a lesser extent from Japan from 1905 to 1914 was renewed in 1922–33 (*14*, *89*). During these years of active foreign work more than 40 species of parasites and predators were imported and colonized. Of these, 9 parasites—2 egg, 6 larval, and

1 pupal—and 2 predators have become established. Up to 1927 a total of approximately 92 million parasites had been released, the great bulk being of the 2 egg species, which were reared or collected from established colonies in enormous numbers for redistribution.

The egg parasites are *Anastatus disparis* and *Ooencyrtus kuwanai*, the first coming from Europe and Japan and the second from Japan only. *Anastatus* is generally established in all infested sections of New England and *Ooencyrtus* throughout the southern portion of the host range. The combined parasitization by the 2 species reached its peak in 1921–24, when it averaged 20–27 percent, but for a time thereafter it declined to less than 10 percent. However, recently these egg parasites have again become as abundant as in 1921–24.

Among the larval parasites, *Compsilura concinnata*, *Blepharipoda scutellata*, and *Apanteles melanoscelus* are the most effective. *C. concinnata* is now widely distributed and often parasitizes 40 percent or more of the gypsy moth larvae, and it is of equal or greater importance as an enemy of several other lepidopterous pests. *B. scutellata*, which emerges from the host pupae, frequently attains a parasitization of 70 percent or more, and an average for all collections of up to nearly 50 percent in some seasons. *A. melanoscelus* ranks third among the larval parasites and, although unusually variable in the extent of its attack, each of its 2 broods often parasitizes 20–30 percent of the larvae. These species were already abundant when the infestation at Pittston, Pa., was found in 1932. *Exorista larvarum* and *Parasetigena silvestris* also show promise of contributing to the control of the pest.

Other established parasites of lesser importance are *Phobocampe disparis* and *Monodontomerus aereus*.

Sturmia inconspicua (Meig.) *(148)*, a promising tachinid parasite from central Europe, was introduced and colonized during 1906–11 and 1923–28. At least one colony from the later releases in Massachusetts persisted for several years, but failed of permanent establishment. This may have been due to the lack of a suitable alternate host for the overwintering generation.

The carabid predator *Calosoma sycophanta* is one of the most important natural enemies of the gypsy moth. It attacks both the larvae and pupae, and field observations have shown that it is abundant in many localities. It destroys an appreciable proportion of the insect pests.

Another important agency in control is a wilt, or polyhedral virus disease *(80)*, recently determined as *Borrelina reprimens* Holmes, which first appeared in New England in 1907. It is common in Europe and probably reached the United States among the large numbers of caterpillars imported in the parasite-introduction program. It assumes epidemic proportions only in heavy infestations, which are often almost completely destroyed.

It is exceptionally difficult to determine the influence of natural-control factors on an insect such as the gypsy moth, which is subject to wide and frequent changes of population levels. It is believed, however, that the combined effect of the parasites and predators has given appreciable control. Instead of occurring frequently in epidemic form and for extended periods, the gypsy moth outbreaks are now

reduced so that they are comparable in range and severity to those occurring in Europe.

Brown-Tail Moth

(*Nygmia phaeorrhoea* (Donov.))

Large-scale importations of natural enemies from Europe for the biological control of the brown-tail moth were made from 1905 to 1911, concurrently with the work on the gypsy moth, and during that period 20 or more species of parasites and predators were received and colonized (*14, 89*).

Seven species of parasites became established on this pest in the infested areas of New England, the most effective of which are *Apanteles lacteicolor* and *Townsendiellomyia nidicola*. *T. nidicola* parasitizes, on an average, 10–20 percent of the hibernating larvae, whereas in some years *lacteicolor* may destroy 20–30 percent. *Carcelia laxifrons* attained a general field parasitization of about 23 percent by 1916, but declined thereafter to less than 5 percent; so for many years it has been of minor importance. *Meteorus versicolor* is also generally established, but the field parasitization is consistently low. *Euplectromalus nidulans*, which attacks both larvae and pupae and is also hyperparasitic through several Braconidae, is likewise of little value in field control. The pupal parasite *Monodontomerus aereus* is considered to be more important as a secondary parasite, through several Tachinidae, than in its primary capacity on the brown-tail moth. However, in most seasons it is not sufficiently abundant to be of importance in either role.

It has not been possible to evaluate the effectiveness of the imported parasites and predators of the brown-tail moth, and no effort was made to do so. However, for many years since the establishment of the parasites the moth has been of little consequence in New England, with no serious outbreaks, and it is reasonable to credit the parasites with a substantial role in bringing about that situation.

During 1908–11 a series of experiments were conducted in Massachusetts with a disease-producing fungus in the field control of the brown-tail moth (*134*). The fungus was *Entomophthora aulicae* Reich., which is well known in Europe and has occurred commonly on this host in New England for many years.

Several methods were employed for the distribution of the fungus, including a water suspension of spores, but most of the releases comprised infected caterpillars. They were released in the field during May or August and September, 20 to 30 such larvae comprising a colony, which was placed on the tree in or near a brown-tail web. Colonies were distributed in more than 100 localities in Massachusetts and in one locality in Maine. The results of the field tests were variable, yet it was concluded that, under favorable conditions, the fungus could be depended on to kill 60–100 percent of the caterpillars in the treated areas. The lack of dependability of this method of control, presumably associated with adverse climatic conditions, prevented its general adoption, and the experimental work was finally discontinued.

Satin Moth

(*Stilpnotia salicis* (L.))

As a result of importations of parasite material from central Europe during 1927–34 for use in the biological control of the satin moth, *Apanteles solitarius* and *Meteorus versicolor* have been established in the United States (*97*). In addition, *Compsilura concinnata* and *Euplectromalus nidulans*, originally imported against other insects, have proved useful against this pest.

A. solitarius is the most important of these species, and many field collections of overwintering host material, both in New England and Washington, show a parasitization up to 60 percent or more. *M. versicolor* from brown-tail moth stock did not become established on the satin moth in New England, but occurred in abundance in Washington after the importation from Europe of stock from the satin moth during 1932–34 and its release in the State. Field parasitization ranged up to 50 percent, and many infestations were quickly reduced to a noninjurious level. *C. concinnata* at times also attains a high parasitization, often amounting to 50–70 percent in areas where alternate hosts are sufficiently abundant to carry it through periods when satin moth larvae are not available. In recent years *E. nidulans* has become of increasing importance as an enemy of this pest in New England. The decline of moth infestations in New England and the satisfactory control in Washington are attributed to the effectiveness of these parasites.

Oriental Moth

(*Cnidocampa flavescens* (Wlkr.))

The oriental moth, not to be confused with the oriental fruit moth, occurs in a small area in Massachusetts centering about Boston, and is of minor importance as a pest of several shade and ornamental trees. The first attempt to introduce parasites for its control was in 1917–18, when the Massachusetts Agricultural College received several shipments of cocoons from China (*56*). They yielded a number of *Chrysis shanghaiensis* Sm. adults, which were released in the infested area. Recovery collections early in 1919 showed a parasitization of 6 percent, but the parasite has not been taken since then.

The major parasite of the oriental moth in Japan, *Chaetexorista javana*, increased very rapidly after its importation and initial colonization in Massachusetts in 1929–30 (*48*), and reduced the infestations to a noninjurious level. However, the periodic extremely low winter temperatures of that area, such as occurred during 1933–34, are very detrimental to the parasite. It passes the winter as a young larva within the body of the caterpillar in its egglike cocoon, and these low temperatures cause a high mortality of the parasites without a corresponding effect on the hosts. The parasitization of the host brood the following season is consequently low, and the pest population builds up accordingly. However, the parasite quickly increases and soon brings the pest again under control. A similar decline in effectiveness, followed by rapid recovery, must be anticipated at intervals in the future.

European Pine Shoot Moth

(*Rhyacionia buoliana* (Schiff.))

The European pine shoot moth was first found in the United States in 1914, and is now a serious pest in nurseries and plantations and on ornamentals in many of the Northeastern States. The search for its natural enemies in Europe, the region of origin of the pest, was begun in 1931 (*49*). From that year until 1937 large-scale shipments, comprising 15 or more species of parasites, were sent to the United States, mainly from Austria, but some from Holland and England. Two larval parasites, *Cremastus interruptor* and *Orgilus obscurator*, and a pupal parasite, *Tetrastichus turionum*, have become established as a result of this work. Recoveries of each species have been made at release points in several Northeastern States, but no information is available regarding their abundance, spread, or effect on the host infestations.

Pine Tip Moth

(*Rhyacionia frustrana bushnelli* (Busck))

The control of the pine tip moth in a large artificial planting of pine in Nebraska is an interesting example of the utilization of native parasites. The infestation there became so heavy that planting of yellow pine, the favored host, was discontinued. Several species of parasites obtained from Virginia were released in 1925 (*6*), and one, *Campoplex frustranae* Cush., became established. Within 4 years the parasitization was about 80 percent, and the injury to the terminal shoots declined from over 90 to 15 percent. This control has persisted, but unfortunately has been masked by the increase of another species of tip moth, which is not attacked by *Campoplex*.

Larch Casebearer

(*Coleophora laricella* (Hbn.))

The larch casebearer is of European origin, and now occurs throughout the range of its host in the eastern half of the United States. Importations of large numbers of its natural enemies from central Europe, numbering 11 or more species, were undertaken in 1932–37. Two of these species are known to be established—*Chrysocharis laricinellae* at one or more points in Maine, New Hampshire, Vermont, and New York and *Agathis pumilis* in Maine, New Hampshire, New York, and Michigan (*49*). The progress of these colonies has not been followed closely, and their effect on the host infestations is therefore uncertain. However, it is known that both species effect a high parasitization in Maine and New York, and they are credited with reducing the host infestations in adjacent areas in Canada.

Elm Leaf Beetle

(*Galerucella xanthomelaena* (Schr.))

The importation of natural enemies for the control of the elm leaf beetle was begun in 1907 when beetle eggs parasitized by *Tetrastichus xanthomelaenae* Rond. were received from France. Many thousands

of these eggs were imported during 1907–8, 1917, and 1933–35 from various countries of Europe, and the parasites reared from them were widely colonized in the Eastern States. Another species of the genus was obtained in Japan in 1934, 1936, and 1938, and more than 14,000 adults were released in central California. These 2 species are not known to be established.

In 1934–35 large-scale importations were made of the tachinid parasite *Erynnia nitida* from France for colonization in New England, but establishment was not accomplished. A small consignment sent to California in 1939 resulted in establishment and widespread distribution (*63*). One consignment of a carabid parasite, *Lebia scapularis* Fourc., was released in New England, but failed to maintain itself.

A pupal parasite, *Tetrastichus brevistigma*, which is native to the Eastern United States, was forwarded to the University of California in 1934 for colonization in that State. It quickly became established and is now abundant in the infested areas.

Although none of the imported parasites were able to maintain themselves in the Eastern United States, the establishment of *E. nitida* and *T. brevistigma* in California was followed by a high parasitization, especially by *Erynnia*, but not sufficient to prevent the occasional defoliation of elm trees in the Central Valley areas. The injury is not nearly so general or destructive as occurred prior to the establishment of the parasites.

Southern Pine Beetle

(*Dendroctonus frontalis* Zimm.)

The serious injury to forest trees by bark beetles led to studies on biological control at an early date. In 1892–93 A. D. Hopkins, of the West Virginia Agricultural Experiment Station, conducted investigations in Germany and noted that a predaceous clerid beetle, *Thanasimus formicarius* (L.), was abundant and appeared to be of value in checking the pest. A total of 6,098 adult beetles and larvae were shipped to West Virginia during 1892–94, and 2,200 were released in the forests of that State. No field recoveries have ever been made.

Birch Leaf-Mining Sawfly

(*Heterarthrus nemoratus* (Fall.))

The birch leaf-mining sawfly is an accidental introduction from northern Europe, and now causes serious injury to birch in the Northern New England States and New York. A large number of parasite species were introduced from central Europe during 1930–34 (*47*). Two of them, *Chrysocharis laricinellae* and *Phanomeris phyllotomae*, have become established. The first has maintained itself at one or more points in Maine and New Hampshire, and *Phanomeris* has been recovered only in Maine (*49*). Their progress has not been followed in recent years.

European Spruce Sawfly

(*Diprion* (*Gilpinia*) *hercyniae* (Htg.))

The European spruce sawfly first appeared in the United States in 1929, when it was found in New Hampshire, the infestation probably

spreading from Canada. In that country a very destructive outbreak developed on the Gaspé Peninsula in 1930, rapidly extending the area of heavy defoliation and death of trees westward and southward during the following years. An extensive biological control program was undertaken by the Canadian Department of Agriculture, with large-scale importations of natural enemies from Europe and a few from Japan from 1933 to 1939. A pupal parasite, *Dahlbominus fuscipennis*, was reared and distributed by the millions, and it and a number of additional species became established.

Heavy infestations of the sawfly began to develop in Maine, New Hampshire, and Vermont in 1937 and caused much concern over the possible destruction of the spruce forests of New England and New York. Through the courtesy of the Canadian Department of Agriculture large stocks of 16 parasite species were obtained and released during 1935–41. The pupal parasite *D. fuscipennis* was reared and distributed in enormous numbers by the Maine Forest Service and the Federal Bureau of Entomology and Plant Quarantine. It is the only parasite to become well established.

In the early 1940's the sawfly infestations in both Canada and the United States subsided sharply, apparently owing to an epidemic virus disease of the larvae. This development, of course, has been independent of the parasite-introduction program; consequently, it has not been possible to evaluate the effectiveness of the latter in the United States.

Larch Sawfly

(*Pristiphora erichsonii* (Htg.))

Attempts have been made to establish the larval parasite *Mesoleius tenthredinis* Morley on the larch sawfly at several points in the United States. This parasite was established in Canada through importations from England, and was credited with aiding materially in checking the pest. Small shipments were received from Canada in 1912 for release in Michigan, in 1929 for Massachusetts, and in 1931 for New Hampshire and for further colonization in Massachusetts.

So far as known none of these releases resulted in establishment, but in recent years the parasite has been collected in Montana, Minnesota, Wisconsin, Michigan (*46*), and Pennsylvania. These establishments are attributed to natural spread from Canada.

Pine Sawfly

(*Neodiprion sertifer* (Geoff.))

The pine sawfly, of European origin, was first recorded in New Jersey in 1925 and has since become established in several other States. Severe defoliation of several species of pines occurred in the New Jersey infestations. During 1935 and the following years, when a biological control project on the spruce sawfly was undertaken, colonies of a number of European parasites, obtained from the Canadian Department of Agriculture, were reared and released by the New Jersey Department of Agriculture in pine sawfly infestations. They included *Dahlbominus fuscipennis* and *Aptesis basizonia*. Both species are known to be well established on this pest in New Jersey, though

the recovery surveys have not been sufficiently extensive to give detailed information on their abundance or influence in control of the pest infestations.

Barnacle Scale

(*Ceroplastes cirripediformis* Comst.)

The barnacle scale and the Florida wax scale (*Ceroplastes floridensis* Comst.) are pests of ornamental plants in the Gulf States. Several shipments of parasite material were received from Italy in 1895 and the following years, and releases of the egg predator *Scutellista cyanea* were made at Baton Rouge, La., in 1898. Observations in 1906 and 1923 showed that *Scutellista* was abundant on both species of *Ceroplastes*, but nothing is known regarding its effectiveness. Probably the same situation exists as with the black scale in California, where it was found that the larva of *Scutellista* usually does not consume all the eggs in the host egg chamber, so that a high percentage of attack has little or no effect in reducing the infestations.

European Elm Scale

(*Gossyparia spuria* (Mod.))

The European elm scale is distributed throughout the United States. The elm trees, so generally used for park, street, and garden planting, are rendered unsightly by the heavy deposits of honeydew in which the fungus causing sooty mold grows profusely. Young trees if heavily infested may be killed.

Parasite material imported from Italy in 1939 and from France in 1949–53 was utilized for rearing and colonization in California. The parasites comprised *Coccophagus gossypariae* Gahan and *Trichomasthus cyanifrons* Dalm. One colony of *C. gossypariae* was released at Los Gatos, Calif., in 1939 and others at San Jose, Sacramento, Pasadena, Redlands, and other localities during 1949 and the following years. Recovery collections at Redlands in 1951–53 from 1949 releases revealed establishment of the species (74). In fact the scale almost disappeared from the trees on which the parasites had been placed, and dispersion extended for some distance. Establishment was not effected at any other release sites. Failure of establishment in other localities may be due to the need for the males to develop as parasites of the female larvae of their own species. This reproduction habit makes necessary repeated releases at proper intervals to provide conditions suitable for the development and the perpetuation of both sexes.

For many years there has been confusion regarding the identity of the *Coccophagus* species attacking the European elm scale. The form in Europe has generally been listed as *C. insidiator* (Dalm.), whereas that occurring commonly in the Eastern States is identified as *C. gossypariae*. Taxonomists who have recently examined specimens from both sources agree that they are the same.

Releases of *T. cyanifrons* were made in several localities in southern California in 1949 and recoveries were made 2 months later, but the species did not persist.

Nigra Scale

(*Saissetia nigra* (Nietn.))

The nigra scale was an important pest of ornamental shrubs and plants in California prior to its control by the biological method. This was accomplished by the University of California incident to the large-scale program for the control of the black scale on citrus. The introduction of *Aphycus helvolus* from South Africa for control of the latter pest was highly successful, but was even more so in the case of the nigra scale. Field releases on the latter were relatively few, and most infestations were invaded by parasites dispersing from citrus groves in which *A. helvolus* had been released. The field control by *A. helvolus* throughout southern California was rapid and complete (*133*), and the infestations have been held at a consistently low level since 1938. Several imported species of *Coccophagus* have established themselves on this host, though they have not contributed appreciably to its control.

MISCELLANEOUS INSECT PESTS

Horse Flies

(*Tabanus dorsifer* Wlkr. (=*T. hyalinipennis* Hine))

The tabanid flies are serious pests of cattle and horses in Texas and other Southern and Southwestern States. The most abundant species in Texas is *Tabanus dorsifer*, which deposits its eggs in masses on stones projecting from rapidly flowing water. In some sections these eggs are heavily parasitized by *Telenomus emersoni* (Gir.).

For several years, beginning in 1914, an attempt was made to reduce the numbers of these flies by collecting quantities of eggs in localities where they were known to be heavily parasitized and colonizing them in other sections where the parasite was absent or scarce (*117*). These egg masses were set out in cages that permitted the parasites to escape, but prevented the newly hatched fly larvae from doing so. In 1914, 10 to 12 gallons of egg masses, representing 20 to 25 million eggs, were collected in 1 locality in Texas; they were so abundant that 1 collector could obtain about 2 million per day. Observations the following season indicated a reduction of approximately 50 percent in the fly population where the eggs had been collected, as compared with areas where no collections had been made, and a marked reduction where the releases were made. It was concluded that this was a practicable means of reducing horse fly infestations under certain climatic and physical conditions. However, this conclusion must be regarded as only tentative, as the experiments covered only a single season and were not checked sufficiently to determine accurately the results of the releases.

Blow Flies

Blow flies of the genera *Sarcophaga* and *Phaenicia* (*Lucilia* sens. lat.) are serious pests of livestock in the Southwest. A native parasite,

Alysia ridibunda Say, was found to attack the puparia of these pests in certain areas, but was not of general distribution. A program was undertaken in 1933 (*102*) for the rearing and colonization of the parasite in Uvalde County, Tex., where it was not known to occur. A total of 50,221 adults were released, in colonies averaging about 80 individuals, during late 1934 and early 1935.

Recovery collections made during the summer of 1935 near a number of release sites showed an average parasitization of 37.1 percent. The parasitization declined sharply thereafter, and in 1937 and 1938 only occasional individuals could be recovered.

Laboratory tests showed that *A. ridibunda* was unable to complete its life cycle on *Callitroga hominivorax* (Coq.), the most common and injurious blow fly in the Southwest, or on *C. macellaria* (F.), a related species that occasionally produces myiasis in sheep.

European Earwig

(*Forficula auricularia* L.)

Biological control of the European earwig was undertaken in 1924 as a result of heavy infestations developing in the Pacific Northwest, especially in the area about Portland, Oreg. The parasite material was imported by the Federal Bureau of Entomology and Plant Quarantine from England, France, and Italy, and comprised two tachinid species, *Bigonicheta setipennis* and *Racodineura antiqua* (Meig.). The rearing and colonization work (*108*) was first handled at a laboratory established in 1924 by the Oregon Agricultural Experiment Station. The project was then conducted by the city of Portland for a number of years and was finally transferred back to the experiment station in 1930. During 1925–29 large numbers of these parasite species were received, reared, and colonized in Portland and the surrounding area. Special attention was given to *Bigonicheta*, and it became established as a result of these releases.

In 1931 the Bureau of Entomology and Plant Quarantine undertook an extensive importation, rearing, and colonization program with the objective of distributing the parasites to all infested States. The importations, comprising both species of parasites but with special emphasis on *Racodineura*, were made in 1931 and 1938–39. Field releases in 1938–41 totaled 94,450 parasitized earwigs and an unrecorded number of adult female parasites. *R. antiqua* again failed to become established, though occasional field recoveries were made. Rearing, colonization, and recovery studies of *Bigonicheta* continued through 1940.

B. setipennis is generally established in the area about Portland and throughout Washington, as well as in Idaho and Utah. The earwig is subject to such wide fluctuations in population because of climatic and other conditions that it is difficult to appraise the status of the parasite. It is abundant in a number of localities and has spread widely, but detailed information is lacking as to its influence on the pest infestations. According to C. W. Getzendaner of the Bureau, who was in charge of the later phases of the work, the infestations have subsided in several localities.

Rocky Mountain Wood Tick

(*Dermacentor andersoni* Stiles)

The biological control of the Rocky Mountain wood tick, a highly important vector of several human disease organisms, was undertaken in 1926, when the encyrtid parasite *Hunterellus hookeri* How. (=*Ixodiphagus caucurtei* du B.) was imported from France by the Montana State Board of Entomology. In the following years it was reared and distributed widely in Montana, Idaho, and adjoining States by that organization and by the United States Public Health Service (*31*). During 1927–32 the releases in the Bitterroot Valley and other parts of Montana alone totaled 4,158,600 adults.

Prior to the synonymizing of the American and European forms by A. B. Gahan in 1934 and before its introduction from Europe, *H. hookeri* had been recorded from a number of widely separated points in the United States, though not from the Rocky Mountain area. The populations now existing in that area may be derived entirely from the imported stock, though this of course cannot be proved. The parasite is not known to be sufficiently abundant to effect any appreciable reduction in the tick infestations. It attacks several genera and species of ticks in addition to the Rocky Mountain wood tick.

Several attempts have been made to establish *H. hookeri* on the American dog tick (*Dermacentor variabilis* (Say)) and other species in the Eastern States. One colony of European origin released in 1926 persisted on the Elizabeth Islands, Mass., for at least 12 years, and another released on Capers Island, S. C., in 1929 apparently became established. In 1937–39, 91,000 adults and a large number of parasitized American dog ticks were released on the island of Martha's Vineyard, Mass., but no field recoveries were made in the following years.

THE ESTABLISHED PARASITES AND PREDATORS

In the following pages is a brief account of the importation, colonization, recovery, and effectiveness in the field of each of the 95 species of parasites and predators (pp. 4–8) that are now established in the continental United States. The principal features in the biology and habits of each species, where these are known, are included. However, many of the species were introduced and established without detailed study beyond determination of their host relationships.

Agathis diversus (Mues.) (Braconidae)

Agathis diversus, a parasite of the oriental fruit moth, was imported from central Japan during 1933–36 (*82*), the total number of adults being approximately 1,360. Some of them were utilized for insectary rearing, and 20,800 were produced during 1934 and 1935. The first releases were made in New Jersey and Pennsylvania in 1933, and the colonization program of the following 2 years covered the States from Connecticut to Michigan and southward to North Carolina. The first field recoveries were made at 4 points in New York in 1935 from releases of the same season. However, these colonies did not persist. A number of colonies in other States and in later years showed considerable promise, with rates of parasitization in excess of 20 percent

of the larvae in peach twigs, but the parasite population always declined and the colonies apparently died out. Large-scale rearings of fruit moth larvae from peach twigs and immature peach drops during 1939–47 failed to yield a single specimen of *diversus*.

Recent observations (*3*), however, have indicated that the species is firmly established in at least one area in New Jersey. The circumstances under which it was found indicate a pronounced change in the habits of the species, which explains the lack of success in recovering it previously. In Japan, the country of origin, *diversus* generally attacks fruit moth larvae infesting peach twigs in spring and midsummer, and it was assumed that this habit would persist in the United States. This did not prove to be the case, and its persistence in the field was determined only when collections of hibernating fruit moth larvae from late peach drops were made near Moorestown, N. J., during 1943 and in the following years. Overwintering larvae from apple drops on the same properties did not yield the parasite. The discovery of this change in habit may reveal the establishment of the species in other States where colonization took place on a large scale but where early recovery collections comprised only infested twigs.

The occurrence of the parasites in appreciable numbers only in late peach drops leaves unanswered the question of what host species is attacked during the spring and midseason. It appears that there must be one or more alternate hosts, as yet unknown, that carry the species through that period.

A. diversus is a solitary internal parasite of the fruit moth larvae. It has several generations each year, and hibernates in the young larval stage in the full-grown cocooned host larvae. Oviposition is in young fruit moth larvae that have only recently entered the fruit or twigs. This species is one of the few that produces female progeny generation after generation without need of fertilization.

Agathis pumilis (Ratz.) (Braconidae)

Importations of *Agathis pumilis*, a solitary internal parasite of the larvae of the larch casebearer, were begun in 1932, and in that and the following 3 years shipments from Austria totaled 620,000 field-collected larval cases. They were followed by 102,000 from England in 1936 and 53,500 from Holland in 1937. The *pumilis* content of this material was low, and the total number of adult parasites reared from the Austrian material was only 7,048. The first field releases were made at Sidney, Maine, in the summer of 1933 and at Berlin, N. H., and Saranac, N. Y., in the following year. Recoveries were made at 4 points (*49*) in 1936, and it has since been found to be established in Michigan. *A. pumilis* has not been extensively colonized, and no evidence is available as yet that it is exerting any appreciable check on the host infestations at the points where it first became established.

Agathis stigmaterus (Cress.) (Braconidae)

The circumstances surrounding the introduction of *Agathis stigmaterus*, a parasite of the sugarcane borer, are not known with certainty. A total of 127 parasite cocoons were forwarded from Argentina in 1929–30, but none, so far as known, from Peru (*93*). It was first recovered at Canal Point, Fla., in 1934 in the general vicinity where

releases of other parasites from Peru had been made in 1932 and later at 3 other points (*94*). No intentional releases of *stigmaterus* were made at that time in either Louisiana or Florida, and it is believed that the introduction resulted from accidental inclusion of a small number of adults among the large consignments of *Iphiaulax rimac* from Peru that were released in Florida in 1932. In some fields an average parasitization of 30 percent was noted in 1941.

A colony of 68 *stigmaterus* adults obtained from the field in Florida were released at Raceland, La., in September 1944. Recoveries were made in that area in 1947 and 1949, and cocoons containing living stages were found in 1950. There is then a possibility that the species may be able to persist under Louisiana conditions.

A. stigmaterus is a solitary internal parasite of the sugarcane borer larva. Several generations are produced each season, and the winter is passed as a first-instar larva within the hibernating host.

Allotropa burrelli Mues. (Platygasteridae)

The first observations on *Allotropa burrelli*, a gregarious internal parasite of *Pseudococcus* spp. in Japan, were made by H. S. Smith in 1913, who shipped it to California for colonization against the citrus mealybug. Additional material was imported in 1917, 1921, and 1923, and laboratory tests indicated that it was unable to develop in any of the mealybugs found on citrus trees in California.

The outbreak of the Comstock mealybug on apple in the Eastern States in more recent years led to an investigation by the Bureau of Entomology and Plant Quarantine of the possibility of obtaining effective natural enemies in Japan, as the pest had originally been described from that country and several parasites, in addition to *burrelli*, were known to attack it there. The studies revealed that *burrelli* is a valuable parasite not only of this mealybug but of the closely related form that occurs on citrus in that country. In 1939–41 a total of 47,780 field-collected host "mummies," containing approximately 700,000 full-grown parasite larvae, were shipped from Japan to the United States. The first liberations against the Comstock mealybug on apple were made at Batesville, Va., and several other points in Virginia and West Virginia in June 1940, and first-generation recoveries were made at a number of these points the next month. It has since been colonized and become established throughout the range of its host in the United States.

A. burrelli (*20*) oviposits in the nymphs and adult females of the mealybug, and up to 18 eggs, with an average of 8.8, are deposited at each insertion of the ovipositor. The number of adults emerging from a single host depends on the size of the latter at death, the maximum observed being 57, though the average is about 11. Females predominate among the progeny in the ratio of about 3 to 1. Hosts of the first or second instar at the time of parasitization often produce only a single parasite. Dead parasitized mealybugs have a distinctive "mummified" appearance, with the shell of the body hard and distended, and those containing several full-grown larvae or pupae of the parasite show clearly the outline of the cell occupied by each one. The average life cycle covers about 40 days at summer temper-

atures, and the winter is passed in the full-grown larval stage within the dead host in sheltered places.

Anagyrus antoninae Timb. (Encyrtidae)

Anagyrus antoninae, a parasite of the Rhodes-grass scale, was imported into Texas from Hawaii in 1949 (*119*), when three small consignments of field-collected host material were received during March to May. Several hundred adult parasites emerged from each of these shipments, and the first field releases were made that season. The rearing and colonization program has been conducted by the Texas Agricultural Experiment Station. Field recoveries have been made at a number of release points in the lower Rio Grande Valley, and the parasite is reported to be established in Florida also.

This parasite is solitary and develops internally in the female scale. Oviposition usually takes place in the young nymphs, and the cycle from egg to adult is completed in 18 days or less at summer temperatures.

Anagyrus fusciventris (Gir.) (Encyrtidae)

The importation of *Anagyrus fusciventris*, a parasite of the long-tailed mealybug, from Hawaii was accomplished by the University of California in 1936 (*62*). It was propagated in the insectary and the first field releases were made in May and June of that year. It was recovered at one colony site, at Otay in San Diego County, the following December and has persisted since that time. Although the parasite is known to have a wide range of hosts, it has not developed extensively on any of those occurring in California and has had no appreciable effect on infestations of the long-tailed mealybug.

A. fusciventris is a solitary internal parasite and deposits its eggs in the early-stage mealybugs. The cycle from egg to adult is completed in about 25 days at summer temperatures.

Anarhopus sydneyensis Timb. (Encyrtidae)

Anarhopus sydneyensis, a parasite of the long-tailed mealybug, was imported from Australia by the University of California in the autumn of 1933 (*28*, *62*). The first shipment yielded only 6 females, 1 of which was permitted to oviposit in a small number of hosts and then was placed in cold storage to await the development and emergence of her male progeny. She was then mated and progeny of both sexes resulted. The second shipment yielded 6 females and 1 male. The first field colonization on citrus, from insectary-reared stocks, took place in March 1934 at Downey, Calif. This grove was reported to be commercially clean by the following November. It was assumed that this control was a result of the parasite releases, though no recovery collections were made. It was not until 1939 that the parasite was reared from field-collected material taken at that location and at Santa Barbara.

The female *sydneyensis* oviposits in mealybugs of all sizes, though the larger ones are preferred. Only a single individual develops in each host. The life cycle covers about 1 month at 80° F.

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Anastatus disparis Ruschka (Eupelmidae)

Importations of gypsy moth eggs to obtain parasites for colonization in the United States were begun in 1906, when a few were obtained from Switzerland. Several lots were received from Japan and Russia the following year (*14, 89*). None of these consignments yielded *Anastatus disparis* (listed in early-American literature as *A. bifasciatus* Fonsc.), but the 1908 shipments from Russia produced 470 adult parasites, and 14 shipments from Japan yielded more than 5,000. Larger shipments were received from Japan and various countries of Europe during 1909–10. The total number of parasites obtained from foreign sources was 138,680, and later domestic collections at established colony sites permitted the liberation of more than 65 million, mostly as parasitized host eggs, in 6 States during a 15-year period.

The first field colony, consisting of 513 adult parasites was released near Boston, Mass., in 1908, the only colonization of the year. In the following year 128,000 were released at 5 sites in that State and thereafter in all sections infested by the gypsy moth. Each colony consisted of about 2,000 host eggs, and the colonies were placed at ¼-mile intervals along the roadways. The first recovery was made in 1910. The parasite became established in all sections of the generally infested area of New England. The apparent peak of abundance was attained about 1922, when an average parasitization of 30 percent was observed, but this declined gradually to less than 10 percent 5 years later. More recent records are not available.

A. disparis (*34*) is a solitary internal parasite of the gypsy moth egg. Oviposition takes place very soon after the host egg is laid, and the parasite larva is full grown within 2 weeks. The larva then remains inactive in the egg until the following spring, and emergence of the adult takes place in June and July, when the eggs of the new host generation are available for attack. At times a few adults emerge during the autumn and give rise to a partial second generation. This egg parasite has occasionally been reared also as a hyperparasite from the cocoons of *A. melanoscelus*.

Apanteles glomeratus (L.) (Braconidae)

Apanteles glomeratus, a gregarious internal parasite of the larvae of the imported cabbageworm, was the first insect parasite or predator intentionally introduced into the United States. In 1875, or shortly thereafter, C. V. Riley received a shipment of parasite cocoons from England, but no emergence occurred. In 1881 while visiting in Germany O. Lugger, of the Maryland Academy of Sciences, collected about 3 pints of cocoons and brought them to Baltimore, where they were distributed in infested fields during October. The time at which these liberations were made was not favorable and establishment was not accomplished. The next effort was in the winter of 1883–84, when Dr. Riley obtained a considerable quantity of cocoons from a correspondent in England. Forty-five adults were released in a field at Washington, D. C., in April 1884, and others during the following months. The first recovery consisted of 2 masses of cocoons taken from the fields that received the May releases. An additional shipment of cocoons was received from England in the spring of 1891,

and they were colonized in Iowa and Nebraska. Definite establishment was obtained from the releases at Ames, Iowa.

In all probability this parasite was distributed to a certain extent from Washington and other points after its establishment, though no mention is made of it in later publications. The capacity of a parasite to spread widely by natural means is well illustrated by this species, which in a relatively short period spread almost from coast to coast, and it is now found in all sections of North America inhabited by its host. It was intentionally colonized in California in 1915.

A. glomeratus (55) oviposits in host larvae that are only 1 or 2 days old and occasionally in older larvae. The ovipositor is inserted in the lateroventral region, and 15–35 eggs may be deposited at a single insertion. The eggs float free in the body fluids and hatch in 3–7 days, depending on the temperature. The larvae attain full growth in about 13 days, by which time the host larva has likewise completed its growth. The parasite larvae then emerge from the body of the host through individual holes cut in the integument, usually at the sides and in the middle of the body. The outward movement of all individuals in the brood is closely synchronized so that all emerge the same day. The cocoons are spun in an irregular mass on the leaf surface near the body of the host. The life cycle is complete in a minimum of 23 days; consequently, a considerable number of generations may be produced each year. The winter may be passed as early-stage larvae in the host in regions where larvae of the latter persist through the winter, or as full-grown larvae in the cocoon in areas where hibernation by the parasite itself is obligatory.

The reproductive capacity of this species is high, 2,000 eggs having been counted in the ovaries of a single female. The brood from a single host larva may number more than 100, though the average is much less.

A notable feature in the biology of this parasite is that the host larva is not killed by the large mass of larvae that develop within its body or directly by mechanical injury at the time they emerge. There is partial recovery, with the power of movement considerably curtailed, and death may not take place until 2–4 weeks later. Only rarely is one of these parasitized individuals able to pupate. Death is apparently due to an irremediable upsetting of the physiological processes of the host rather than to direct injury incident to feeding and emergence of the parasite brood.

Apanteles lacteicolor Vier. (Braconidae)

Apanteles lacteicolor, a solitary parasite of the young caterpillars of the brown-tail moth, was imported from Europe during 1906–10 (*14, 89*). Large quantities of overwintering host webs were received each year, and the various parasites associated with them were reared out at the laboratory at Melrose, Mass. Among them were 55,000 *lacteicolor* adults from Austria and Italy that were liberated during 1907–10. The liberations during 1911–18, totaling 255,245, were from the early established domestic colonies.

The first field colonies, consisting of 336 adult parasites, were liberated at 3 points in Massachusetts in 1907, but none of them became established. The colonies of the following years contained much

larger numbers, and recoveries were made in 1909 in 2 localities where releases had been made in 1908. By the following year one of these colonies had extended several miles from the point of release. The parasite is now generally established over practically the entire infested area in New England and Canada.

A. lacteicolor attacks the young larvae of the gypsy moth and of several native Lepidoptera. These alternate summer hosts have aided in the establishment and increase of the parasite. It is considered to be one of the important factors in reducing the brown-tail moth population in New England. The average field parasitization in 1925–26 was 25–30 percent.

The egg of *lacteicolor* is inserted into the body of the first- or second-instar caterpillar and floats free in the body fluids (*109*). It hatches after about 3 days, and the young larva develops slowly, keeping pace with the growth of the host. The winter is passed within the caterpillar and growth is accelerated in the spring. The growth of the host is much retarded, as it does not develop beyond the stage in which it passes the winter. The host dies 7–12 days after the parasite larva begins feeding. Unlike the cabbageworm larva parasitized by *A. glomeratus*, the brown-tail moth larva is killed just before the parasite larva emerges from its body. This is due to the destruction of the central nervous system by the parasite larva at the completion of its feeding.

The adult parasites from the overwintering generation emerge in late May and early June in New England, and 2 summer generations may be produced on alternate hosts, such as the gypsy moth and various native Lepidoptera of several families. The cycle of a summer brood is completed in 19–20 days, and the adults from the brood developing in gypsy moth larvae emerge in late June and early July. The white oblong cocoons of the overwintering brood are found in the brown-tail moth webs, whereas those of the summer broods are found on the underside of leaves and in crevices in the bark.

Apanteles melanoscelus (Ratz.) (Braconidae)

Apanteles melanoscelus, a solitary internal parasite of gypsy moth caterpillars, is generally distributed in Europe, being especially abundant in Sicily. It was from this island that 142,000 parasite cocoons were secured in 1911 and 22,000 in 1912 (*14, 89*). From this material 23,476 adults were obtained for field colonization, mainly in 1911, and these were supplemented by 132,177 produced by insectary rearing and released during 1915–27. The first liberations were made in Massachusetts in the late spring of 1911, and field recoveries were made the following season. The parasite is now generally established over the infested area of New England.

A. melanoscelus (*33*) has two generations each season. This habit has greatly facilitated establishment, inasmuch as no alternate host is required. However, it does attack several other hosts, including the satin moth and the white-marked tussock moth (*Hemerocampa leucostigma* (J. E. Smith)). Its increase in the field in the United States was rather slow, and there is a marked variation in its abundance from year to year. Many collections of host larvae show a parasitization of 20–30 percent and occasionally more.

The adult parasites of the spring brood emerge from their overwintering cocoons in May and immediately attack the newly hatched gypsy moth larvae. The eggs are deposited singly in the posterior portion of the body. Development is rapid, as feeding is completed in 6–12 days after deposition of the egg and the cocoon stage covers 7–11 days. The females of the second brood attack mainly the third-stage caterpillars, though the fourth stage is also suitable for oviposition. Though the host larvae are now very much larger than those attacked by the spring generation, only a single parasite develops in each. The developmental period is longer, however, as emergence of the larvae from the host occurs 15–31 days after oviposition. Activities of parasitized caterpillars are considerably reduced, and they consume much less food than healthy individuals. The host caterpillars may live 1 or 2 weeks after the parasite larvae emerge, but they do not feed during this period. The parasites pass the winter in the full-grown larval stage in their cocoons. These cocoons are usually found in sheltered places on or near the infested trees, to which the parasitized caterpillars had crawled before death. The cocoons are much heavier and a darker yellow than those of the spring generation.

Apanteles solitarius (Ratz.) (Braconidae)

In the early publications relating to the biological control of the gypsy moth, *Apanteles solitarius* was reported as having been imported in 1909 and 1911, but it has since been determined that the material represented other species of the genus. The true *solitarius* is generally distributed in Europe, and is mainly parasitic in the caterpillars of the satin moth, though it is able to develop in those of several other species also.

Importation of field-collected satin moth cocoons was begun in 1927 (*118*), when 105 were received from Hungary, from which 55 adult parasites emerged and were used as a breeding stock for insectary production. They provided all the material used for colonization, apart from relatively small numbers contained in shipments received in 1932–33 from Austria. From 1927 to 1932 liberations of adult parasites and sometimes of parasitized host larvae were made in satin moth infestations in 5 localities in Massachusetts, 1 in New Hampshire, and 1 in Washington (*97*). The first field recovery was made in 1928, and establishment of most of the other colonies was recorded the season following release. One colony in New Hampshire spread about 15 miles within 1 year after release. The species is now generally distributed in New England over the entire area inhabited by the host. The single colony of 267 adults liberated at Kent, Wash., in 1932 became established and spread over practically the entire State in 2 years (*97*).

Field parasitization of overwintering satin moth larvae by *solitarius* often reaches 60 percent or more in both New England and Washington. This species has been the most important of the established natural enemies responsible for the marked decline in satin moth infestations.

The seasonal cycle of *solitarius* is somewhat complex as compared with that of other species of the genus already discussed. This is due to an adaptability for bridging the winter period, whereby it hibernates

either as a first-instar larva in the host caterpillar or as a prepupal larva in its cocoon. There are consequently two broods of adults from the overwintering generation, each of which produces a second generation during the summer. The adults from overwintering cocoons emerge in early May and attack the host larvae coming out of hibernation. The adults from the brood that passes the winter in the host larvae emerge during late May and early June, and the life cycle of the summer broods is completed in 30–38 days. The second generation of adults of both groups attacks the newly hatched satin moth larvae, which begin to appear in early July. From then on some of the young larvae persist in the living host through the winter; others mature immediately and form overwintering cocoons; and a few even reach the adult stage during the autumn, and thus a partial third brood develops.

This species is very similar morphologically to *A. melanoscelus*, which is mainly a parasite of the gypsy moth. Crossbreeding experiments yielded fertile progeny, the F_1 and F_2 generations tending to resemble the female parent. Those of intermediate character represented only approximately 24 percent of the progeny in the 2 generations.

Aphycus helvolus Comp. (Encyrtidae)

Aphycus helvolus attacks the early nymphal stages of the black scale, and produces several generations on each host brood. It also attacks various other lecaniine Coccidae. The first importation was made from South Africa by the University of California in 1924. A small number of adult parasites emerged after arrival, but no field releases were made at that time. Additional material was imported in 1937 and a rearing stock obtained, from which millions were produced by State, county, and private organizations for liberation in southern California during the following years.

The first field releases were made in Los Angeles and Ventura Counties in the autumn of 1937 and in Orange County in 1938. Recoveries were made in the autumn of 1937 in a grove in Ventura County, after which the parasite was taken at many points in these counties during 1938. In many groves it increased very rapidly and brought about complete control within 1 year. Certainly *helvolus* is now the most effective of all the parasites of the black scale established in California (*126*). The suppression of the pest was especially rapid in the coastal areas.

A. helvolus (*64*) is a solitary internal parasite of the young stages of the black scale. In the areas of southern California where the "uneven hatch" condition of the scale exists, only two generations of *helvolus* are produced per host generation. Eight or more generations may be produced in "even hatch" areas, but there is a long early-summer period when stages suitable for attack are not present.

The adult female feeds regularly on the body fluids of the host scale, a habit very destructive to the scale in its young stages. The egg is deposited dorsolaterally in either end of the host body, and the stalk, with its aeroscopic plate, remains fixed at the point of insertion in the integument. The life cycle is completed in 13 days at summer temperatures. If the host scale is not in a suitable stage for feeding

and oviposition by the female, the production of eggs ceases and those already developed in the ovaries are absorbed. This characteristic is advantageous to the species in enabling it to bridge extended periods when suitable host stages are not available.

Aphycus lounsburyi How. (Encyrtidae)

Several shipments of black scale parasite material were received from South Africa by the California State Commission of Horticulture during 1900 and 1914, and a few specimens of *Aphycus lounsburyi* emerged from the latter shipments after arrival. No liberations from this South African stock were made. In 1916 a small colony of adult parasites was brought to California from Australia (*53, 129*). They were used in laboratory propagation, and colonies were released at several points in central and northern California in 1918. The first liberations upon citrus in southern California were at Santa Paula and Alhambra during September 1919. These groves were not chemically treated for scale control in order that the parasite might increase without hindrance. Evidence that *lounsburyi* was reproducing in the field was noted at Santa Paula the following month. During 1921 and 1922 large numbers of the parasite were produced by several county and private organizations. Satisfactory control resulted for a time in the coastal sections when the trees were left unfumigated, but the outcome was not so satisfactory in the inland areas where the scale has a single distinct generation each year.

During 1920–24 *lounsburyi* showed great promise of solving the black scale problem, but it has declined greatly in importance since that time owing, in part perhaps, to heavy attack by secondary parasites, mainly *Quaylea whittieri*. Its attack on the scale had the effect of evening the development of the host in the coastal areas so that a much greater portion of the brood was in the same stage at a given time.

A. lounsburyi (*131*) is a solitary or gregarious internal parasite of the black scale and oviposits in the "rubber" stage and older scales. The egg is of the same type as that of *A. helvolus*, but the manner of oviposition is different. The ovipositor is thrust beneath the scale and then upward through the soft integument of the ventral side of the body. The larva severs its connection with the egg stalk after the second molt. The cycle from egg to adult is completed in 16 days at optimum summer temperatures, and there are several generations each year.

Aphycus stanleyi (Comp.) (Encyrtidae)

Aphycus stanleyi, one of the minor parasites of the black scale, was imported from South Africa by the University of California in 1937 (*26*). The insectary stock was built up from 150 adult parasites that emerged from the imported material. The first releases were made in the autumn of that year at Whittier and in Ventura and Riverside Counties, and it was recovered at San Fernando in 1938. At the present time it is established in most sections of southern California. The soft scale has proved to be its preferred host, though occasionally it is sufficiently abundant on black scale to bring about an appreciable degree of control. It has also been recorded on citricola scale and *Eucalymnatus tessellatus* (Sign.).

This parasite is either solitary or gregarious in habit. The stalked egg is usually placed at the anterior or posterior margin of the host body, with the tip of the stalk projecting to the exterior. The life cycle is very short, covering only about 2 weeks at summer temperatures.

Aphytis "A"[4] (Eulophidae)

Aphytis "A" is indistinguishable morphologically in the adult stage from *A. chrysomphali*, a long-established species in California, but may be separated from it by color differences in the pupal stage. Mixed lots of parasitized California red scale and Florida red scale (*Chrysomphalus aonidum* (L.)) received by the University of California from South China during 1947 yielded *Aphytis* "A," which was utilized for insectary propagation (*75*). This species attacks only the gray stages of the host scale.

The first field releases were in Santa Barbara County during July 1948, and the parasite was reared and distributed in large numbers in that and the following 6 years. It was first recovered in Orange County in March 1949, and establishment has since been recorded in a number of orchards in all infested counties in southern California. However, it has difficulty in persisting under the climatic conditions of the hot interior areas.

The females feed on the body fluids of the host and also sting indiscriminately without ovipositing, the result being a much higher total mortality per individual than from direct parasitization alone.

Aphytis maculicornis (Masi) (Eulophidae)

Aphytis maculicornis is a solitary external parasite of the olive scale. The first importations were made by the University of California in 1948–49, when material was obtained from Egypt. Further importations were made from various countries in eastern Asia, the Near East, and the Mediterranean region in 1951. It developed, in the course of the domestic rearing work, that 4 distinct strains were represented, which have been designated the Indian, Persian, Egyptian, and Spanish strains, indicating the countries of origin. The adults are morphologically indistinguishable, but there are important biological differences between them (*84*). The Persian and Indian strains reproduce biparentally, whereas the Spanish and Egyptian are uniparental, and the biparental strains do not interbreed. In the Persian strain the life cycle is shorter and the reproductive capacity is greater than in the other forms.

In California the Persian strain is much the most effective in the field, and attains a high percentage of parasitization within a few months after release. Its greatest effectiveness is during the late winter and the spring months in attack on the first host generation, whereas the second host generation is only lightly parasitized (*44*).

[4] Recently described as *Aphytis lingnanensis* Compere.

Aphytis "X" [5] (Eulophidae)

Aphytis "X" is a solitary parasite of the purple scale, and was presumably first imported from China into California by George Compere prior to 1910, though it did not become established at that time. The second effort was by the University of California in 1948–49 (*70*), when shipments were received from South China and Formosa. The initial stocks were used for insectary propagation. The first field release was late in 1948, and very soon thereafter the parasite was colonized in all infested areas in southern California. The first field recovery was in January 1950, and by September of that year the parasite was abundant in several areas where releases had been made 1 year or more previously.

This parasite develops externally on second- and third-instar hosts. The egg is placed beneath the body of the scale and development is completed in about 15 days. Male and female progeny are produced in approximately equal numbers. The efficiency of *Aphytis* "X" in the control of its purple scale host is greatly increased by the female's habit of feeding on the body fluids of the scale, and the mortality resulting may equal or exceed that brought about by parasitization.

Aptesis basizonia (Grav.) (Ichneumonidae)

Aptesis basizonia, a parasite of the larvae of several sawflies, is native to Europe, and was first imported into Canada from Hungary in 1933 and the following years for control of the European spruce sawfly. Consignments of adult parasites were received, beginning in 1935, from the Canadian Department of Agriculture for use in the United States. Releases at Lake Portage, Maine, on the spruce sawfly in August 1935 totaled 3,650 adults, and additional colonies were released over a period of several years in that State, New Hampshire, Vermont, New York, and Massachusetts. In August 1940, 5 colonies were released in Essex County, N. J., against the pine sawfly. Approximately 12,000 adults have been released in infestations of the 2 pests. Recoveries were made from the pine sawfly cocoons collected in 1947 and 1948. The parasite is well established at 4 points in New Jersey, but has not yet been recovered from the spruce sawfly.

Aspidiotiphagus Sp. (Eulophidae)

Aspidiotiphagus sp., a solitary internal parasite of the olive scale, was contained in host material forwarded from Iran to California in 1951. Nearly 2 million were reared and widely colonized in the San Joaquin Valley in 1952. Field recoveries have been made at a considerable number of colony sites since that time, but practically all of these were from dooryard trees. Orchard conditions appear to be unfavorable for its establishment and increase.

[5] Recently described as *Aphytis lepidosaphes* Compere.

Azya trinitatis Mshll. (Coccinellidae)

Azya trinitatis, a predator on the coconut scale and native to Trinidad, was imported from Puerto Rico into Florida in 1938. A consignment of 800 adults was received in May of that year and colonized at Miami and Lantana. A survey in August 1939 revealed that establishment had been effected at Miami. No information is available regarding its present abundance or effectiveness.

The eggs of this species are yellow and are deposited singly on infested foliage and on other parts of the tree. The life cycle is complete in 33–47 days at summer temperatures.

Bathyplectes curculionis (Thoms.) (Ichneumonidae)

The importation of natural enemies of the alfalfa weevil was first undertaken from Italy in 1911 (*18*). There was some confusion regarding the several species of *Bathyplectes* contained in the shipments, though it is known that 787 cocoons of *Bathyplectes curculionis* were in the consignments of 1912, whereas mixed lots forwarded in 1911 and 1912 contained 1,667 of this and other species of the genus. In addition, 146,000 host larvae and cocoons were imported during 1911–13.

The single 1911 liberation at Sandy, Utah, consisted of 40 adult parasites, which were placed in field cages from which the tops were later removed. The number released in 1912 is unknown, though certainly small. The 1913 releases in the vicinity of Salt Lake City and those of 1914 at Kaysville and Ogden totaled 1,335 adults.

No recoveries were made from the 1911 and 1912 colonies, and this failure of establishment is believed to be due to the very small number released. Definite establishment was observed in 1914 in a field where colonies had been placed the previous season, and spread thereafter was very rapid, the entire infested area in Utah being covered by 1920. The parasite was colonized and established in Colorado in 1918–19, Nevada in 1921–22, California in 1933–34, and Oregon in 1934, and it has spread by natural means into Idaho and Wyoming. It now occurs in practically every section of the Western States inhabited by the host, and in most sections it attains a high parasitization.

B. curculionis was colonized by the Bureau of Entomology and Plant Quarantine in 1942 in infestations of the legume weevil (*Hypera brunneipennis* (Boh.)) in the Yuma, Ariz., area. It was recovered at Bard, Calif., across the Colorado River from the colonization site in 1953. It had also been reared from this host in San Diego County in 1952. This establishment, several hundred miles from known infestations of the alfalfa weevil, may have resulted from carriage of cocoons in shipments of alfalfa hay from the central part of the State.

B. curculionis is a solitary internal parasite of the larvae of the alfalfa weevil. The females oviposit in the spring in larvae of any stage of development, and death of the host takes place after it has spun the cocoon. The adults of this generation then attack the cocooned hosts that remain in the field. There are, consequently, two full generations on the single generation of the host. The cocoon of the parasite is distinctive, being broadly oblong, chocolate brown

in color, and with a pale band encircling the middle. These cocoons are formed within the cocoon of the host and in them the prepupal larvae pass the winter.

Bigonicheta setipennis (Fall.) (Tachinidae)

The nymphs and adults of the European earwig are parasitized to some degree by *Bigonicheta setipennis* in all the countries of Europe. The importation of this parasite into the United States was undertaken in 1924 (*108*). Shipments to Oregon from that year to 1929 comprised 2,519 parasite puparia and 3,200 field-collected earwigs from England and France, most of the material coming from the latter country. The domestic rearing and colonization program during this period was conducted by the city of Portland and by the Oregon Agricultural Experiment Station. The first field liberations were made at Portland in June and July 1926, when 2 colonies, totaling 66 parasite females and 26 males, were released. At one of these colony sites 10,000 earwigs that had been previously exposed to the parasite for 1 hour in cages were also released. From 1927 to 1930 releases at the same city totaled 941 gravid parasite females and many thousands of earwigs that had been exposed to parasitization in the insectary. Approximately 65,000 adult flies were released during 1931–33. One colony of gravid parasite females was placed at Corvallis, Oreg., in 1929.

The first recoveries consisted of several parasite puparia taken on the insectary grounds in July 1926, and in 1927 collections of earwigs from one of the colony sites of the previous year yielded the parasite. In the following years it was recovered at many of the colonization sites.

Extension of the colonization program to other States was undertaken by the Bureau of Entomology and Plant Quarantine in 1931 and the years following. In that year approximately 143,000 field-collected earwigs were received from England, France, and Italy, from which about 2,800 flies were obtained to serve as rearing stock. Large-scale rearing was then undertaken, and numerous colonies were released in Washington during 1934–40, consisting of mated parasite females, parasitized earwigs, and, in a few instances, parasite puparia. Releases were also made in California in 1934–35, Idaho in 1935, Connecticut in 1936 and 1939, Rhode Island in 1936 and 1939, Massachusetts in 1938–39, and Utah in 1939. Additional imported material became available in 1938–39 incident to the attempt to establish another parasite, *Racodineura antiqua*.

B. setipennis is now generally established in the area about Portland, Oreg., and throughout Washington, and some collections have shown a parasitization in excess of 20 percent. Recoveries have also been made in Idaho and Utah, but the outcome in the Eastern States is not known.

B. setipennis is a solitary or occasionally gregarious internal parasite of the earwig. The winter is passed in the pupal stage in rubbish on the surface soil. In Europe, where detailed biological studies have been made (*142*), the adults begin to emerge in late April and, after a preoviposition period of 19 days or more, the females deposit their fully incubated eggs, 250 or more, upon the substratum near the host

or, at times, directly upon it. Hatching takes place within less than 1 minute, and the young larvae, which are very active, immediately begin the search for a host earwig. Entry into the body is effected through the softer portions of the integument, most often in the neck area. A respiratory sheath is formed about the posterior portion of the body, attached at the point of perforation in the integument of the thorax of the host, which provides a channel for outside air to fulfill respiratory needs. During larval development within the host, which may cover 21–90 days, the parasite feeds only on the body fluids and fat, and consequently inflicts a minimum of injury. The larva then cuts a hole in the intersegmental membrane near the posterior end of the abdomen of the host and emerges for pupation. The longer periods of larval development mentioned above are in younger earwigs, which do not provide sufficient food material for rapid growth. A parasitized earwig may live for 24 days or more after emergence of the parasite larva from the body.

According to C. W. Getzendaner, who was in charge of the Bureau of Entomology and Plant Quarantine program from 1931 to its conclusion, the original Portland releases were the progeny of stock originating in England, whereas the later releases were from Italian stock. These 2 strains showed marked differences when reared in Washington. The Italian strain emerges earlier in the spring and develops 2 generations and a partial third each season as compared with 1 and a partial second generation from the English strain. The adults of the Italian strain are larger and have a much greater reproductive capacity.

Biolysia tristis (Grav.) (Ichneumonidae)

The records regarding the importation and colonization of *Biolysia tristis*, a solitary internal parasite of the larvae of the clover leaf weevil, are very incomplete. It is known that a large number of parasite cocoons were imported from Italy in 1912, some being forwarded direct to Salt Lake City, Utah, and others to Washington, D. C. There is no record of any releases in Utah. Correspondence of that year reveals that adults emerged in some numbers in Washington, but there is no record of actual colonization. At that time there was a heavy weevil infestation in Potomac Park and nearby areas, and it is probable that the adults were released there. So far as known no recovery collections were made during the following years, and it was not until 1935 (*41*) that the parasite was reared from hosts taken in the field at Arlington, Va., near the site of the earlier infestation. This discovery was made incidental to other studies on the weevil. This delay in recording establishment is clearly attributable to lack of search for the parasite during the intervening period. Adults were taken by collectors at Norfolk, Va., in 1932 and in Shenandoah County, Va., in 1941, and it appears that a considerable natural spread has taken place.

Blepharipoda scutellata R.-D. (Tachinidae)

Importation from Europe of *Blepharipoda scutellata*, a parasite of gypsy moth larvae, was begun in 1905 (*14, 89*), when small shipments of full-grown caterpillars sent to the United States yielded several

hundred parasite puparia. These did not survive hibernation, and consequently none were colonized. Slightly better results were obtained the following year, and a small number of adult parasites, probably less than 100, were released in Massachusetts in 1907 and 1908. The 1909 shipments from southern France were more successful. Several thousand full-grown parasite maggots were liberated in the forests that season and others were held at the insectary. Three colonies of adults were released in the spring of 1910. The total number of adults liberated from 1908 through 1911 was 5,372.

A few recoveries were made in 1910, probably from material liberated that season, but in 1911 the parasite was taken at several points, and spread thereafter was very rapid. Further colonization with domestic stock was undertaken in later years, 71,314 parasite puparia having been placed in the field during 1917–23. Additional material from foreign sources became available during 1924–27, incident to importation of other parasites, and 5,725 adults were liberated, as well as 2,232 from domestic sources.

This parasite is now distributed throughout the range of its host in the United States, and is proving to be one of the most valuable enemies of the gypsy moth. Field collections of pupae frequently show a high parasitization, ranging up to 70 percent or more. Maximum abundance was attained in 1923, when the average parasitization of all collections of female gypsy moth pupae was 49 percent.

B. scutellata is a solitary internal parasite of gypsy moth larvae, and has a single generation each year. The winter is passed in the pupal stage in the soil. The adults emerge in the spring, a week or two before general hatching of the gypsy moth eggs. The female fly may deposit 5,000 or more minute black eggs, which are hard shelled and able to withstand prolonged exposure. They are deposited on the foliage of plants on which caterpillars are feeding, and a portion of them are consequently eaten with leaf tissue by the caterpillars. Incubation takes place while the eggs are still within the oviduct of the female, but hatching occurs only in the digestive tract of the host caterpillar. The young maggot then enters the body cavity and feeds until the host has attained the full-grown larval or the pupal stage. The full-grown maggot usually issues from the pupa, though occasionally from a caterpillar, and drops to the ground for pupation.

Bracon piger Wesm. (Braconidae)

Importations of *Bracon piger*, a parasite of the larvae of the lima-bean pod borer, were made from Europe during 1936–38, when a total of 1,021 adults and 2,941 cocoons were received from France. From these shipments 2,540 adults became available for release in California. The first releases were made in 1936 at Ventura and Oxnard in waste areas overgrown with *Lupinus arboreus*, a wild host of the pod borer. Observations at Ventura in August and September 1938 showed that the parasite had become well established and had effected a parasitization of approximately 20 percent. The progress of the field colonies has not been followed since that time.

B. piger is a gregarious external parasite of the half- to full-grown larvae of the pod borer. The host is permanently paralyzed at the time of oviposition. The female parasite may construct a feeding tube

through which she feeds on the body fluids of the host. The eggs, up to 15, are placed directly upon the body, and, after hatching, the young larvae distribute themselves over the body and begin feeding. The entire body contents of the host are consumed within about 4 days. The cycle from egg to adult requires 19 days at summer temperatures. The colony developing on each host may number from 2 to 8, and the individual cocoons are spun in the cell of the host in the bean pod. There may be a number of generations each year, but in the late-season generations an increasing number of the larvae go into diapause. These overwintering larvae spin much heavier cocoons than do those which develop and emerge without delay. The first brood of adults emerges in June.

Calosoma sycophanta (L.) (Carabidae)

Among the European predators of the gypsy moth and other Lepidoptera, *Calosoma sycophanta* ranks high. It was one of the first of the large number of natural enemies of that pest to be introduced into New England (*12, 13, 14, 89*). In the summer of 1905, a shipment of 216 beetles was received from Italy, but only a single individual arrived alive. The following year 3 additional consignments were received from the same source and 10 consignments from Miss M. Ruhl in Switzerland. A total of 693 *Calosoma* beetles were alive upon arrival. The importations of 1907–10 brought the total received alive to 4,045, of which 2,711 were released in the field in New England. In addition, laboratory rearing provided 14,780 *sycophanta* larvae for release in 1908–10. Total liberations of imported, reared, and domestic-collected beetles and larvae in New England up to 1927 comprised 35,830 beetles and 19,930 larvae. In addition, 5,490 were colonized at 11 other points in the United States outside the range of the gypsy moth.

The first releases of *sycophanta* in New England consisted of 6 colonies of 30–50 beetles each at 5 towns near Boston, Mass., in 1906, and the liberations the following years were extended to include the entire infested area. *C. sycophanta* larvae were found under bands on trees at several of the colony sites during the summer of 1907, and recoveries were made thereafter at many points. One colony spread over 11 square miles within 2 years of release. The beetle now occurs throughout the area inhabited by the gypsy moth and has extended its distribution to adjoining States. It has not been recovered in the Southern and Western States, where releases against other pests were made from 1913 to 1921 and occasionally in later years.

It is difficult to evaluate the effect of a predator of this type, but the abundance and general distribution of *Calosoma* in the areas heavily infested by the gypsy moth warrants the belief that it is one of the most important of the imported natural enemies of this pest, and the large number of larvae and pupae that are destroyed by it indicates that it contributes substantially to reducing the infestations.

C. sycophanta is predaceous on both the larvae and pupae of the gypsy moth and of many other lepidopterous pests. Both the larvae and the adult beetles feed very freely on the 2 stages of the host. The beetles live 2–4 years. The eggs are laid in the soil during June and July and hatch in 4–5 days. The larval period covers about 14 days

and the pupal 13 days. The newly transformed adults remain in the pupal cells in the soil until the following spring.

The larvae are exceedingly voracious and feed both by day and night. Tests have shown that a larva will destroy at least 50 full-grown gypsy moth larvae during its 2-week developmental period, and each adult beetle will destroy several hundred. This predator is highly prolific, especially during the second year of life, and as many as 653 eggs have been obtained from 1 female in a single season.

Carabus auratus L. (Carabidae)

The data relating to the importation and colonization of *Carabus auratus*, a predator on the gypsy and brown-tail moths, are incomplete. It is recorded that 478 beetles were received from Europe and liberated in New England (*14*) during 1907, and no further reference to this predator is made in the literature except mention of its establishment. According to R. C. Brown, it was first recovered in 1920.

Carcelia laxifrons Vill. (Tachinidae)

The first importations of *Carcelia laxifrons* (referred to in early-American publications as *Parezorista cheloniae* Rond.), a parasite of the brown-tail moth, were made from Europe in 1906. They were of the immature stages in living host caterpillars (*14, 89*). The 1906–10 importations yielded a total of 9,742 adult parasites for liberation. The number placed in the field during 1906–7 was very small; whereas 1,500 were released in a single colony in 1908, relatively few in 1909, and the largest number in 1910. The 1908 releases were of mated females, and recoveries were made at the colony site the same season. Adult parasites were reared out in considerable numbers from domestic host material in 1909. The parasite then apparently declined for a time, but it spread rapidly over practically the entire area of New England inhabited by the host.

An average field parasitization of about 23 percent is recorded for 1916, but the average since that time has been low, not exceeding 5 percent. Thus it cannot be regarded as of any importance in the control of the moth.

C. laxifrons has a single generation each year, and the winter is passed in the pupal stage in the soil. The adult flies emerge from April to June, and the females deposit their thin-shelled, stalked eggs on the brown-tail moth caterpillars very soon after they emerge from hibernation. Upon hatching the maggots immediately enter the bodies of the hosts, and development is completed by the time the latter are full grown and ready for pupation. Only a single individual develops to maturity in each host.

This European species has its American counterpart in *C. malacosomae* Sellers, parasitic mainly in *Malacosoma* larvae, and from which it can be distinguished only with difficulty. Progeny have been obtained from crosses of these two species.

Chaetexorista javana B. & B. (Tachinidae)

In Japan the oriental moth is rather heavily parasitized by *Chaetexorista javana*, and arrangements were made in 1929 for its importa-

tion into Massachusetts. Thirty thousand host cocoons, a large portion of them containing parasitized larvae, were forwarded early in 1929 and 779,000 in 1930. From these 2 consignments a total of 92,900 parasites emerged, of which 85,000 were colonized at 16 points in Boston and its vicinity during 1929–30. Recoveries were made in 1930 at Boston and Revere, where colonies had been placed the previous year. The parasite increased and spread very rapidly, as indicated by an average parasitization of 63.5 percent in 1933 (*48*) and approaching 100 percent in some collections.

This parasite has a single generation each year, and winter is passed as a second-instar larva in the full-grown host larva within its hard-shelled, egglike cocoon. Larval development is completed in the early summer and pupation takes place in the host cocoon. The adult parasite emerges by pushing off the circular cap at the anterior end of the cocoon, which normally serves for the exit of the adult moth. The eggs are deposited directly on the caterpillar, and the young maggot bores into the body, attaching itself to the point of entry by a respiratory funnel. Only a single individual develops to maturity in each host.

Chelonus annulipes Wesm. (Braconidae)

Chelonus annulipes is parasitic in the larvae of the European corn borer. Since it was found in appreciable numbers only in certain restricted sections of northern Italy, it was imported into the United States rather late in the campaign for the biological control of that pest (*4*). During 1929–30 parasite cocoons and field-collected borers shipped to the United States totaled 10,767. Further large-scale shipments of host larvae and also some cocoons and adults of the parasite were made in 1932–37, which yielded a total of 45,917 adult parasites for colonization. Mass laboratory production was undertaken in 1938, the Mediterranean flour moth being used as host, and in a 3-year period an additional several hundred thousand were thus reared and colonized.

The first field colonization, consisting of 1,052 adult parasites, took place in 1929, and 8,066 were released in 1930, all of these being in the 1-generation area in Ohio and Michigan. Additional large-scale releases were made in the Great Lakes area during the following 9 years. Occasional recoveries of a few individuals were made at several points in Ohio and Michigan in 1933 and later, but the colonies did not persist. It is now known that one of the main factors contributing to the failure of establishment of these early colonies was the lack of proper synchronization of the releases with the peak of host oviposition. One 1938 release in Ohio, with proper synchronization, showed a parasitization of 12.6 percent the following season, but even this colony failed to persist.

The first release in the 2-generation area was near Taunton, Mass., in 1932, and for several years releases in the East were limited to that State and Connecticut, after which colonization was extended to all the other infested Atlantic Coast States. In 1935 a parasitization of 6.5 percent was noted in the Taunton area, where releases had been made in 1932. This general area, the adjoining Connecticut areas, and the Hudson River Valley in New York appear to be particularly

favorable to the parasite, and it has persisted there from year to year, though the rate of parasitization except at localized points, continues to be low, seldom exceeding 1 percent.

C. annulipes is a solitary internal parasite of the corn borer larvae (*144*). Two generations are produced each year in areas where the host has a corresponding cycle. The female deposits her eggs in those of the host, which may be in any stage of embryonic development. The parasite egg enlarges considerably during incubation and hatches within 2 days. The larva feeds internally until its second molt, after which it emerges from the fourth-instar host and completes its feeding externally. A white, papery cocoon is then spun in the burrow of the dead host. In this summer generation the incubation period is 2 days, the larval period 20–30 days, of which the final day is represented by external feeding, and about 8–12 days are spent in the cocoon.

The second generation carries through the winter as late first-instar larvae in fourth-instar caterpillars. These parasitized caterpillars at the time they go into hibernation are somewhat lighter in color and appreciably smaller in size than healthy individuals, so that they can readily be recognized in the field. The parasite larvae complete their feeding in the spring, and adult emergence takes place in late May and early June.

The life cycle of *annulipes* is closely synchronized with that of the host, and in northern areas where the latter has a single annual generation the parasite likewise has only one. The reproductive capacity is relatively high, as each female is capable of producing up to 1,000 eggs during a period of 1–2 months. One female was observed to deposit 165 eggs in a single day.

Chelonus inanitus (L.) (Braconidae)

A few individuals of *Chelonus inanitus*, a parasite of the lima-bean pod borer, appeared in the material collected in France in 1938. This parasite was then reared on the Mediterranean flour moth. A shipment of approximately 10,000 moth larvae, which had been exposed to the parasite in the egg stage, was made to the United States in December 1938. Total parasite emergence from this material the following spring was 780. These adults were used for laboratory propagation and provided stocks for colonization during 1939 and 1940. A total of 18,790 adults were released in 8 colonies in southern California from July to November 1939, 3 of which were in infested beanfields at Ventura, 2 in areas at the same place having a heavy growth of *Lupinus arboreus*, 2 in beanfields at Santa Barbara, and 1 at San Diego. One colony of 380 adults was released at Ventura late in the summer of 1940.

The first field recoveries were made late in 1940 from borers in *Lupinus* pods at one of the 1939 colony sites. Only a small number of individuals have been recovered thus far, and the progress of the colonies was not followed in the succeeding years.

The biology of *inanitus* has not been studied in detail, though essentially its habits are similar to those of *C. annulipes*. When it attacks the summer generations of the pod borer in southern France, a

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generation may be completed in 23 days. In all generations the rate of development is synchronized with that of the host.

Chrysocharis laricinellae (Ratz.) (Eulophidae)

The larval parasite *Chrysocharis laricinellae* is the most important natural enemy of the birch leaf-mining sawfly in Europe. From 1930 through 1934 a total of more than 34,000 chalcidoid larvae and pupae and 320,000 host mines and hibernacula were shipped from Austria to the United States (*47*). The *laricinellae* emergence from this material totaled about 10,000, with smaller numbers of other species. The first field colony, consisting of 63 adults, was released at Strong, Maine, in 1931, followed by larger liberations in that State and Vermont, New Hampshire, and Massachusetts in 1933–35. The total number of adults liberated was 7,268. Recoveries from the birch leaf-mining sawfly were made at Stark, N. H., and Bethel and Eustis, Maine, in 1937 from 1935 releases (*49*).

This parasite is also an important enemy of the young larvae of the larch casebearer in Europe, and considerable numbers were included among the importations of natural enemies of that pest from Austria in 1932–35 and from England in 1936. Liberations were made in infested areas in New England and New York. Recoveries from this host (*49*) were made in 1936 from 1933 releases in Maine and New York, and in New Hampshire and Vermont from colonies released in 1935.

Recoveries of this parasite from infestations of the elm leaf miner (*Fenusa ulmi* Sund.) at a number of points in New England indicate that it may have been present for some time prior to the importations mentioned, possibly having reached this country with that host many years previously.

C. laricinellae is a solitary internal parasite of medium-sized and full-grown larvae of the leaf miners and casebearer. There is one full generation and a partial second each year, and the winter is passed in the full-grown larval stage in the leaf mine of the host. The life cycle of the summer generation is short, requiring only 17–23 days. The tendency of the female parasite to feed on the body fluids of the host, probably killing large numbers of leaf miners in this way, adds to the effectiveness of the species.

Cleodiplosis koebelei (Felt) (Itonididae)

Cleodiplosis koebelei (recorded as *Diplosis* sp.) (*29*), a predator on the younger stages of mealybugs, is native to Australia, and was imported into the United States in March 1928 by the University of California as a part of the project for the biological control of the citrophilus mealybug. The first colonies were released in the field in southern California in the spring of 1928, and recoveries were made the following August. The fly was reared and colonized in large numbers that season, and it became established at many points. However, it has not become abundant, and is of negligible value in control, though it has been fairly effective against the grape mealybug in greenhouses.

C. koebelei has a very short life cycle, which is completed in 13 days at summer temperatures. The eggs are laid among the egg masses of the host, and the maggots feed on the eggs and young nymphs.

Coccophagus capensis Comp. (Eulophidae)

There is some confusion in the records regarding the importation of *Coccophagus capensis*, a parasite of the "rubber stage" black scale, as it was not distinguished until recently from *C. modestus* Silv. It is a common parasite of the black scale in South Africa (*26*), where it was known in the early years as *C. orientalis* How. It was undoubtedly represented in the numerous shipments of material received by the California State Commission of Horticulture during 1909–12, and presumably also in those made at the time *Scutellista* was introduced in 1900–1901. However, there is no record of any releases having been made. During 1914–15 additional shipments were received from C. P. Lounsbury at Cape Town. This stock was propagated in the insectary, and strong colonies were released in both central and southern California. No recoveries were made at any of these points. In 1918 a colony was obtained from Australia, and several releases were made in central California. In 1921–23 large numbers were again received from South Africa, and colonies were placed in infested groves in the coastal section from Santa Barbara to San Diego. Several small colonies, totaling 78 adults, were placed in White Park, Riverside, in 1924, and the parasite was recovered there in abundance in June 1925. This locality alone provided the special conditions for persistence that are required because of the peculiar differentiation in host relationships of the two sexes.

C. capensis is a solitary internal parasite of the black scale and others of that genus (*17*, *61*, *130*). It is one of the eulophid parasites of scale insects and mealybugs that exhibit a startling sex differentiation in their host relationships, accompanied by a morphological differentiation in the early stages of the two sexes, this latter being evident in some species even in the egg after deposition. The females of all species develop as primary parasites, whereas the males, except *C. ochraceus* How., develop consistently as secondary parasites. The fertilized female *capensis* oviposits through the middorsum of the host, and deposits female eggs in the body cavity of the third-instar, or "rubber-stage," black scale. These eggs hatch in 3–4 days, and the later stages are very irregular in their development. The minimum cycle from egg to adult is 24 days at summer temperatures. Pupation takes place before the death of the host, and the pupa is enveloped in a membranous cocoon surrounded by the organs and body fluids of the host.

The unmated female, in depositing her male eggs, places them within the body of a prepupa or pupa of her own species or of some other primary parasite in various lecaniine Coccidae, and development is completed as an internal parasite in those stages. The first-instar larvae of the two sexes are markedly different, the male larva being teleaform. The minimum life cycle of the male is approximately 20 days.

Coccophagus cowperi Gir. (Eulophidae)

Coccophagus cowperi, a common parasite of the young nymphs of the black scale in South Africa, was imported into the United States from there by the University of California in 1937. It apparently is indistinguishable morphologically from *C. lycimnia* (Wlkr.), but crossbreeding tests were unsuccessful and their host relationships differ. It was propagated in the insectary, and field releases were made in Riverside, Ventura, and San Diego Counties in 1937.

The first field recovery was made in 1938 at San Diego. At the present time it is known to be established only at several points in San Diego and Los Angeles Counties and on the hemispherical scale (*Saissetia hemisphaerica* (Targ.)) and the nigra scale rather than on the black scale. There appears to be no prospect that this parasite will be of any appreciable value in the control of the black scale.

The female is a solitary internal parasite of scales about one-third grown, whereas the male is an external parasite of full-grown larvae and pupae of other parasite species in their cocoons in the host (*26*).

Coccophagus gurneyi Comp. (Eulophidae)

The search for natural enemies of the citrophilus mealybug in Australia by the University of California in 1927 led to the early discovery of *Coccophagus gurneyi*, and it was imported into California the following year (*29*). It was propagated in very large numbers at several county and private insectaries. The first releases were made during June 1928, and field recoveries were made the following month. An appreciable reduction in the field infestations was noted in the spring of 1929, and by 1930 the pest had been satisfactorily controlled in all sections of southern California.

This parasite, like several other species of the genus, shows a marked difference in form and habit in the immature stages of the two sexes (*17, 61*). The egg in each case is deposited in the body cavity of the host. The female egg hatches in 3–4 days, and the cycle from egg to adult is completed in 24–43 days. Embryonic development of the male is completed in 3 days, but hatching does not take place until the body fluids of the coccid host have been consumed by a primary parasite larva. The male egg may remain alive up to 86 days if conditions essential for hatching do not appear. If a female larva of the same species develops in the host, the male egg eventually hatches and the larva enters the body of the full-grown primary larva. Here it feeds internally for a time and then completes its development as an external parasite. However, if the primary parasite larva is *Leptomastix dactylopii*, the male larva of *gurneyi* feeds externally throughout its development.

Coccophagus pulvinariae Comp. (Eulophidae)

Coccophagus pulvinariae, another minor parasite of the young stages of the black scale, was imported from South Africa by the University of California in 1937 (*26*). Colonies were released in San Diego and Ventura Counties in 1937–38. At present it is known to be established only on the nigra scale, rather than on the black scale, at Santa Paula, where it had been released in 1938 and was first recovered in 1939.

This species is similar in its habits to *C. cowperi*. The male eggs of both species are attached externally to the derm of full-grown chalcidoid larvae in various lecaniine Coccidae.

Coccophagus rusti Comp. (Eulophidae)

Coccophagus rusti is the most common parasite of the black scale in East Africa and the Transvaal, and was imported into California from the latter area by the University of California in 1937 (*26*). It was propagated extensively in the insectary, and was released in Orange and San Diego Counties during late 1937 and 1938. It was first recovered at Hewes Park in Orange County in 1938, and is now known to be established at several points in Orange, Riverside, and Santa Barbara Counties. In only a few localities has it shown a capacity to effect full control of the host on citrus, but in general its greatest effectiveness has been in reducing infestations on oleander and pepper trees.

The mated female of *rusti* deposits her eggs through the dorsum of the half-grown black scale, and only a single female develops to maturity in each one. The life cycle is approximately 20 days. The male progeny develop as internal parasites in full-grown larvae and in pupae of various parasites of lecaniine Coccidae.

Coccophagus trifasciatus Comp. (Eulophidae)

Coccophagus trifasciatus is a common parasite of the black scale in South Africa, and it was imported from that region into the United States by the University of California in 1924–25 (*131*). More than 1,000 adult parasites were obtained from the imported scale material during these years. The first colonies that were liberated comprised a total of 168 adults, which were placed in White Park, Riverside, during late 1924 and early 1925. The species was recovered there in the summer of 1925 and has persisted since that time. Its establishment at this point was possible because of the presence of *C. lycimnia* on the soft scale and occasionally on the black scale also. This parasite species and others of similar habit usually serve as hosts of the *trifasciatus* males.

C. trifasciatus (*17*, *61*) is able to produce a very high proportion of female progeny generation after generation. The female egg is deposited in the body cavity of a second- or third-instar black scale, and the cycle from egg to adult is completed in a minimum of 27 days. The winter is passed as a first-instar larva in the body of the host.

The male egg is likewise deposited in a young scale, and embryonic development is completed in about 3 days. However, hatching is delayed until the body contents of the host have been consumed by a female larva of some other primary parasite, whereupon the male develops as an external parasite on it. The first-instar male larva is of the planidium type.

This species and *C. rusti* oviposit with great rapidity—in about 1 second—and consequently both are able to work effectively even in the presence of ants.

Comperiella bifasciata How. (Encyrtidae)

The search for parasites of the California red and the yellow scales by the California organizations has extended over many years. The first importation of *Comperiella bifasciata* was from Hong Kong in 1906, and others have been made periodically up to the present time from points in South China, Formosa, and Japan. Shipments of *Aonidiella taxus* Leon. and *Chrysomphalus bifasciculatus* Ferris from Japan in 1924 yielded stocks of *bifasciata*, which were tested on California red scale, but they failed to reproduce. This parasite was finally established on *bifasciculatus* at Pasadena, and the adaptability of the Japanese material to the yellow scale was determined in 1931 (*69*). Releases were then made on that host in the Redlands, Santa Paula, and Visalia areas in cities, where there is more overlapping of the stages of the scale than in the orchards, and it not only became established but effected satisfactory control. It is now present in practically all sections of California inhabited by the yellow scale, though not effective under orchard conditions in the San Joaquin Valley. This general distribution has been accomplished only over a period of years because of the exceedingly slow rate of natural spread, which may be only a few tree rows per year. This strain of *bifasciata* appears to be especially effective in light infestations, so that its greatest use may be in holding the pest in check after chemical treatments rather than in reducing the initial heavy infestations.

The later studies on this problem revealed a complex relationship between *bifasciata* and its hosts, which explains the seeming inconsistencies and failures of the earlier efforts. It developed that there were at least 2 distinct strains of the parasite in the Far East. That on the yellow scale was able to develop not only in that host but in *A. taxus*, *Chrysomphalus bifasciculatus*, *C. conidum*, and *C. dictyospermi* (Morg.), but only rarely in the red scale. The importation program from the Far East was further complicated by the fact that the red and yellow scales often do not show the sharp color differences that are seen in California, and the differences in distribution of the scale on the plant are not nearly so pronounced. It was not until 1932 that morphological characters became known, whereby these 2 host species could be distinguished.

In 1941 a strain of *bifasciata* having the red scale as its normal host was found in South China and imported into California (*37*). With an initial stock of only 5 mated females, over 2 million adults were produced for distribution during the next 15 months. This strain is now established generally over the interior infested areas in southern California, but there are no indications that it is able to check the scale infestations.

The females of *bifasciata* are very deliberate in their activities, requiring considerable time for examination of the host and for oviposition. For this reason it is essential, for maximum efficiency in control, that ants be eliminated from the infested trees; otherwise oviposition will be largely prevented.

An interesting situation has been revealed with respect to the effect of the food of the host on successful parasitization by *bifasciata*. The South China strain reproduces normally in red scale grown on citrus, but populations grown on sago palm show a very high mortality

of the immature stages of the parasite, which is attributed to a nutritional deficiency.

C. bifasciata is a solitary internal parasite of the female scale (*68*), attacking preferably the second instar, though it also develops to a lesser extent in the male scale. It has the stalked egg, characteristic of the family, but the stalk is functionless and the egg lies free in the body cavity of the host. A female may deposit up to 136 eggs during an oviposition period of about 3 weeks. The life cycle covers 20–40 days, depending on the stage of development of the host at the time of attack. If attack takes place on the very young scale, its development is retarded, and the parasite emerges from the early third-instar host during the gray stage rather than later.

The female punctures the young stages of the scale with her ovipositor in order to feed on the body fluids, but seldom deposits eggs in them. Many scales are punctured by the ovipositor without being fed on. This mutilation of the young scale, causing its death, adds appreciably to the effectiveness of the parasite.

Compsilura concinnata (Meig.) (Tachinidae)

Compsilura concinnata, a parasite of gypsy moth larvae and of many other lepidopterous larvae, is the most important of the many parasites imported into the United States against that pest (*14*, *89*). Shipments of gypsy and brown-tail moth caterpillars received from various countries of Europe in 1906 yielded a very few specimens of *Compsilura* for colonization; an unknown but much larger number were colonized in 1907 and none in 1908. Importations were continued until 1911. Releases in New England during the following years totaled 69,167 adults up to the end of 1927. The colonization stock since 1912 has been of domestic origin.

The first definite recovery was in 1909, when the species was found to have spread widely from a colony site near Boston. Dispersion of 25 miles from 1 colony site in a single year was observed. It quickly became established throughout the New England areas inhabited by the gypsy and brown-tail moths and has spread to adjoining States. Season averages for field parasitization have been as high as 40–50 percent, though often dropping below 10 percent.

Colonies have also been liberated on other hosts in New Jersey, New York, Pennsylvania, District of Columbia, New Mexico, Minnesota, Arizona, California, Idaho, Oregon, and Florida. The parasite was widely colonized on the satin moth in Washington from 1929 to 1934, and became well established (*97*).

Since its introduction into the United States, *concinnata* has been reared from nearly 200 species of Lepidoptera, representing 20 families, and from 3 families of Tenthredinoidea, most of these records having been reported in 1926 (*149*). Because of this wide range of hosts there is practically never a shortage of suitable hosts in the field, and the parasite is able to maintain a high population level at all times. It is a valuable element in the parasite complex attacking the gypsy and brown-tail moths in the United States, and field parasitization of the satin moth is often high, amounting at times to 50–70 percent.

C. concinnata (*35*) is a solitary or gregarious internal parasite of the larvae, 1 to 4 developing in each host, and it attacks practically any stage of host larva that is available. There are 3 or 4 generations each year, and the winter is passed as a young maggot within the host. The overwintering hosts comprise certain native caterpillars, and do not include the gypsy or brown-tail moths. The first of these latter hosts is in the egg stage during the winter, and the second occurs as young larvae in the webs. The brown-tail moth larvae are attacked in large numbers by *Compsilura* during the autumn, and the parasitized individuals invariably die during the winter. Its value as a control for these 2 pests is therefore dependent on the availability of alternate hosts to support the overwintering generation. Larval development in suitable hosts is rapid in the spring, and the first generation of adults emerges in late April to June.

The female is equipped with an ovipositor of the piercing type, which is thrust through the skin of the caterpillar, and a living maggot is injected into the body cavity. The reproductive capacity is not large, probably not exceeding a hundred. Larval development is completed in about 13 days, after which the full-grown maggot emerges from the host and pupates in the soil. If the host is a brown-tail moth, the puparium may be formed in the cocoon. The pupal stage covers 10–14 days.

Cremastus interruptor Grav. (Ichneumonidae)

Importations of *Cremastus interruptor*, a parasite of the larvae of the European pine shoot moth, were made from Austria during 1931–35, England in 1936, and Holland in 1937. The number of parasite cocoons received during that period is uncertain, as those in the 1931–32 shipments were not separated from related species, but the total for 1933–37 was 10,100, of which by far the greatest number came from England in 1936.

The first field releases were made at Brookline and Hingham, Mass., in July 1931. The 1936 releases in several States totaled 6,177 adults, and recoveries were made in Connecticut, New York, and New Jersey (*49*). Information on later dispersion and effectiveness is not available.

This species is a solitary internal parasite of the larvae of the pine shoot moth and several related species. The winter is passed in the young larval stage in the hibernating host larvae and the adults appear in the field in June and July. Sometimes the full-grown larvae emerge from the host pupae rather than from the caterpillars. There is a single generation each year on the pine shoot moth.

Cryptochaetum iceryae (Will.) (Agromyzidae)

The trip of Albert Koebele to Australia in 1888–89 in search of natural enemies of the cottony-cushion scale was prompted by the report of the occurrence in that country of a dipterous parasite, *Cryptochaetum iceryae*, rather than the vedalia beetle, which at that time was not known as an enemy of the scale. It was quickly found (*99*), and his first shipment, which arrived in San Francisco on November 26, 1888, consisted of about 6,000 parasitized adult scales, containing about 4 *Cryptochaetum* parasites each, and 1 Wardian cage

of infested citrus and *Pittosporum* plants (*53*). A second shipment followed a few days later, consisting of about 3,000 parasitized scales, but the parcel was damaged in transit, and only a single fly emerged. Five shipments in all were received at Los Angeles between November 1888 and the end of February 1889, and the total fly emergence from these consignments was 548. The flies reproduced readily in the field cage in which they were released, and in the following April a large portion of the scales were found to be parasitized. Colonies were distributed from this source, and the parasite very soon became generally established over the entire infested area. Today it is almost invariably present whenever a small host infestation is found, and is most abundant in the coastal areas.

A shipment received from a correspondent in Australia in 1888, prior to Koebele's trip, yielded a number of adult flies, which were released on a caged tree, but these were from *Monophlebus*, and the parasite species was almost certainly *Cryptochaetum monophlebi* Skuse. Establishment was not attained.

C. iceryae is a solitary or gregarious internal parasite of the female cottony-cushion scale (*128, 143*). Half-grown (second-instar) scales are preferred for oviposition, though larger or smaller individuals may be attacked successfully. The female parasite is equipped with an ovipositor of the piercing type, and the egg is placed in the body cavity of the scale by a quick thrust of the ovipositor through the skin. The egg hatches in 3–5 days, and the complete life cycle covers 1 month or more. The host is killed by the fourth-instar parasite larva, and pupation takes place within the partly dried remains of the host. From 1 to 17 individuals may develop to maturity in a single scale. There are 5 or 6 generations each year. A distinctive feature of the larva of this parasite is a pair of long tubular processes, or "tails," at the posterior end of the body, which fulfill a respiratory function.

Cryptognatha nodiceps Mshll. (Coccinellidae)

Since *Cryptognatha nodiceps* had been exceptionally effective in controlling the coconut scale in Fiji and Puerto Rico, arrangements were made for its importation and use against the same pest in Florida. One consignment of 156 beetles from Trinidad was released at Miami in February 1936, and another of 115 beetles from Puerto Rico at the same place in September 1938. A survey in August 1940 revealed that the species had become established. No further information is available regarding its abundance, spread, or effectiveness.

The eggs of *nodiceps* are slightly green in color, and are deposited singly under a scale covering, from which the female scale has been removed and devoured. The life cycle is completed in 19–25 days at summer temperatures, but may be considerably prolonged if the food supply is not abundant. At such times the larvae are markedly cannibalistic. As with many other species of this family the larvae assemble in clusters for pupation.

Cryptolaemus montrouzieri Muls. (Coccinellidae)

There is little published information regarding the details of the importation and colonization of the mealybug predator *Cryptolaemus*

montrouzieri, except the statement that considerable numbers were included in Koebele's shipments from Australia that arrived at San Francisco in December 1891 and the early months of 1892. The beetles were reared and widely distributed in southern California during 1892, and establishment was readily effected.

This predator appears to be especially adapted to the coastal sections of southern California, but is not able to persist in the interior valleys. During the years after its introduction it was credited with controlling a number of outbreaks of the citrus mealybug in the coastal areas, but it then subsided and was of little value thereafter. This condition was believed to be due to the inability of the beetle to survive the winters in sufficient numbers so that a controlling population could be built up early enough the following season.

A marked change took place in the status of *Cryptolaemus* about 1917 as a result of the development by the California State Commission of Horticulture of mass-production methods (*127*), whereby the mealybugs were grown on potato sprouts, and the consequent adoption of the practice of releasing the beetles in considerable numbers whenever an infestation appeared. This practice involved liberations in infested groves at the rate of 10–20 beetles per tree each season so long as conditions demanded, and proved to be a practical means of controlling the several species of mealybugs that were then injuring the citrus groves in southern California. Large insectaries were established by county, cooperative, and private organizations for producing the beetles, and they were reared and distributed by the millions each year.

Although *Cryptolaemus* is found most generally in infestations of mealybugs of the genus *Pseudococcus* that are gregarious and that deposit their eggs in large masses, it also attacks related genera, such as *Ripersia*, *Phenacoccus*, *Ferrisia*, and even *Icerya*. It has been recorded as feeding extensively on lecaniine Coccidae of the genus *Pulvinaria*. These genera deposit their eggs in cottony masses very similar to those of the true mealybugs.

The adults and larvae of *montrouzieri* feed mainly on the eggs and young nymphs. The eggs of this species are placed singly in or near the host masses and hatch in about 8 days. The larval feeding period is 12–20 days and the pupal period 8–12 days. Pupation takes place in curled leaves or in other sheltered places on the tree or on the ground beneath it, and the winter is passed in this stage.

Cybocephalus Sp. (Nitidulidae)

This undescribed species of *Cybocephalus* is a predator on the California red scale and other diaspine Coccidae. It is native to the Asiatic region, and was imported into California from South China in 1932–33 by the University of California. An extensive rearing program at the Orange County Insectary provided 20,000 adults for general release on red scale throughout that county during the following few years. No field recoveries were made at that time, but in 1944 it was found to be abundant in infestations of *Diaspis boisduvalii* Sign. on cactus at Costa Mesa, on *D. cocois* (Licht.) on palm at Santa Ana (*11*), and in small numbers on purple scale in 1952. How-

ever, the infestations of the first 2 hosts have not been appreciably reduced, and the beetle has not yet been taken on red scale.

The life cycle of *Cybocephalus* is about 24 days at summer temperatures (*60*). The eggs are deposited singly in vacated male host scales or beneath mature female scales. The larvae feed mainly on adult female scales. When feeding is completed, these larvae enter the soil or conceal themselves in debris on the surface and spin spherical, white, parchmentlike cocoons.

Dahlbominus fuscipennis (Zett.) (Eulophidae)

Dahlbominus fuscipennis is a common parasite of the cocoon stages of the European spruce sawfly and other sawflies in Europe. Importations from that region by the Canadian Department of Agriculture have been made since 1933, and several hundred million have been propagated in the insectary since then for release against the pest in that country. During 1935–39 several million adults were sent to the United States by that Department, a portion of which were liberated directly against the spruce sawfly and related species, and the remainder were utilized for large-scale rearing by the Bureau of Entomology and Plant Quarantine, the Maine Forest Service, and the New Jersey Department of Agriculture.

The first release in the United States, consisting of approximately 30,000 adults, was made in northern Maine in August 1935, and in the following years the parasite was colonized in very large numbers throughout the range of the host in the Northeastern United States. More than 200 million were liberated in Maine by the end of 1939, and 30 million in New Hampshire, Vermont, and New York (*50*). In 1941 releases were made in Alabama, Michigan, South Dakota, and Tennessee in infestations of native sawflies.

The initial field recovery was made at Orange, Conn., in 1936 from a colony released the same season, and the following year it was taken at two points in Maine and in New York, where liberations had been made in 1936. It is now established, and at times shows a high parasitization at many points in the infested area.

Releases were made in infestations of *Neodiprion sertifer* in New Jersey in 1939, and establishment at a number of points was recorded the following season. Collections of cocoons in 1941 showed a high percentage of parasitization.

The recovery of this parasite from *Diprion frutetorum* (F.) at Southington, Conn., in 1941 is of particular interest, as this locality is 25 miles from the nearest release point where *fuscipennis* had been established in 1936.

D. fuscipennis (*107*) is a gregarious external parasite of the full-grown larvae, prepupae, and pupae of the sawflies in their cocoons. Twenty or more eggs are laid on a single host at one insertion of the ovipositor after the host has been partially paralyzed by stinging. The cycle from egg to adult ranges from 25 to 50 days, with an average of about 31 days at summer temperatures. Hibernation takes place in the mature larval, prepupal, and pupal stages in the host cocoons. In Canada there are 2 generations and a partial third each year. A portion of the larvae of the first summer generation go into diapause,

with adult emergence delayed until the following season. The average number of individuals developing in a cocoon is 34, though more than 100 have been recorded. The entire colony emerges from the cocoon through a single emergence hole. The average number of progeny per female is less than 100. The sex ratio is variable, with the females always predominating; it is as high as 9 to 1 in some rearings.

Dexilla ventralis (Ald.) (Tachinidae)

Dexilla ventralis, a polyphagous parasite, was first found in Korea in 1922 (*24*), where it is parasitic in grubs of several species of *Popillia* other than *japonica*, and in *Miridiba*, *Phyllopertha*, *Anomala*, and *Serica*. The first shipment to the United States was made in 1925, and others during 1926–27 and 1929–31. A total of 50,324 insectary-parasitized grubs were forwarded. The first liberation was made at Haddonfield, N. J., in 1926 (*15*), and adults were recovered the following season. Releases have been made at other points in New Jersey and in Pennsylvania, New York, Maryland, and Illinois, but the Haddonfield colony is the only one known to be established, and even there the population is exceedingly low and there are no indications of spread.

The failure of *ventralis* to become effective against the Japanese beetle in the United States may be attributed mainly to a lack of suitable alternate hosts to bridge the summer period when *Popillia* grubs of a suitable stage of development for parasitization are not available in the field.

D. ventralis is a solitary internal parasite of the grubs of the various scarabaeid genera mentioned. The female fly deposits young larvae or eggs in varying stages of incubation on the surface of the soil, presumably near host grubs. The larvae then burrow about in the soil in search of the grubs, which they enter by boring through the skin. A respiratory funnel is formed at the point of entry, and this attachment is retained through almost the entire life of each larva. The blackish funnel is distinctly visible within a few hours after the host grub is entered and serves as a ready means of recognizing parasitized individuals. The host grub is usually full grown before death. Pupation of the parasite takes place in the soil near the remains of the host.

In Korea, where detailed life-history studies were made, there may be 3 generations each year, the overwintering one being in grubs of *Miridiba*, the second in *Popillia*, and the third in *Serica*, all of which are reasonably abundant. However, a portion of the winter generation is in *Popillia*, and the flies from this host emerge later than those from *Miridiba*. The summer generation from this stock is in *Serica*, followed by attack on *Popillia*, *Phyllopertha*, or *Miridiba*, so that only 2 generations develop during the year rather than 3 when *Miridiba* is the overwintering host.

Erynnia nitida R.-D. (Tachinidae)

Efforts have been made over an extended period of years to establish *Erynnia nitida*, a European parasite of the elm leaf beetle, in the

Eastern United States. The first importation was in 1909, when a consignment of puparia was received from Italy, but no parasite emergence was obtained. A second lot was received in 1911, from which liberations of an unknown number of adult parasites were made in New England. Additional importations were made from France in 1924–25 and 1932–35, comprising more than 100,000 field-collected hibernating beetles, 5–15 percent of which contained parasitic larvae, and 1,500 puparia. Emergence from this material was very poor, and the number of adult parasites that became available for release was small. Small parasite colonies were liberated in the field in Virginia in 1925, Massachusetts in 1934, and Connecticut and New Jersey in 1935. A single individual was recovered in 1935 at Woburn, Mass., where a colony had been placed the preceding year. The parasite has not been taken since that time, and there is no reason to believe that it is established in the Northeastern United States.

In 1939 the University of California undertook the importation of *Erynnia* for colonization against the beetle in that State (*63*). The shipment from France consisted of only 55 puparia, from which 28 male and 14 female parasites emerged after arrival. They were mated and utilized for laboratory propagation. On May 23, 1939, 11 mated *Erynnia* females were liberated in 3 colonies at Stockton and Manteca, and these were supplemented by the release of 16 females on June 17 and 4 on August 8. Thus only 31 mated females were released. Recoveries were made at the 3 original colony sites in September, and later collections of overwintering beetles at one of these points showed a parasitization of about 10 percent. Beetles collected during the winter of 1940–41 showed a parasitization of 20 percent, and an even higher rate of attack was noted in some localities in later years. A small liberation of adult parasites from the California colonies was made in Oregon in 1941.

The fully incubated egg of *nitida* is deposited externally on the leaf beetle larva, and on hatching the maggot bores into the body. There are at least 2 summer generations in these larvae, the life cycle being about 1 month. Parasitized larvae leave the elm foliage and move to the trunk of the tree, where they die. Pupation takes place within the dried skin of the host. A very unusual change in habit takes place in the overwintering parasite generation. Instead of maturing and pupating in the autumn brood of host larvae, the parasite larvae carry through into the adult beetles, which pass the winter in sheltered places. In the spring, after the beetles emerge and begin feeding, the parasite larvae resume their development. The host is quickly killed, and pupation takes place in the beetle body. Only a single individual develops to maturity in each host larva or adult.

Eupteromalus nidulans (Thoms.) (Pteromalidae)

During the winter of 1905–6 enormous numbers of hibernating webs of the brown-tail moth were received from various parts of Europe (*14, 89*), and from them large numbers of *Eupteromalus nidulans* (referred to in early-American publications as *Pteromalus egregius* Foerst.) emerged during the spring of 1906. Forty thousand adult parasites were colonized that year at 9 points near Boston, Mass., and about the same number at 8 additional points in 1907. The 1908

liberations totaled 116,000, some of which were colonized in the spring and the remainder in September. Total liberations during 1906–9 were 530,000, most of which were obtained by domestic rearing.

The first field recoveries were made at Concord, Mass., in the fall of 1908 at points where the parasite had been colonized earlier that season. By 1916 it had spread over practically the entire area inhabited by the host. It declined in abundance after that time and has since been of little consequence as an enemy of the brown-tail moth.

Since the establishment of the satin moth in New England, where it was first found in 1920, *nidulans* has attacked it more extensively than the brown-tail moth, and it is assuming a status of some importance in the control of that pest. In 1929 the average parasitization over the entire infested area in New England was 9 percent. It was colonized in Washington against this pest during 1931–34, when a total of 11,727 adults were liberated. Several recoveries were made in 1935 at considerable distances from the colonization sites.

E. nidulans (*118*) is a solitary or gregarious external parasite of the larvae and pupae of the brown-tail and the satin moths and of several other Lepidoptera. The winter is passed in the full-grown larval stage in the webs of the brown-tail moth and the hibernacula of the satin moth, and pupation takes place in those locations in the early spring. The adults emerge in May and June. The spring generations, of which there appear to be 2, develop mainly as hyperparasites, through *Apanteles*, *Meteorus*, and other Hymenoptera, though only in very small numbers. These hosts are present in the cocoon stage at that season. There are 3 generations on the satin moth in the fall, the last of which hibernates. In oviposition the female first stings the larva, inducing permanent paralysis, and then deposits her eggs on the body. The female often feeds on the body fluids of the host after stinging it, a feeding tube having been made for this purpose. This habit of feeding may add to the pest mortality. The adults of *nidulans* are long lived, and the reproductive capacity is high. A number of females under observation averaged 251 eggs each, with a maximum of 583.

Exochomus quadripustulatus (L.) (Coccinellidae)

Exochomus quadripustulatus is one of the most common coccinellids in southern Europe, where it preys on various lecaniine Coccidae and aphids. It was first imported into the United States from France in 1905–6, and small colonies were released in mixed infestations of scale insects at North Saugus, Mass., in the spring of 1906, but there is no record of any recoveries. Importations were made from Italy in 1915 by the California State Commission of Horticulture and in 1927 by the University of California. The 1915 releases were on citrus and olive trees infested with several species of scale insects and mealybugs in Sacramento County, but again establishment was not effected.

The 1927 and 1928 releases, consisting of insectary-reared material, were on a larger scale and in infestations of several scale insects (*105*). The first recovery was made in August 1928 in San Mateo County, where the beetles were found feeding on *Physokermes insignicola* (Craw) on Monterey pine. Specimens were later taken also from sycamore infested with *Stomacoccus platani* Ferris. By 1934 the

predator had spread to many parts of the State. The most recent observations indicate that it is becoming an important enemy of the woolly apple aphid.

Exorista larvarum (L.) (Tachinidae)

Exorista larvarum is one of the important parasites of the gypsy and brown-tail moths in many parts of Europe, and it attacks a number of other lepidopterous insects as well, including the satin moth. The first importations into the United States that yielded *larvarum* were from Italy in 1905 (*14, 89*), but no releases were made that year. The shipments from several other European countries in 1906 through 1908 produced a few small and unsatisfactory colonies for liberation in New England against the gypsy moth, but those of the following 3 years were on a larger scale. The releases of 1906 through 1912 totaled 3,363 adult parasites. No recoveries were made from any of these colonies, and the attempt to establish the species was abandoned until 1923, when importations were again undertaken, this time on a much larger scale, and continued until 1932. The liberations in New England totaled 3,001 parasites in 1925, 16,749 in 1926, and 19,039 in 1927, with an unknown number from 1928 through 1932.

The first field recovery from the gypsy moth in New England was at Waterbury, Conn., in 1940, and in 1941 the parasite was taken in 11 townships in Maine, New Hampshire, and Massachusetts (*123*). The greatest number were recovered at Salisbury, Mass., where a parasitization of 9 percent was noted. It was also recovered from the brown-tail moth at 2 points in New Hampshire the same year and from the satin moth in Connecticut in 1940. Small releases were made against the satin moth in Washington in 1933, but no recoveries have yet been made in that State.

E. larvarum is virtually indistinguishable in the adult stage from the American species *E. mella* (Wlkr.), though it differs in habit to the extent that pupation is normally outside the host body, whereas the latter species pupates within the remains of the host. In the course of the early work in New England it was considered probable that the 2 species would interbreed, and that the preference of *larvarum* for the gypsy and brown-tail moths would consequently be eliminated. *E. mella* seldom develops on these pests in the field. No experimental data have been presented in support of the above conclusion, but because of its possibility *larvarum* was removed in 1912 from the list of European species considered to be promising in the biological control of these 2 pests in New England. This decision was later reconsidered, and the large-scale releases since 1925 resulted in establishment. The delay in recovery until 1940 and 1941 can probably be attributed to the difficulty of distinguishing the imported species from *E. mella* and, to a lesser extent, to insufficient surveys in the colonized areas.

E. larvarum is a solitary or gregarious internal parasite of the gypsy, brown-tail, and satin moth larvae. Its relatively large eggs are deposited directly on the caterpillar where they hatch, and the maggots immediately burrow into the body. They mature quickly and emerge from the caterpillar for pupation, though on certain other hosts in Europe they are reported to emerge consistently from the pupa.

There are several generations each year. At least one alternate host is required to enable the parasite to bridge the period in which gypsy, brown-tail, and satin moth larvae are not available for parasitization.

Habrolepis rouxi Comp. (Encyrtidae)

Habrolepis rouxi, a parasite of the California red scale, was imported from South Africa by the University of California in 1937, and during 1937–39 approximately 50,000 adults were reared and liberated in infestations on citrus in southern California (*67*) and an equal number on the olive scale in the San Joaquin Valley during 1941–42. Field recoveries from the red scale were made at many points during the season of release, but the parasite has persisted in only a single locality. This is at Chula Vista near San Diego, where about 1,000 females were released in 1937. In 1943 it was observed to be abundant, though apparently exerting no appreciable control, on a few semi-abandoned, untreated trees.

H. rouxi is a solitary internal parasite of the advanced stages of the red scale. Female progeny are produced generation after generation without the intervention of the male, though a small portion of the brood may be of that sex. The production of males is affected by several factors, such as the temperature and the type and condition of growth of the foliage or fruit on which the host scale grows.

Hambletonia pseudococcina Comp. (Encyrtidae)

In 1935–36 *Hambletonia pseudococcina* was found in Brazil and Colombia and was imported into Hawaii and Puerto Rico, where it became established on the pineapple mealybug. Two consignments of adult parasites obtained from Puerto Rico in 1943 for release in Florida failed to survive, but in May of the following year a total of 374 were received alive and utilized for field release. Colonies were placed in infested pineapple plantings at Fort Pierce, Boynton, and Sebring. Recovery collections made later at the first 2 points failed to show establishment, but the parasite was reared in some numbers from collections at Sebring in November 1944, 1945, and 1947. No information is available regarding its later spread and effectiveness.

Horogenes punctorius (Roman) (Ichneumonidae)

Horogenes punctorius is one of the important parasites of the larvae of the European corn borer in Europe and the Far East. It passes the winter in the early larval stage in the host caterpillars, and thus was contained in the millions of hibernating borers shipped to the United States from France and Italy during 1921–23 and 1925–37 and from Manchuria during 1930–32 (*4*). From this material 84,710 adult parasites became available and were released in all infested areas. These colonies were supplemented in later years by 44,475 obtained from domestic sources. The first colonies derived from imported summer cocoons were released in Massachusetts in 1921 and 1922, but they comprised only 178 parasites. None were released in 1923 and only 186 in 1924. Recoveries were recorded in Massachusetts and Michigan in 1926, Ohio in 1927, Rhode Island in 1928,

and Indiana in 1929 from the larger releases of later years, but only the colonies in Massachusetts and Rhode Island persisted.

The increase of *punctorius* in the 2-generation area was particularly encouraging. Thus in 1 locality in southeastern Massachusetts in the autumn of 1939 the field parasitization averaged 11 percent, and parasitization up to 35 percent was noted in Connecticut. The 1940 collections showed a marked increase in central Connecticut, where 33 percent of the borers collected were parasitized, and a considerable number of samples showed a parasitization in excess of 50 percent. However, this field abundance did not continue, and the 1945–48 collections showed a maximum parasitization of only 14 percent in Massachusetts, where the species is now most abundant, and much less in adjoining States. Recent surveys show that the parasite has also persisted, but at a low level, at the Cattaraugus Indian Reservation in New York.

Results of the introduction of the parasite in the Lake States were not encouraging until 1948, when it was found to be widely established in northwestern Ohio. Additional recoveries in 1949 and 1950 disclosed establishment in adjoining areas in Indiana and Michigan. Releases in Iowa and Minnesota in 1949 resulted in establishment and spread at several points.

H. punctorius is a solitary internal parasite of the larvae, and has one or more generations each year, depending on the seasonal cycle of the host. It passes the winter as a first-instar larva in the body cavity of the full-grown host larva. The adults emerge in late June and July and oviposit in second- to fourth-instar hosts. A summer generation is completed in 25–36 days, with the egg, larval, and cocoon stages requiring an average of 1¼, 15, and 9–10 days, respectively, at 80° F.

Hyperecteina aldrichi Mesnil (Tachinidae)

Hyperecteina aldrichi (=*Centeter cinerea*), a parasite of the adult Japanese beetle, was the first of its natural enemies to be discovered in northern Japan shortly after the investigations were begun in 1920 (*24*). In Hokkaido, the northern island, it was very evident that the fly was mainly responsible for holding the pest in check, as field parasitization ranged up to nearly 90 percent of the females in years when the beetle population was relatively low and slightly less in years when the beetle population was considerably higher. This finding led to high hopes that the species would be equally useful and effective against the beetle in the United States.

The first importations were made in 1920, and a total of 637,000 dead parasitized beetles containing parasite puparia were shipped to the United States during 1920–24, 1927–30, and 1933. Colonies of adult parasites were first liberated in Burlington County, N. J., in 1922, and recoveries were made the following season. The parasite is now established over an area of about 500 square miles in New Jersey and Pennsylvania, and at South Egremont, Mass., and East Hartford, Conn., but unfortunately it has not lived up to expectations. The flies emerge in the field several weeks or more in advance of the beetles and, although a fair portion of the early-emerging beetles may

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be parasitized, the flies disappear before the peak of beetle emergence is reached, and the total parasitization of the host brood is consistently less than 1 percent. It has been hoped that this difficulty in time of emergence might be overcome by natural selection, but during the more than 30 years that the species has been established in the United States there has been no indication of a closer synchronization in time of emergence.

H. aldrichi has a single generation each year, and the winter is passed in the pupal stage within the body of the dead beetle in the soil or under rubbish. Emergence takes place in early summer, mostly in June, and after a short preoviposition period, the female begins her attack on the adult beetle. About 90 percent of the eggs are placed on the dorsum of the thorax, and 85 to 96 percent on the female beetle. The egg is hard-shelled, white, and very conspicuous against the dark-green background of the beetle thorax. Hatching takes place after about 2 days, and the young maggot bores directly downward through the heavy wall of the thorax into the body cavity. It moves about freely in the body, and at no time is there a permanent respiratory attachment with the tracheal system or through the integument of the host. The larval period is completed in about 9 days, and death of the host takes place 5–6 days after deposition of the egg. The puparium is formed in the beetle abdomen, and always lies with its head end at the tip of the abdomen. This position facilitates the later emergence of the adult fly. Only a single parasite develops to maturity in each beetle.

Lecaniobius utilis Comp. (Eupelmidae)

The importation from Brazil and Argentina of *Lecaniobius utilis*, an egg predator of the black scale, was undertaken by the University of California in late 1934 and early 1935 (*25*). A total of 151 adult parasites emerged from the scale material after arrival in California. This stock was increased by insectary propagation, and the first colony, consisting of 100 mated females, was liberated at Oxnard, Calif., on June 13, 1935. Field recoveries were made the following October. Inasmuch as the habits of *utilis* are the same as those of *Scutellista cyanea*, which effects a high parasitization in the coastal sections, it was not expected that this species would aid appreciably in control. Establishment is known to have taken place only in Riverside and Ventura Counties, and in the latter county the species was found in 1941 in an infestation of nigra scale rather than on the black scale.

L. utilis oviposits preferably beneath lecaniine scales when they are beginning to deposit eggs. The ovipositor is thrust beneath the scale margin, and the stalked egg is placed so as to adhere to the venter of the scale or to the substratum. The minimum life cycle is about 30 days, whereas the maximum approaches 6 months, owing to the larval diapause during the winter.

Leis dimidiata 15-spilota (Hope) (Coccinellidae)

Leis dimidiata 15-spilota, a predator on various aphids, was imported from South China in 1924 by the University of California.

It was propagated and liberated in California during 1925, but did not become established.

A consignment was sent from California to the Florida Agricultural Experiment Station in June 1925, and between 40 and 50 colonies were reared and released in citrus groves in that State during 1926. The species has become well established at Windermere and Orlando, where it feeds on a variety of aphids. In the latter locality in 1933 it was abundant on papaya foliage, feeding on *Trialeurodes variabilis* (Q.). At that time the *Leis* beetles were noted on papaya and citrus in greater numbers than any native species had been seen in the State. The adults feed extensively on honeydew secreted by leafhoppers on corn. For several years after its establishment *Leis* was considered to be an important agency in the control of citrus aphids in the sections of the State where it was established, though unfortunately it proved later to be seriously affected by below-average winter temperatures.

Leptomastidea abnormis (Gir.) (Encyrtidae)

The importation of *Leptomastidea abnormis*, a parasite of the citrus mealybug, from Sicily to the United States was accomplished by the California State Commission of Horticulture in 1914 (*145*). Several consignments of host material were received during July and August of that year, and from one of these a small number of *abnormis* emerged. Insectary propagation resulted in the production of several hundred thousand adult parasites for field release during the following two seasons. The first field liberations were at Alhambra, Calif., from August 1914 to March 1915, and recoveries were made in July of the latter year. Colonies were then released in all infested sections of the State, and establishment was effected in almost every locality. Shipments were also made during this period to Florida, Louisiana, and Hawaii. Increase of this parasite in the field in California was rapid and high populations were attained. Although it has unquestionably had some influence on field infestations, it has not been able, alone, to hold the pest generally at a noninjurious level.

Since its establishment in California, the parasite has been recorded from many sections of the United States, where it has not been intentionally colonized, and its distribution is probably very general at the present time. The host is a common greenhouse pest, and it is assumed that distribution of the parasite has taken place incidental to movement of infested greenhouse plants.

L. abnormis is a solitary internal parasite, and attacks the first and second instars of the host. Development from egg to adult is complete in about 25 days at optimum temperatures. In addition to the citrus mealybug, this parasite has been reared from *Pseudococcus krauhniae* (Kuw.) in California and from that host and *Ferrisia virgata* (Ckll.) in Hawaii.

Lindorus lophantae (Blaisd.) (Coccinellidae)

Lindorus lophantae was included among the many Coccinellidae imported into California from Australia by Koebele in 1891–92 for use mainly against the black scale. It was first liberated in southern

California in 1892 and recovered the same season. It now occurs generally and often abundantly in that section and in central California (*53*), and preys most frequently on various diaspine Coccidae, especially the California red scale and to a limited extent on soft scales and mealybugs.

The eggs are placed singly in crevices near the host scales, and the life cycle covers 22–29 days at summer temperatures.

Lixophaga diatraeae (Tns.) (Tachinidae)

Lixophaga diatraeae is the most important parasite of the sugarcane borer in Cuba and some other West Indian islands. The efforts to bring about its establishment in the United States cover a period of about 25 years beginning in 1915, at which time small importations were made from Cuba and 1 colony was released at New Orleans (*94*). Further importations were made in 1918 and a few individuals were released. In 1919 and 1920 large numbers were received, and colonies totaling 2,718 adults were released at 45 points in southeastern Louisiana. Field recoveries were made at most of these points, and rather extended spread was noted from some of them. The parasite persisted for a number of years, and recoveries were made at 3 colonization points as late as 1925, but none thereafter.

It was thought that conditions in southern Florida where sugarcane is grown would be more favorable for the parasite than Louisiana; consequently, the importations from Cuba in 1926–27 and those from Puerto Rico in 1936 and 1938 were colonized in that State (*92*). The 1926–27 importations were by the Florida Agricultural Experiment Station and comprised 1,760 parasite puparia. The number of adults released exceeded 1,000. The 1936–40 imports from Puerto Rico and Cuba were utilized in part as rearing stocks, from which a total of about 2,500 adult parasites were released. Since 1938 the Fellsmere Sugar Producers' Association has cooperated in this work, and has employed an experienced entomologist to conduct parasite rearing and colonization.

The first field recovery was made at Fellsmere in January 1937, and the parasite has since been taken in increasing numbers each season. A 20-percent parasitization was noted in one field in 1938 and 55 percent in another in 1939. Establishment has also been effected in the Lake Okeechobee section. The parasite survived the severe winter conditions of 1939–40, and a parasitization up to 35 percent was noted early in 1941, increasing to an average of 47 percent later the same season (*122*). It has been credited with bringing about an appreciable reduction in the infestations in the Fellsmere area, though populations appear to be seriously affected by exceptionally low winter temperatures, and recolonization following such winters may be helpful in restoring the parasitization to its previous level.

L. diatraeae (*121*) is a solitary internal parasite of the cane borer larvae. In Cuba there are 8–10 generations each year, though in Florida the number is probably somewhat less. The eggs are fully incubated and hatch in the oviduct of the parent female. The young maggots are deposited on the cane stalk at or near a borer entrance hole, and they then enter the tunnel and bore into the bodies of the host larvae. The respiratory funnel, formed very soon after entry

by the maggot, is connected with one of the main tracheae of the host near one of the first or second abdominal spiracles. Some of the second-instar maggots lie free in the host body, and this is always true of those of the third instar. Larval development of the parasite is complete in about 9 days, and the host dies 1–2 days before the maggot emerges for pupation. The pupal stage covers 9–11 days, and the puparium is found in the tunnel of the host. Although *diatraeae* is normally solitary in habit, several individuals have been known to develop to maturity in a single host. On occasion maggots may issue from the host pupa rather than from the full-grown larva.

Lydella stabulans grisescens R.-D. (Tachinidae)

Lydella stabulans grisescens, listed in the early publications as *Masicera senilis* Rond., is a common parasite of the larvae of the European corn borer in Europe and the Far East, and was the most important parasite observed attacking that pest in Japan and Korea. It passes the winter as a young larva in the hibernating host caterpillar, and it was in this stage that most of the material from abroad was received. The large-scale shipments of hibernating borers from France and Italy during 1920–35 yielded 668,120 adults of *Lydella* for release, whereas those from Japan and Korea during 1929–36 produced 90,147. A few small colonies were released in Massachusetts during 1920–22 and in 1925, following which large colonies were placed in all of the heavily infested States (*4*). Total releases by the end of 1935 numbered more than 700,000.

The first field recovery was made in Massachusetts in 1927, and in the following years this parasite was recovered in Rhode Island, New York, Ohio, and Michigan. However, most of these recoveries did not represent permanent establishment. In the Great Lakes area the parasite has persisted only in a small section of Ohio and Michigan, representing a strip only a few miles wide bordering Lake Erie and extending from Sandusky, Ohio, to Detroit, Mich. In this limited area it is the most abundant of the established foreign parasites, many collections showing a parasitization in excess of 50 percent. In New England the area of establishment is limited to Massachusetts, Connecticut, and Rhode Island. The parasite is now generally distributed over an area of approximately 22,000 square miles in the Middle Atlantic States, extending from New Jersey and eastern Pennsylvania southward into North Carolina. The parasitization ranged from 16 to 45 percent for all samples taken in 1948.

The extensive colonization program in the North Central States since 1944 has resulted in wide establishment in Illinois, Indiana, and the eastern half of Iowa, with a percent parasitization during 1949–50 ranging up to 63 in Illinois, 45 in Indiana, and 70 in Iowa. Dispersion from colony sites in southern Indiana has exceeded 10 miles per year. This species has also become abundant at 2 points in Kentucky.

L. stabulans grisescens is a solitary internal parasite of the corn-borer larvae, and attacks principally those of the fourth instar. There are two generations each year, and the winter is passed as a second-instar maggot, occasionally as a first instar, in the body of the host. A portion of the young larvae of the early-summer genera-

tions enter diapause and do not progress to maturity until the following spring.

The female fly deposits living larvae rather than eggs, and up to 1,000 eggs in various stages of incubation may be found in the oviduct. Hatching takes place during larviposition. The young maggots are deposited directly into the opening of the burrow of the host or in the frass and excrement, which often cover the opening. They immediately seek the host larva and enter the body either through a natural opening or by boring through the skin. An attachment is soon made with one of the main tracheal trunks in the anterior portion of the body, and a respiratory funnel is formed. This connection is maintained until the host dies, which takes place shortly after the second molt of the parasite. At the completion of feeding, the maggot leaves the host through a rupture in the skin and pupates in the burrow nearby. The larval and pupal stages of the female cover 8 and 9 days, respectively, when reared at 80° F., and each stage of the male requires 1 day less.

Macrocentrus gifuensis Ashm. (Braconidae)

Macrocentrus gifuensis is common in some parts of Europe, where it at times parasitizes up to 40 percent of the caterpillars of the European corn borer occurring in *Artemisia*. It is likewise one of the most important parasites of this pest in the Far East, especially in southern Japan and Korea. The first importations comprised 3,885 cocoons from northern France in 1926 and 2,080 in 1927. Large-scale rearings from the millions of hibernating host larvae received from that country up to 1933 and from Japan and Korea during 1929–32 yielded 337,870 adult parasites for colonization in the United States. Total releases through 1940 comprised approximately 421,000 adults in 8 States (*4*).

The first liberations were in Massachusetts in 1926, and large releases were made in all infested States during the following 6 years and in 1940. Recoveries were made near Boston in 1928 and thereafter in most States in which there had been releases. However, the colonies in the Lake States area did not persist, and the present general distribution is limited to certain sections of the 2-generation area, especially southeastern Massachusetts and Connecticut. In these sections it spread rapidly and effected a high parasitization in some localities. At the end of the 1939 season the average parasitization in southeastern Massachusetts was 11 percent, with a maximum of 52 percent in one collection; whereas in 1940 the average of the samples taken was 26 percent. However, in 1941 the figure declined to 14 percent, this being correlated with a marked reduction in the host population. Up to 25 percent of the hibernating borers in Connecticut, Massachusetts, and Rhode Island were parasitized during 1946–50.

The development of *gifuensis* to a status of importance as the dominant species in southeastern Massachusetts is of particular interest. The last releases of foreign stock were made in 1932, and for a number of years thereafter the species was found only in very small numbers, indicating establishment but giving no promise of becoming of value in control of the host. In the autumn of 1937

the average parasitization at Taunton, Mass., was only 1 percent, but this increased to 8 percent in 1938 and to 25 percent or more from 1938 to 1948. Because of this demonstration of potential value in control a further colonization program was undertaken in 1938 and the following years with stock from field collections made in the Massachusetts area. This program covered mainly the 2-generation area from Connecticut south to Virginia.

During 1944–47 an extensive colonization program was undertaken in the North Central States, but permanent establishment is not yet certain.

M. gifuensis is one of the interesting groups of parasites that reproduce polyembryonically (*114*). The seasonal cycle is synchronized with that of the host, so that there may be 1, 2, or 3 generations each year. The adults emerge in June and July in the 1-generation areas, earlier in more southern localities, and deposit their eggs in second- and third-instar corn borer larvae. A single minute egg is deposited in the body cavity at each insertion of the ovipositor. This egg then undergoes a complex growth and development, which culminates in the production of 10 or more first-instar larvae from the single egg. From then on the larvae develop as in the monembryonic species, passing through 4 stages. Emergence from the body of the host larva takes place immediately after the third molt. Feeding is completed externally in a few hours, or it may extend to 1 day. The larvae then spin individual cocoons, all of which are bound together in a compact, irregular-shaped mass in the tunnel of the host. The winter is passed in the "morula" stage in the body cavity of the hibernating full-grown borers, and the first-instar larvae appear in April.

The adults that develop from a single parasitized host may number 40 or more, but the general average is 21. They may be the product of a single parasite egg or of several. The colony may be exclusively of one sex or it may comprise both sexes. Among 200 representative colonies, 71 were of males alone, 54 were exclusively female, and 75 included both sexes. The mixed broods are presumably the product of several eggs deposited in the individual host, at least one of which has been fertilized. Usually there are more larvae and germs present than can be nourished by the amount of food in the host body. The excess number are destroyed through the feeding of the survivors.

The reproductive capacity is relatively high, as each female is capable of producing 200–300 eggs. On the basis of 10 individuals being derived from each egg there is a total potential of several thousand progeny.

Meteorus versicolor (Wesm.) (Braconidae)

Meteorus versicolor, a solitary parasite of the larvae of the gypsy, brown-tail, and satin moths in Europe, was first imported for use against the brown-tail moth in New England during 1906–11 (*14, 89*). The emergence from the 1906 and 1907 shipments totaled less than 100 individuals, and these were utilized mainly in laboratory experiments, though it is recorded that a few were colonized, and recoveries were made at the colony site the same season. The first satisfactory field colony, consisting of 1,000 individuals, was liberated in a brown-

tail moth infestation in New England in 1908, and numerous recoveries were made during the autumn of that year. Total releases up to 1916 numbered approximately 11,000 adults, of which 3,113 were of foreign origin and, in addition, an unknown number were contained in imported brown-tail webs that were placed directly in the field for emergence of other parasite species. The parasite is now rather generally established over the infested area in New England, though the parasitization is consistently less than 5 percent. It therefore cannot be considered as an important aid in checking the brown-tail moth.

Importations directed specifically against the satin moth were made from 1932 through 1934. During this period 35,226 cocoons of this moth were shipped to the United States from Austria and Hungary, and 20,000 adult parasites emerged and were liberated in New England and Washington, the releases in the latter State totaling 5,500 during 1932–34. The parasite did not become established on the satin moth in New England, but was recovered in considerable numbers in Washington in 1934 and the following years (*97*).

When the females of *versicolor* are attacking the brown-tail moth, they oviposit in the young caterpillars during August and September (*109*). The egg increases greatly in size during incubation and hatches in 5–6 days. The first-instar larva has an exceptionally long tail, or "caudal horn." The winter is passed in this stage within the hibernating caterpillar. After the host begins feeding in the spring, the parasite larva renews its growth and attains the full-grown stage in 10–14 days. The parasitized host molts only once and dies after the parasite larva leaves the body. The parasite cocoon is unusual in that it is suspended from the leaf or twig by a silken thread, an inch or more in length, extending from the posterior end. The cocoon stage covers 13–14 days.

The adults that emerge in the spring immediately attack the caterpillars then available, which are of the last two instars. There are thus two full generations on the brown-tail moth, followed by a partial third on various native hosts, of which the early stages are present in the field during midsummer. The females are long lived, so that these alternate hosts are not essential for the perpetuation of the species.

The cocoon stages are exceptionally susceptible to attack by other hymenopterous parasites, the mortality being consistently 50–75 percent or more. Also many larvae fail to progress to the pupal stage after spinning their cocoons. These two factors greatly reduce the effectiveness of the parasite against the brown-tail moth.

Monodontomerus aereus Wlkr. (Torymidae)

Monodontomerus aereus is a parasite of the pupae of the gypsy and brown-tail moths, and was imported from various parts of Europe during 1905–10 (*14, 89*). The bulk of the early material consisted of hibernating adult parasites obtained from winter nests of the brown-tail moth, which had been imported for other more important parasites that they contained. *M. aereus* was also reared in large numbers from gypsy moth pupae imported from Italy. A total of 1,700 adult parasites issued from brown-tail nests imported during the winter of

1905–6, and a colony of unknown size was released near Boston in the spring of 1906. No releases were made in 1907, but those of foreign stock obtained in 1908–10 brought the total number colonized in New England to 15,541.

Collections of winter nests of the brown-tail moth during the winter of 1908–9 near the original 1906 colony site showed that the parasite not only had become established but had spread at the rate of about 10 miles per year. By 1910 the species was distributed over the entire area of New England inhabited by the host.

M. aereus usually has only a single generation each year, though there may be a partial second. The winter is passed in the adult stage, and by the females only, in the compact brown-tail moth webs and in old cocoon masses (*111*). These females become active in April and May and begin oviposition 2–3 weeks later. Oviposition takes place in the pupae, and 1–4 eggs are deposited at each insertion of the ovipositor. This parasite also develops in the pupae of the gypsy moth and of several native Lepidoptera.

A striking feature in the biology of this parasite is that although development is internal when the host is a lepidopterous pupa, it becomes external in habit when in the secondary role through various Hymenoptera and Diptera. The most common hosts among these orders are the several ichneumonid, braconid, and tachinid primary parasites of the gypsy and brown-tail moths. The most serious effect results from attack on several of the more important tachinid species that do not enter the soil for pupation. The eggs are placed externally on the larvae or pupae within the cocoon or puparium. These stages are usually killed or permanently paralyzed at the time of oviposition. However, in very fresh tachinid puparia, the eggs are placed internally, but many individuals die after attaining larval maturity, apparently due to unsuitable physical conditions in the puparium at that time.

The egg of *aereus* is distinguished from that of most other species of similar habit that are associated with the gypsy and brown-tail moths, because its surface is thickly covered with minute spicules. Only 18–30 days are required for development from deposition of the egg to emergence of the adult. Twenty-four adults have been reared from a single puparium of *Compsilura concinnata*.

Among the progeny, females normally predominate in the ratio of about 2 to 1. The females are very long lived, persisting for 11 months or more, and they may go into hibernation as early as the middle of August. During their active period they feed very extensively on the body fluids of the hosts. The insertion of the ovipositor is often to provide a means of access to the body fluids of the host for feeding rather than for oviposition. A feeding tube, extending from the body wall of the host to the outer surface of the cocoon or puparium, is formed about the ovipositor, and when the latter is withdrawn the tube serves as a channel by means of which the parasite can feed.

This parasite provides an excellent example of the complex problems that may arise in a biological control project. The species was first released on the assumption that it was a true primary parasite, but when indications of its hyperparasitic habit appeared, with various Ichneumonidae and Tachinidae as hosts, the colonization program was discontinued. Further studies indicated that it was an important

parasite of the pupae of the gypsy moth and, on the basis of this information, more releases were made during 1908–10. A study of the field status of the parasite in New England 20 years after its establishment indicated that, as a whole, it is probably more harmful than beneficial. Collections of *Compsilura* and *Blepharipoda* puparia have shown a parasitization up to 37 percent in some localities, and it is believed that many more are killed by the direct feeding of the females. However, during most seasons and in most localities *aereus* is not sufficiently abundant to be of any importance in either role.

Mymar pratensis (Foerst.) (Mymaridae)

Some confusion exists with respect to the importations of *Mymar pratensis*, an egg parasite of the alfalfa weevil, from Italy during 1911–13 (*18*). All mymarid material contained in dried alfalfa stems received during those years was recorded as *Anaphoidea* sp., and it was not until several years later that *pratensis* and *A. luna* Gir. were differentiated. Consequently, there is no means of determining the number of *pratensis* specimens that were received and liberated. Releases of the 2 species in the vicinity of Salt Lake City, Utah, totaled 345 in 1911, an unknown number in 1912, and 1,395 in 1913. Rather extensive surveys in alfalfa fields in the areas of release, the last in 1923, indicated that establishment had not been obtained.

Importations from Italy were resumed from 1925 through 1928, and field releases in Utah in these years totaled 8, 1,730, 112, and 498, respectively. The first recoveries were made in the spring of 1926 (*86*), when adults were reared from eggs collected at 1 colony site, and in 2 other localities from eggs of the clover leaf weevil. No recoveries were made in 1927, but the parasite was taken during the following 3 years in a field adjacent to one at West Jordan, Utah, in which releases had been made in 1928. In 1929 collections of overwintering eggs of the clover leaf weevil were reported to be parasitized to the extent of nearly 50 percent. Field parasitization of the alfalfa weevil does not exceed 4 percent. It therefore appears that *pratensis* is more properly a parasite of the clover weevil, utilizing the alfalfa weevil as an alternate host, and this may account for the difficulties experienced in establishing it on the latter pest.

M. pratensis is a solitary internal parasite of the eggs of the alfalfa weevil, whereas two individuals usually develop in each egg of the clover leaf weevil. Parasitized eggs in the later stages of their development may be recognized by the presence of circular reddish spots. The life cycle has not been studied, but related species develop from egg to adult in a few weeks and there are probably a number of generations each season. The overwintering habit is not known. Obviously it cannot be in the eggs of the alfalfa weevil, which hibernates as an adult, so that it probably is in the eggs of the clover leaf weevil, a few of which are reported to persist through the winter.

Ooencyrtus kuwanai (How.) (Encyrtidae)

The first importations of *Ooencyrtus kuwanai*, an egg parasite of the gypsy moth, were received from Japan in the spring of 1907 and the winter of 1907–8 (*14*, *89*), though no living parasites emerged

from the shipments after arrival in the United States. The importations of the winter of 1908–9 yielded a single female in February, and an unsuccessful attempt was made to secure reproduction in the laboratory by mating her with her own male progeny. Twelve adult females were obtained in April 1909, and these, with 21 that emerged later, provided a rearing stock from which large numbers of progeny developed in the following generations. Increase was so rapid that more than 1 million were on hand early in 1910. The total number of living *kuwanai* received from Japan and liberated during 1909–10 was 1,703, whereas more than 25 million were produced in the insectary and liberated by the end of 1927.

The first field colony was released in Massachusetts in August 1909, and releases were limited to that State during 1910–11, after which the parasite was colonized throughout the infested areas of New England and in New Jersey. Field recoveries were made at several of the colony sites the season of release, and the parasite soon became established throughout the southern portion of the range of its host in New England. Winter conditions are apparently adverse to its survival in the northern sections.

This species is a less valuable parasite in the United States than *Anastatus disparis*, though collections at a number of points in Massachusetts have shown a parasitization ranging up to 48 percent. The occurrence of several generations on the eggs of each brood of the host permits *kuwanai* to increase very rapidly under favorable conditions.

O. kuwanai, like *A. disparis*, is a solitary internal parasite of the egg of the gypsy moth (*34*), but differs from it in habit by ovipositing preferably in eggs in which embryonic development is well advanced rather than in freshly laid eggs. In New England there are four complete generations and a partial fifth each year, and the winter is passed by the adult females in the forest debris. These females become active during April. Two generations are produced in the spring in the overwintering host eggs, a portion developing in dead and infertile eggs. The adults are sufficiently long lived so that a portion of the females from the first spring generation survive to attack the freshly laid host eggs that are deposited in July. The third, fourth, and possibly several additional generations develop in the new eggs during the late summer and autumn.

The cycle from egg to adult is completed in about 21 days at summer temperatures. After deposition of the egg, the stalk remains fixed in the oviposition puncture in the shell, and the developing larva retains its connection with the egg remains, for respiratory purposes, until it is nearly full grown.

Mated females deposit an average of about 150–200 eggs each, and the progeny show a predominance of females in the ratio of about 3 to 1. Unmated females produce only male progeny, and the total number is much less than from mated females.

This parasite has been successfully reared in the laboratory in the eggs of a number of native Lepidoptera, some large eggs yielding up to five individuals, but it has not been found to attack these hosts in the field. A startling variation in its host relationship is revealed by its occasional development in cocoons of *Apanteles melanoscelus*.

a parasite of gypsy moth larvae. In one instance 17 adults emerged from a single cocoon.

Orcus chalybeus (Boisd.) (Coccinellidae)

Orcus chalybeus, a predator of diaspine Coccidae, was contained in the shipments forwarded by Albert Koebele from Australia that reached California during the first half of 1892 (*53*). The number of consignments that were sent and the number of beetles that survived are not known, but the total liberated from all importations was 978. They were placed in several orchards in Los Angeles and Santa Barbara Counties in southern California. Recoveries were made at Santa Barbara late in 1892 and the following season at Los Angeles. The original colonies at Santa Barbara were released in infestations of the black scale, and the beetles appear able to develop on lecaniine as well as diaspine Coccidae. This species apparently is not adapted to the hot interior valleys, and at the present time can be found only at Santa Barbara, where it is common but not abundant in infestations of California red scale.

Orgilus obscurator (Nees) (Braconidae)

Among the European pine shoot moth material imported from Austria, beginning in 1931, *Orgilus obscurator* was included in uncertain numbers, but the 1933–35 shipments from that country and from England in 1936 and Holland in 1937 totaled 4,200. The first field liberations were made at Brookline, Mass., in July 1931, after which releases were made at many points in New England.

Field recoveries were made at 2 points in Massachusetts in 1934, and the parasite has since been taken at 8 release points in Connecticut, Massachusetts, New York, and New Jersey (*49*). This parasite was first taken in the United States at Newport, R. I., in 1925, where it had apparently become established from an earlier accidental introduction, but all other recoveries are quite certainly from intentional colonizations.

O. obscurator is a solitary internal parasite of the full-grown larva, and may emerge from either the host larva or pupa. The adults appear in midsummer.

Parasetigena silvestris R.-D. (Tachinidae)

Parasetigena silvestris, which is listed in earlier publications dealing with biological control of the gypsy moth as *P. segregata* Rond. and *Phorocera agilis* R.-D., is found commonly throughout Europe as a parasite of the caterpillars of the gypsy moth, the nun moth (*Lymantria monacha* (L.)), and, to a lesser extent, the brown-tail moth. The early records relating to its importation are confused because of difficulty in distinguishing it from several native species. It was contained in the shipments of gypsy moth material received from Europe during 1906–11 (*14, 89, 123*). A total of 641 adults were liberated at North Andover, Mass., during May and June 1910, but no recoveries were made at this colony site.

A second attempt to effect establishment was made in 1924–33, when colonies were placed in 22 localities in Massachusetts, New

Hampshire, Maine, and Connecticut. Approximately 97,000 adults, mostly mated females, were released during this period. Field recoveries were made at Boxford, Mass., in 1927, where the parasite had been released the same season, and at 5 other colonization points in that State, the only ones surveyed, in June 1940. In 1941 it was taken in 33 out of 70 townships surveyed in the 4 States in which releases had been made. The field parasitization ranged up to 18 percent, and a spread of more than 35 miles from several colony sites was noted. The delay in recovery is accounted for by the absence of collections in the colonized areas during the intervening period.

P. silvestris is normally a solitary internal parasite of half-grown and larger gypsy moth caterpillars. There is a single generation each year, and the winter is passed in the pupal stage in the soil. Emergence of the adults takes place in May and June. The preoviposition period following mating ranges from 5 to 15 days or more, depending on prevailing temperatures. The conspicuous white, hard-shelled eggs are usually deposited on the dorsum of the caterpillar, usually in the anterior region. Hatching takes place in a minimum of 2 days, and the young maggot immediately enters the body of the host at a point near where the egg was laid. A respiratory funnel is formed at the point of entry. The larval stage may range from 16 to 35 days. Emergence of the maggot is usually from the full-grown caterpillar, but occasionally from the pupa.

Paratheresia claripalpis (v. d. W.) (Tachinidae)

The first importations of *Paratheresia claripalpis*, a parasite of the sugarcane borer, were made from Argentina in 1929, when 7,146 parasite puparia were received. Shipments from Peru included 629,000 puparia during 1929–31 (*93*), in addition to 13,748 adult flies in 1932 and 314 in 1936. Field releases in Louisiana totaled 158,680 adults from 1929 through 1932, and additional releases were made up to 1936. Recoveries were made in 1937 from the 1932 releases, but the parasite has not been taken in that State since 1942.

The Florida releases consisted of 4,048 adult parasites placed at Canal Point and Sarasota in 1932 and 48 in 1936. In 1936 and the following years the parasite was recovered at several of the colonization points and at Jupiter, Fla., about 55 miles from the nearest colony sites. Samples from one field showed a parasitization of 30–40 percent (*94*). It was found to be common in the Punta Gorda area in 1945, the last year in which surveys were made. The persistence and the abundance of the parasite in these localities are attributed to the milder climatic conditions and to cane being left in the field through the winter.

This parasite is solitary in habit, and develops internally in the larger host larvae, though occasional individuals may emerge from the pupae. The life cycle averages about 32 days, so that several generations are produced each year. In areas having a definite winter season the parasite passes this period as a first-instar larva within the hibernating host.

The gestation period is 9–10 days, and a gravid female contains 500–600 eggs and larvae. The young maggots are deposited singly

on the cane stalk, usually in the general vicinity of the burrow entrance of a host larva. The maggot then makes its way into the burrow and to the host larva, into which it bores its way, usually through the skin in the ventral area. It then lies free in the body cavity until after the first molt, when a respiratory attachment is made, usually at one of the spiracles of the eighth abdominal segment. This connection is maintained until after the second molt. When feeding is completed, the maggot leaves the body of the host and pupates nearby in the burrow.

Phaeogenes nigridens Wesm. (Ichneumonidae)

Phaeogenes nigridens, a parasite of the European corn borer, is widely distributed in Europe and occurs also in the Far East, but is most abundant in northern Italy, where the parasitization ranges up to 20 percent. The first shipment to the United States, consisting of 1,601 adult parasites, was forwarded from Italy in the summer of 1924 (*4*), and consignments of parasitized host pupae from 1925 through 1932 totaled 27,000. Additional shipments, totaling 8,422 adults and 13,000 parasitized host pupae, were received from the same source in 1937 and 1938. A small consignment was also received from Japan in 1931. The first liberations were made near Boston, Mass., in 1924 and in Michigan in 1926, Ohio in 1927, and thereafter in other infested States. The total releases to the end of 1939 were 52,734 adults distributed in 8 States.

The first indication of definite establishment was at Bedford, Mass., where recoveries were made in 1929 at points where releases had been made 3 years previously. In later years the parasite was recovered at several other locations in Massachusetts. The field parasitization is consistently very low.

This species is a solitary internal parasite of the pupae of the corn borer (*124*). It passes the winter as an adult female in sheltered places, a habit common to many species of the subfamily. The seasonal cycle varies greatly, but because of the long life of the females the species is able to persist, if necessary, in the most northern sections on the basis of 1 generation each year. However, in most of the 1-generation host areas in Europe the parasite appears to have 2 generations, as it does over most of the 2-generation host areas. In some localities there may be a partial third or even fourth generation on an alternate host.

The adult females emerge from hibernation in the late spring and attack freshly formed corn borer pupae as soon as they become available. In accomplishing this the female first enters the borer tunnel, cuts a hole in the cocoon with her mandibles, enters the cocoon, and then stings the pupa, usually at or near the base of a wing pad. The primary larva is of the mandibulate type. Pupation takes place within the shell of the host pupa. The egg, larval, and pupal stages average 2, 15, and 4½ days, respectively, at 77° F. The reproductive capacity of *nigridens* is relatively low, as each female deposits not more than 50 eggs. The progeny comprise approximately equal numbers of the 2 sexes.

Phanerotoma planifrons (Nees) (Braconidae)

The importations of *Phanerotoma planifrons*, a parasite of the lima-bean pod borer, from Hungary from 1936 through 1938 comprised 7,476 parasite cocoons and 96,000 host larvae that had been exposed to the parasite in the egg stage. From this material more than 33,000 adults were obtained for colonization, of which 30,000 were available in 1938. Laboratory rearing on Mediterranean flour moth larvae provided additional numbers for release in 1939.

The first field releases were made at Ventura, Calif., in September 1936, when 493 adults were liberated in areas having a heavy growth of tree lupine (*Lupinus arboreus*). The colonizations of the following 3 years were in similar areas in Ventura County and in lima bean fields in that county and in Santa Barbara and San Diego Counties. The first field recovery was from lupine pods in September 1940. Later field records are not available.

P. planifrons is a solitary internal parasite of the larvae, and is one of the group of Braconidae that oviposit in the host egg and delay growth until larval development of the host is well advanced. Parasitized larvae are appreciably smaller than healthy individuals. In Hungary, where material was obtained for importation, there is one complete and a partial second generation each year, and, according to H. L. Parker, the winter is probably passed as a partly grown larva within the host. The completion of internal feeding by the larva is followed by its emergence from the body and then by a period of external feeding until only the collapsed host skin is left. The papery cocoon is spun within the cocoon of the host.

Phanomeris phyllotomae Mues. (Braconidae)

Phanomeris phyllotomae is an external parasite of the larvae of the birch leaf-mining sawfly, and was one of several species attacking that pest that were imported from Austria during 1930–35 (*47*). A total of 3,885 adult parasites emerged from the imported cocoons, and these were released in Maine, New Hampshire, and New York. The first release, consisting of 60 males and 28 females, was at North Conway, N. H., in 1931, with the same number of mated females liberated there the following year. The parasite was recovered at Bar Harbor, Maine, in 1937, where it was colonized in 1933, and at Eustis, Maine, in 1937 from 1935 liberations. It was again collected at both points in 1938, but no further information is available regarding its spread or effectiveness.

P. phyllotomae has one generation with a partial second each year, and the winter is passed in the full-grown larval stage in its cocoon in the larval mine of the host. Pupation takes place in the spring, and the adults emerge from May to July. Males predominate in the ratio of about 3 to 2. In oviposition the female first stings the host larva, inducing a partial but permanent paralysis, and then deposits an egg in the mine, but not directly on the larva. The egg hatches in 1½–2 days, and the young larva then crawls to the host and begins its external feeding. Many of these larvae apparently fail to reach the

host and die of starvation. Feeding by the parasite larva is completed in 6–8 days, and the cocoon is then spun.

Phobocampe disparis (Vier.) (Ichneumonidae)

Small numbers of *Phobocampe disparis*, a parasite of the gypsy moth, were imported from Russia and Austria during 1907–10 (*14, 89*), but there is no record of liberations during that period. In 1911 about 125,000 parasite cocoons were collected in Italy and 171,000 the following year. The 1911 shipments yielded 12,543 adults the following spring, and these were liberated at 4 localities in eastern Massachusetts and at 1 place in southeastern New Hampshire. No material for release was obtained from the 1912 shipments. Importations were resumed in 1924 and continued until 1931, during which period about 5,000 parasite cocoons were received from Hungary and Yugoslavia. From this material 3 colonies were released in Massachusetts during 1929–31.

Field recoveries were made the season of release at all of the 1912 colony sites. So far as known the present distribution of the parasite is restricted to northeastern Massachusetts and southeastern New Hampshire. The species has not spread to any great extent nor has it become abundant at any time, so that it is a negligible factor in the control of the host.

This species is a solitary internal parasite of the gypsy moth larvae (*112*). Oviposition takes place most readily in the first- and second-instar larvae. The egg and larval stages within the host cover 7 and 12–25 days, respectively. The host is killed when in the fourth instar, and the full-grown parasite larva then emerges and spins its cocoon on a leaf or twig nearby. The cocoons are only lightly attached, however, and soon drop to the ground. Pupation takes place 20–21 days later, and the pupal stage requires 11 days. There is only a single generation each year, and the winter is passed in the adult stage in the cocoon. The reproductive capacity is high, as individual females have been known to deposit in excess of 1,200 eggs during a period of 5–8 weeks. The species apparently is not fully adapted to the gypsy moth, as a number of dissections of field-collected caterpillars showed that about 34 percent of the eggs and larvae contained in them were dead and encysted.

Physcus "B" (Eulophidae)

This undescribed species of *Physcus*, a parasite of the purple scale, is native to South China and Formosa, and was imported from the latter island by the University of California during 1950–51 (*73*). The first field release was made in Orange County in 1950 and at other points in that county and San Diego County in 1951. Recoveries were made at Chula Vista and Oceanside in 1952, and the species has persisted since that time.

Physcus "B" is a solitary internal parasite of the purple scale, and, like many species of *Coccophagus* and several other genera, exhibits a differentiation in the host relationships of the sexes. The male is a solitary internal parasite of the full-grown female larva of its own species.

Pleurotropis metallica (Nees) (Eulophidae)

Pleurotropis metallica (=*Entedon epigonus* Wlkr.) is a solitary internal parasite of the larvae of the hessian fly in Europe, and was first imported from England by C. V. Riley in the spring of 1890, when 2 lots of adults totaling 305 were received from London. All were dead upon arrival at Washington. Two further consignments, this time consisting of parasitized host puparia, were received from the same source the following spring. The material was distributed to entomologists in Indiana, Illinois, and Michigan, and a small quantity was also sent to Canada. Results of this work are known only from Illinois, where S. A. Forbes liberated the adult parasites in cloth cages in the field during early May and noted the emergence of the first domestic brood of adults. A portion of the parasitized puparia were distributed to other parts of that State, and the adult parasites were released in open fields, as were also a small number at the Illinois Experiment Station farm. No recoveries were made in 1892 or in the years immediately following.

The final shipment of parasitized host puparia from London was received in May 1894, and the adult parasites that emerged were liberated in a field at Cecilton, Md. The first field recovery was made there in May 1895, and the parasite was not again taken until 1915, when specimens were reared from material collected at Hagerstown, Md., and at 5 localities in Pennsylvania. Its natural spread must have been relatively rapid, however, as it was recorded in 1921 (*147*) from 151 localities in 12 States, representing a solid block from the Eastern Coastal States to Illinois and, in addition, Oregon and Washington. It has since been recovered in Missouri, Iowa, and Kansas. The lack of recovery in the early years can therefore be attributed to insufficient collections. It has never been found in sufficient numbers to exert any appreciable effect on the hessian fly infestations (*87*), though it is the most abundant of the parasite series in north-central New York.

Prosena sibirita (F.) (Tachinidae)

Prosena sibirita, a parasite of Japanese beetle grubs, was first found in northern Japan in 1921, and has since been reared from various other scarabaeid hosts in China, Malaya, and India. Shipments from Japan to the United States were begun in 1921 (*23*, *24*, *79*), and during a 10-year period a total of 33,500 laboratory-parasitized grubs and 159,000 field-collected grubs, having an average parasitization of 10 percent, were forwarded. The first field liberation, consisting of 53 adult parasites, was made at Moorestown, N. J., in 1923, and the parasite was first recovered at that point in 1927. Total releases from 1923 to 1930 were 12,364 adults in 5 localities.

At the present time only the single colony at Moorestown is known to be established and it is very weak. This situation is believed to be due to the lack of a suitable alternate host or the absence of a 2-year phase in the Japanese beetle in the infested areas. In northern Japan, where *sibirita* is most abundant, a considerable portion of the beetle grubs carry over to the second season. Also several additional host

species, of which well-developed grubs are present in the soil during midsummer, are available as alternate hosts. In the Northeastern United States the adult flies emerge in late spring or early summer, when few grubs of suitable size for parasitization are present in the soil, and it is not until late August that second-instar grubs are available. This midsummer gap in host stages suitable for parasitization can only be filled by a carryover of a portion of the host grubs to a second season, as suitable alternate hosts that are full grown at that time apparently are lacking.

This parasite is a solitary internal parasite of the Japanese beetle and other grubs. A single generation is produced each year, and the winter is passed as an early second-instar larva within the host grub in the soil. Development is renewed in the spring after the grub begins feeding, and larval maturity is attained at the time the normal host is preparing for pupation. The full-grown maggot leaves the grub through a hole made in the venter of the abdomen, and pupates in the soil 1 or 2 inches below the host remains. The pupal stage covers 22–30 days, and the adult fly emerges in late July and August.

The adult flies are crepuscular in habit, and feed at the blossoms of umbelliferous plants. The reproductive system of the gravid female contains up to 800 eggs and larvae, the latter numbering 50–300. These young maggots are deposited on the surface of the soil, presumably in the general vicinity of host grubs. When a grub is found, the maggot bores through the derm, usually in an intersegmental area, and enters the body cavity, where it lies free until after the first molt. A respiratory connection is then made to one of the main tracheal trunks of the host near a thoracic or first abdominal spiracle. This connection is maintained until after the death of the host grub. The respiratory funnel, being attached to a tracheal trunk, is seldom visible externally, thus differing from that of *Dexilla ventralis*, which is conspicuous because of being connected directly with the integument at the point of the original entry of the parasitic maggot.

P. sibirita is widely distributed through the north temperate and tropical regions from Japan to Malaya, India, and Europe, and must therefore have a considerable number of hosts in addition to the species of *Popillia, Anomala, Miridiba*, and *Serica*, which were observed in Japan and Korea.

Prospaltella perniciosi Tower (Eulophidae)

The strain of *Prospaltella perniciosi*, parasitic on the California red scale in Formosa, was imported by the University of California in 1949 (*71*), and was released at many points in all counties of southern California in that year. Recovery collections have not been on a wide scale, but the parasite is known to be well established in Los Angeles and Riverside Counties. It appears most abundantly in late winter and early spring.

The California red scale strain of this species is indistinguishable morphologically from that which is found as a common parasite of the San Jose scale in Asia and North America. However, the two are distinct in certain habits, and are sharply restricted in their host preferences. Reproduction of the red scale strain is unisexual, where-

as that of the strain on the San Jose scale is bisexual in the North Atlantic States and unisexual in the Southern States.

Pseudaphycus malinus Gahan (Encyrtidae)

Pseudaphycus malinus was the last of the series of parasites imported for the control of the Comstock mealybug. It is one of the least common species found attacking that pest in Japan, and the small initial stock was obtained from mealybugs collected from pear at Shindembaru, Fukuoka-ken, on the island of Kyushu. A total of 1,596 parasitized mealybugs, which had been reared in the insectary in Japan, were received during the summer of 1941. Emergence from the first consignment was obtained in July, and during the following 2 months a total of 5,134 adult parasites were released in a number of heavily infested apple orchards near Charlottesville, Va., and also in West Virginia and Ohio. Parasitized mealybugs were observed in abundance in the Virginia orchards within 2 months after the first releases, and most of the colonies became established.

Laboratory rearing was undertaken in 1943 (*83*), with a production of approximately 50,000 adult parasites, and the next year 54,000 adult parasites and 7,000 host mummies were produced and utilized in the colonization program extending to all infested localities in Virginia, West Virginia, Ohio, New Jersey, Connecticut, and Michigan. The species soon became generally established and abundant in all the infested sections.

P. malinus, a gregarious internal parasite, deposits its eggs in the nymphal and adult female stages of the host. The life cycle is short, being completed in about 17–21 days at summer temperatures. Usually 5–10 individuals, of which about 75 percent are females, develop in each host. There are 2 or 3 generations to each one of the host, and the winter is passed in the full-grown larval stage in the dead host.

Quayleа whittieri (Gir.) (Encyrtidae)

Quayleа whittieri (=*Hemencyrtus crawii* Timb.) was found as a member of the parasite complex reared from the black scale in Australia during investigations there in 1900–1901, and was intentionally introduced and established in the United States in the belief that it was a primary parasite of that pest. Its strictly hyperparasitic habit was not determined until some years later. The species is included in this account in order to complete the historical record and to illustrate the difficulties encountered in the early work and the potentially serious results that may follow a mistaken decision regarding the relationships of a parasite to the pest insect.

The small number of *whittieri* contained in the shipments of black scale material received in California were propagated in the insectary for distribution during the spring of 1901. Twenty-five colonies were released in Santa Clara, Monterey, Santa Barbara, Ventura, Los Angeles, and San Diego Counties (*53*, *131*). No information is available regarding the time of its recovery in the field, though its distribution became general in the coastal sections within a very few years.

The highly injurious nature of *whittieri* was not fully revealed until the development of the large-scale colonization of *Aphycus lounsburyi* since 1919 in the coastal counties, where the "uneven hatch" condition of the host insect prevails. This latter parasite breeds continuously throughout the year and thus provides suitable conditions for uninterrupted increase of a secondary parasite. During 1920–24 *A. lounsburyi* was the most effective black scale parasite present in California, and in some coastal areas the pest on citrus was reduced to the point where fumigation was no longer required. However, by that time *whittieri* began to make its presence felt, and, as a result, the primary parasite was reduced to a much less effective status. According to Smith and Compere, "This parasite is so elastic in its habits that it may even prevent for all time the control of the black scale by the biological method." Fortunately, subsequent developments have shown that this is not the case. More recent investigations indicate that *whittieri* does not interfere with *A. lounsburyi* in its attack on black scale on pepper trees, a favored host plant. The physical condition of these trees prevents in some way the evening of the hatch of the scale, and suitable stages for parasitization by *A. lounsburyi* are present throughout the year. The life cycle of *whittieri* is appreciably longer than that of *A. lounsburyi;* consequently, it is unable to overcome the latter during the active season.

At the time *Quaylea* was imported from Australia there apparently was a definite doubt as to its exact relationship to the black scale, and specimens of adults were accordingly submitted for examination by taxonomists before any releases were made. The report received after this examination recommended release on the sole basis that the known representatives of the group to which this species belonged were all primary in their relationships and there consequently was no danger involved. From what is now known of the variations in habit even within a genus the final decision with respect to colonization of a particular species cannot safely be made without first confirming the tentative conclusion by careful dissections of parasitized hosts, by rearing experiments, or both. It was perhaps inevitable that such a mistake should be made before the vital necessity for careful study of the habits of imported parasites before release could be fully recognized.

Q. whittieri is a solitary internal parasite of the full-grown larvae of various chalcidoid species that develop internally in *Saissetia* and related genera (*65*). It pupates within the distended skin of the host larva. It also parasitizes, to a lesser extent, the larvae of *Scutellista cyanea,* which develop in the egg chamber of the host.

Rhizobius debilis Blackb. (Coccinellidae)

The numerous shipments of Coccinellidae made to California from Australia by Koebele in 1891–92 (*53*) included *Rhizobius debilis,* which had been observed as a predator on the black scale and other lecaniine Coccidae. Koebele reported that an initial liberation of only 2 adults in an infestation of San Jose scale at Alameda, Calif., in May 1892 resulted in a very large increase in the numbers of beetles within the following 4 months. The beetle was also liberated on the black scale at Santa Barbara and has persisted there and in certain other

coastal sections of southern California, though in small numbers. It has been listed (*32*) as one of the effective predators on the dictyospermum scale (*Chrysomphalus dictyospermi*) in Louisiana.

Rhizobius ventralis (Er.) (Coccinellidae)

In Australia the black lady beetle (*Rhizobius ventralis*) is one of the most abundant of the Coccinellidae attacking the young nymphal stages of lecaniine Coccidae. Large numbers were shipped by Koebele from that country to California in 1888–89, and it was also received from Tasmania in 1889. Apparently no liberations were made as a result of these first importations, and it was not until additional material was forwarded in 1891–92, of which not more than 20 adults were alive on arrival, that colonies were released in fruit orchards infested with black scale (*53*). The first colony was placed in an infested olive orchard at Santa Barbara and others in prune orchards at San Jose in the spring of 1892. In the summer of 1893 beetles were reported to be present by the millions at Santa Barbara, and it was confidently expected that the scale would be completely controlled within a very short time. However, this optimistic outlook was not justified by developments of the following years.

R. ventralis is a predator of the egg and young larval stages of the black scale. Usually a cluster of several eggs is placed beneath the host scale, and the young larvae feed on the eggs and later on the young scale that have settled on the foliage. The adult beetles likewise feed on these young scales. Pupation takes place on the trunk and branches of infested trees.

Rodolia cardinalis (Muls.) (Coccinellidae)

Rodolia cardinalis, more generally known as the vedalia beetle, is the best known of all the insects that have been employed in the biological control of insect pests. On his first trip to Australia in 1888–89 Albert Koebele found it feeding on the cottony-cushion scale, and 5 shipments of adult beetles were forwarded to California between November 1888 and March 1889 (*53*, *99*). The first consignment yielded only 28 live beetles upon arrival, but those following brought the total survivors to 514.

The beetles from the first 3 consignments, numbering 129, were placed immediately after arrival on an infested tree that had been enclosed in a cloth tent at Los Angeles. By the following April they had increased to such an extent that nearly all the scale had been destroyed. One side of the tent was then removed to permit the beetles to escape. Colonies were sent to other parts of the State, and by the middle of June 208 colonies, totaling 10,555 beetles, had been distributed. At this time the infestation in the orchard containing the initial colony had been completely controlled, and in all other localities control was effected within a few months after release of the beetles.

R. cardinalis is predaceous on the egg and early nymphal stages of members of the subfamily Monophlebinae, and is best known for its attack on several species of *Icerya*. There are probably 8 or more generations each year in subtropical citrus areas (*100*). The life

cycle from egg to adult is completed in a minimum of 13 days at summer temperatures, with the egg, larval, and pupal stages covering 2, 8, and 3 days, respectively, and it may be prolonged to 3–4 months during the colder portions of the year. The females may begin oviposition the day after emergence. The eggs are reddish in color and are deposited singly or in small clusters either beneath the female scale and egg sac or on the dorsum. The newly hatched larvae burrow into the egg sac and feed on the eggs and young nymphs. The larger larvae feed also on the more advanced nymphal stages. Pupation takes place on the branches or foliage of the trees. The adult beetle is equally as voracious as the larvae and feeds on all stages.

The potential rate of increase is very great when one considers the number of generations each year and the capacity of the female to produce 500–800 eggs during a life span of 1 month or more.

Scutellista cyanea Mots. (Pteromalidae)

The history of *Scutellista cyanea* as a means of controlling lecaniine Coccidae in the United States has two distinct phases, the first being its introduction into Louisiana against the Florida wax scale (*Ceroplastes floridensis*) and the barnacle scale, and the second its introduction into California against the black scale (*89*). The first consignment from Italy, consisting of twigs infested with *C. rusci* (L.), was received in 1895, but it was not until 1898 that adult parasites became available for field colonization. These adults were permitted to oviposit in scales on a caged plant at Washington, D. C., and this plant, with the remainder of the imported twigs, was sent to H. A. Morgan at Baton Rouge, La., for field release of the parasites. Apparently no effort was made to follow the progress of this colony, at least no reference to it occurs in the literature of the immediate succeeding years. In 1906 and again in 1923 L. O. Howard mentions the recovery of the species in Louisiana, first from the wax scale and then from the black scale.

The stock from which the California releases were made consisted of a quantity of parasitized black scale carried by C. P. Lounsbury from Capetown, South Africa, to Washington, D. C., in June 1900, from where the material was immediately shipped to California. Several additional shipments were made the same season and in 1901, but the number of parasites that emerged at their destination was very small. All established colonies are believed to be from 4 females and 17 males obtained from the last shipment, which reached California in October 1901 (*53, 131*). By 1903 the species was established in all the infested sections of the State and had attained a high percentage of parasitization.

In its relation to the black scale, *cyanea* (*131*) is primarily a predator on the eggs rather than a true parasite. The ovipositor is inserted beneath the adult female scale, usually through the posterior arch, and the double-bodied egg is then deposited among those of the host or adheres to the ventral derm of the body. The egg complement of a large scale is sufficient to bring several *cyanea* larvae to maturity. The egg, larval, and pupal stages cover 3, 11, and 10 days, respectively, during the summer. The first larval stage may be prolonged to several weeks in the absence of host eggs. Several

generations may be produced each season on the black scale in the "uneven hatch" areas. When the larva is mature, it spins a light web of silk between the host body and the twig surface, forming somewhat of a pupation cell, and the dead parasitized scales may remain on the tree for several years. The adult parasite emerges through a circular opening cut through the dorsum of the dead scale.

If eggs are not present beneath the host scale at the time the parasite egg hatches, the young larva may puncture the body wall of the scale and then feed as a true external parasite. It can, if necessary, develop to maturity in this way. The species has been reared from the soft scale, which gives birth to living nymphs.

Scymnus binaevatus (Muls.) (Coccinellidae)

Scymnus binaevatus, a predator on various mealybug species, was imported from South Africa by the University of California in December 1921 (*125*). Only 32 adult predators were obtained from this shipment, but propagation in the insectary was successful, and large numbers were liberated the following seasons in infestations of citrus and citrophilus mealybugs on citrus in southern California and on grape mealybug in central California. The first field recoveries were made at Alhambra in July 1922, Oxnard in October, and Whittier in December of the same year. This predator increases to a much greater extent in infestations of citrophilus mealybug than on the citrus mealybug, and is now well established throughout southern California. No recoveries were made from releases on the grape mealybug in the San Joaquin Valley.

Sympiesis viridula (Thoms.) (Eulophidae)

Sympiesis viridula, a parasite of the larvae of the European corn borer, occurs abundantly only in northern Italy, and all importations were made from that country. The first shipments, totaling 3,273 parasite larvae, pupae, and adults, were received in the summer of 1930 (*4*), and between that time and the winter of 1933–34 the importations totaled 1,760,000 hibernating pupae. The first liberations were made in Massachusetts and Rhode Island in 1930, and in the following 4 years 317,543 adults were released in all the States having a suitable borer population.

During the colonization period occasional field recoveries were made the season of release or the following year, but none of these colonies persisted. It was not until 1938 that established colonies were found in 8 localities in Ohio and in Michigan, and additional recoveries were made at other points in the succeeding years. One of the Ohio colonies was from a 1932 liberation. The parasite field population after this lapse of time was still very low, though in 1940 a spread of 50 miles was observed, and in 1950 a spread of over 100 miles was noted in Indiana and Iowa. Field parasitization exceeding 15 percent was observed in 2 counties in central Iowa in 1950. The most eastern point of known establishment is the Cattaraugus Indian Reservation in western New York, where this parasite was found in 1946–49 after colonization there in 1931.

S. viridula is a gregarious external parasite of the corn borer larvae, which are in the third to fifth instar at the time of attack (*116*). The larva is completely and permanently paralyzed by the sting of the parasite, and the eggs are then placed indiscriminately on the body. The parasite larvae grow rapidly and reduce the host body to an empty skin in 4 to 5 days. Pupation takes place in the host tunnel, and the winter is passed in the pupal stage. Several generations are produced each year. The average summer colony developing on each host larva numbers 28 individuals, whereas the winter colonies are about 3 times as large. The sex ratio is 2 to 1, with the females predominating.

Tetracnemus peregrinus Comp. (Encyrtidae)

Tetracnemus peregrinus was first imported from South Africa by the University of California in 1924 and 1926 for use against the long-tailed mealybug, but it was not established. It was again imported in 1934, this time from Brazil. A total of only 1,250 adults were reared for colonization, and these were placed in Santa Barbara, Los Angeles, and San Diego Counties during October to December 1934 (*62*). Establishment was reported at several San Diego County colony sites where it, in conjunction with *Anarhopus sydneyensis*, appears to be holding the mealybug infestations on avocado in check. *T. peregrinus* has also been effective in controlling infestations on *Dracaena* in Los Angeles County.

T. peregrinus is a solitary internal parasite of the early nymphal stages of the mealybug, and its life cycle covers approximately 1 month.

Tetracnemus pretiosus Timb. (Encyrtidae)

The introduction from Australia of *Tetracnemus pretiosus*, a parasite of the citrophilus mealybug (*29*), took place at the same time as that of *Coccophagus gurneyi*, parasitic on the same host. It was first liberated in southern California in 1928 and was recovered the same season. Distribution and establishment were quickly effected in all areas of the State infested by the mealybug. It competes with *Coccophagus*, which is dominant because of its hyperparasitic males. However, *pretiosus* is capable of controlling infestations alone, and is able to gain over *Coccophagus* during the summer months. Recently the field collections have shown it to be more abundant than *Coccophagus*, and it appears to be more effective in light infestations.

T. pretiosus (*19*) is a solitary internal parasite of the early nymphal stages of the mealybug. It oviposits readily in nymphs that have just left the egg. The egg, larval, and pupal stages cover 6, 17, and 6 days, respectively, at summer temperatures. The parasite egg increases in size during incubation, and nearly half of the first larval stage is passed while the larva is still enclosed within the shell.

Tetrastichus turionum (Htg.) (Eulophidae)

Tetrastichus turionum is a gregarious internal parasite of the pupae of the European pine shoot moth, and was included in the parasite

material received from Austria during 1931–35 (*49*). The total number of parasitized pupae received, each containing about 20 *turionum* larvae, was 6,875. Large releases were made in New England and in New York, New Jersey, and Pennsylvania during 1933–35.

The first field recoveries were at Brookline, Mass., and on Long Island in 1934, and at 3 additional colonization points in Massachusetts and in New York and New Jersey in 1936. Nothing further is known regarding the establishment, spread, or abundance of this parasite.

Tiphia asericae A. & J. (Tiphiidae)

Tiphia asericae is a solitary external parasite of scarabaeid grubs of the tribe Sericini, and was imported for control of the Asiatic garden beetle and *Serica similis* (*23*). It was discovered in central Japan during the search for Japanese beetle parasites, and was later found in Korea and China also. Shipments were begun in 1927, and in a 6-year period a total of 11,260 adults and 62,205 reared cocoons were shipped from Korea to the United States. Adults were first liberated on Long Island in 1928, the colony consisting of 58 females, and others later at many points in Pennsylvania and New Jersey. The 1928 release was unsatisfactory, as the 58 females were the sole survivors of 9,604 shipped from Korea, and they were probably of low vitality. No releases were made in 1929. First recoveries were made in Pennsylvania in 1933 from colonies released in 1930, and the parasite is now known to be well established at several points in that State, though increase and spread have been slight.

The adult wasps appear in the field in late spring and early summer and feed mainly on aphid honeydew. In oviposition the eggs are placed singly on the host grub, almost invariably in the suture between the seventh and eighth abdominal segments, just above a spiracle of the eighth segment, and with the anterior pole directed toward the median dorsal line. Incubation is complete in 3 days, and larval development to the spinning of the cocoon requires 10–12 days. The winter is passed in the adult stage within the cocoon. There is only a single generation each year.

Tiphia popilliavora Roh. (Tiphiidae)

Tiphia popilliavora was the first of the larval parasites of Japanese beetle grubs to be discovered in northern Japan when investigations were undertaken there in 1920, and it was later found to occur also in Korea and South China. The first shipments to the United States were made from Japan in 1920–22 and from Korea and China during 1925–27, 1930–31, and 1934–36 (*23*, *24*, *79*, *98*). The total imports during these periods were 13,945 adult females and 31,833 reared cocoons. The 1921 and 1922 releases in the field in the United States totaled less than 100, and only 9 were liberated in 1923. The stocks of Japanese origin available through 1926 were all concentrated at 4 release points near Moorestown, N. J. The parasite was first recovered at Cinnaminson, N. J., in 1926, and is well established in New Jersey, Pennsylvania, New York, Connecticut, Delaware, and Maryland. Domestic collections for recolonization were started in 1927,

and until the end of 1951 a total of 767 colonies, each comprising approximately 100 females, have been obtained from local sources in New Jersey and Pennsylvania for distribution to other localities.

The adults of *popilliavora* emerge during August, when most of the host grubs are too small for satisfactory parasitization. Attack on young grubs results in a very high percentage of male progeny; thus the increase and effectiveness of the species are limited. The Korean and Chinese strains introduced and colonized during 1926–36 emerge somewhat later in the season, and consequently may be more suitable for American conditions than is the Japanese strain.

This parasite has a single generation each year, and the winter is passed as a full-grown larva in the cocoon in the soil. Pupation takes place in midsummer, and the adult wasp emerges in August and persists for a month or more. It feeds mainly at the blossoms of wild carrot. In oviposition the female parasite first stings the host grub in the ventral thoracic region, inducing temporary but complete paralysis for 15 minutes or longer, after which she kneads with her mandibles the ventral area of the host abdomen that is to receive the egg. The egg is placed transversely in a groove between the fifth and sixth abdominal segments. The entire process of oviposition requires 20–30 minutes. Incubation is complete in 5–7 days, and the young larva begins feeding at a point immediately in front of the anterior end of the egg. There are 5 larval stages. Feeding of the parasite larva does not at first affect the host grub, but the latter weakens and dies after the parasite has attained the fifth instar. The host body, except for the head capsule and legs, is completely consumed The larval feeding period covers 18–30 days, after which the spindle shaped cocoon is spun in the soil cell of the host.

The reproductive capacity of *popilliavora* is relatively low, yet there appears to be a marked difference in fecundity between the strains. Females of the Chinese strain deposited up to 115 eggs under laboratory conditions.

The size of the host grub at the time of oviposition by the female parasite has a definite relation to the sex of the parasite that develops on it (*9*). Individuals reared from second-instar grubs proved to be almost exclusively males, whereas those from third-instar grubs showed a slight preponderance of females. The sex of the progeny is determined at the time of oviposition, the female wasps tending to deposit unfertilized eggs on small grubs, whereas both fertilized and unfertilized eggs are deposited on third-instar grubs. In the infested area in the United States the Japanese beetle is largely in the second instar during August, the period of greatest abundance of the parasite; so the progeny are predominantly male.

Tiphia vernalis Roh. (Tiphiidae)

Tiphia vernalis, a parasite of the grubs of *Popillia* spp., was discovered in Korea in 1922 (*23*, *24*, *79*), and shipments to the United States from that country and South China from 1924 through 1933 totaled 69,237 adult females and 49,835 reared cocoons. The first liberations were made at Moorestown, N. J., in 1925, and the first field recovery of the species was in 1928. Field colonization with domestic stock was started in 1931, and by the end of 1951 more than

239,000 females had been obtained from local sources for recolonization. The species has been extensively colonized in the older infested sections of New Jersey, Pennsylvania, New York, Delaware, Maryland, Connecticut, and Virginia and, to a lesser extent, in 7 other States. A survey made in 1950, covering 1,400 square miles of generally colonized area in Pennsylvania, showed establishment at 86.6 percent of the colony sites. Sometimes a spread of 20 miles from the colony site was observed.

This species is the most valuable of the 5 imported parasites of the Japanese beetle now established in the United States, and, under particularly favorable conditions, it has been found to parasitize up to 65 percent of the grubs. Its abundance may be judged by the collections made at one colony site on a golf course in Pennsylvania, where more than 66,000 females were collected from 1931 through 1941, practically all of them from about 6 trees on which they had become concentrated by the attraction of a 10-percent honey solution sprayed on the low-hanging foliage. *T. vernalis* is the only established parasite of the Japanese beetle that is considered appreciably effective in controlling infestations of this pest. Its distribution, however, is apparently strongly influenced by the food sources of the adult wasps rather than by host grub abundance. Consequently, a high parasitization may occur in an area where the former is favorable, yet a few hundred yards away, where the grubs are equally abundant, the parasitization may be very low (*78*).

T. vernalis, like *popilliavora*, has a single generation each year, but there are several important differences in their life histories and habits. The former passes the winter within the cocoon in the soil, but in the adult rather than the larval stage. The adults emerge in May, and the cycle of the species is consequently well adapted to that of the host, as the grubs of the latter are nearly full-grown at that time. The egg is placed ventrally in a groove between the third thoracic and the first abdominal segments, with the anterior pole directly toward the lateral margin. Incubation requires 8–9 days, and larval development to the spinning of the cocoon covers 24 days or more.

The females feed almost exclusively on honeydew secreted by aphids developing on forest and shade trees and on ornamental and other plants. Spring-emerging species of *Tiphia* are usually dependent on this source of food, whereas the late-summer and autumn species, equally consistently, feed at blossom or other nectar glands. Under favorable laboratory conditions the females deposit, on an average, 80 eggs or more during an oviposition period of 5–8 weeks.

Townsendiellomyia nidicola (Tns.) (Tachinidae)

The shipments of enormous quantities of hibernation nests of the brown-tail moth from Europe during 1905–11 (*14*, *89*) included a variable number of larvae that were parasitized by *Townsendiellomyia nidicola*. Difficulty was experienced in rearing the parasite maggots to the adult stage, as most of the caterpillars died before the parasites could complete their development. During 1906–9 only about 200 adult parasites were obtained, and these were released at North Saugus, Mass., the greatest portion in 1907. An additional 3,300 were colonized in 1911.

The first field recovery was made in the summer of 1910, and by 1916 the parasite had spread over the entire range of the host. It ranks next to *Compsilura concinnata* in value as a check on the brown-tail moth. Field parasitization, as determined by dissection of hibernating larvae, ranges from 10 to 20 percent.

T. nidicola (*110*) is a solitary internal parasite of the brown-tail moth larvae. It has a single generation each year, the adult flies appearing late in July. After a preoviposition period of 7–8 days after mating, the female begins the deposition of her thin-shelled, fully incubated eggs. They are placed on the venter of the host body either between the true legs or the prolegs. A gravid female may contain 600 or more eggs in various stages of development. The parasite maggot bores into the host very soon after the egg is laid. It then lies free in the body cavity for 10–14 days, after which it enters the esophagus and remains there throughout the 9-month hibernation period. There is no feeding then, and the maggot appears to be enveloped in a cyst. It leaves this cyst only in late May or early June, after the host has fed for some time and has molted into the last stage. The maggot then again penetrates the body cavity, moves to the posterior end, and after 3–4 days develops a respiratory funnel at an aperture in the integument. The first molt then takes place, and larval maturity is attained about 12–17 days later. The host dies shortly before the maggot completes its feeding. The pupation habit is unusual, as the puparium is formed in situ in the body of the host and is enveloped by the respiratory sheath.

The life cycle of *nidicola* is perfectly synchronized with that of the brown-tail moth, and no additional hosts are known.

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