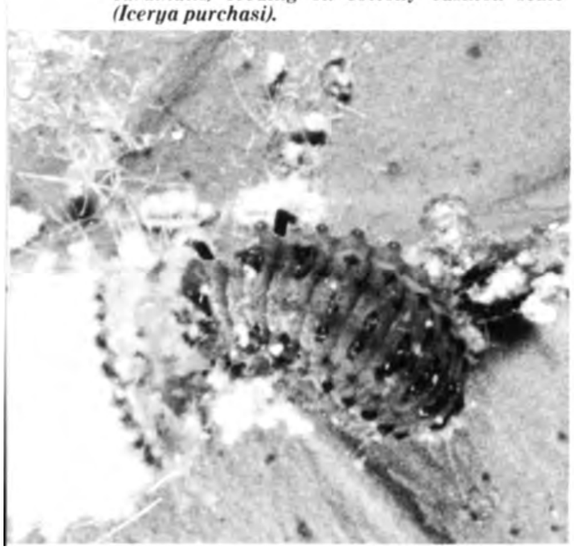
Research review

Biological control: pitting insects against insects

Robert M. Boardman

Vedalia, the Australian ladybird beetle *(Rodolia cardinalis)* feeding on cottony cushion scale *(Icerya purchasi)*.



Vedalia larva feeding on cottony cushion scale. 10 times lifesize

Biological control involves discovering, importing, and using the most effective natural enemies of pest insects or weeds that can be found. More than 10 million natural enemies of many kinds are released each year by the University of California (UC) through its Biological Control divisions at Albany and Riverside.

UC scientists estimate that the importation and release of biological control agents in California alone has saved producers and consumers of food and fiber about $300 million in the last half century. Worldwide, the importation of natural enemies has brought about some degree of control of 186 species of pest insects; there have been 384 successful projects in biological control of pest insects to date.

In this review, "biological control" (BC) refers to only one of the many nonchemical insect control methods on which UC scientists are working. BC is the importation, colonization, and spreading of natural enemies (usually from the "old country" where the pests originated) to reduce a pest's population density to a lower average than would otherwise occur.

First success

The first effective and sustained success of biological control occurred in 1888 against the cottony cushion scale, *Icerya purchasi.* The scale attached itself to leaves and twigs of citrus trees, then sucked out the sap. Discovered in California in 1872, it soon threatened to destroy the citrus industry.

Albert Koebele, a USDA entomologist, was sent to Australia in 1888 to seek a parasite that apparently was keeping the scale under control there. Koebele shipped 514 vedalia beetles (the Australian ladybird, *Rodolia cardinalis*) to California, where they quickly became established.

By 1890 the vedalia had attacked and almost obliterated all infestations in California. Cost of the vedalia program, all told, was less than $5,000. Benefits? – Millions of dollars annually in California. Similar successes were scored with the same beetle in more than 50 countries.

Unfortunately, DDT and other chemicals, used after World War II, destroyed the vedalia in many areas. Cottony cushion scale then re-emerged as a serious pest after 50 years of absence. The vedalia was recolonized after the insecticide residues on tree foliage had dissipated, and soon reasserted its control over cottony cushion scale.

Citrophilus mealybug

Second only to cottony cushion as a success story for biological control is the citrophilus mealybug campaign in California.

In the 1920s citrophilus mealybug was a spreading scourge in citrus orchards. It was highly destructive, it spread rapidly, and it affected other fruit trees and ornamentals. The mealybug's origin was a mystery, but UC scientists deduced it must have come from a climate similar to that of southern California and from a place linked by steamer to England, South Africa, and California, the three places where the mealybug was known. This pointed to Sydney, Australia.

Harold Compere, a UC biological control scientist, was dispatched to Australia in 1927. Within a year he found an infested mulberry tree on which virtually all of the mealybugs had been parasitized. He collected two parasites, *Coccophagus gurneyi* and *Tetracnemus pretiosus*, and accompanied them to California on the steamship *Tahiti.* Both parasites were colonized and released in 1928.

In 1929 citrophilus mealybugs were already being decimated wherever the parasites had been liberated; by 1930 the parasites' eggs laid inside mealybug larvae had resulted in complete economic control. Since that time, no infestations of any importance have occurred. Orange County citrus growers alone saved $0.5 million to $1 million a year. The cost? About $1,700, not including Compere's salary of $150 a month.

Conquering a weed

A classic example of biological control was a joint UC-USDA campaign against Klamath weed (*Hypericum perforatum*), an accidental import from Europe. By 1944 it occupied over 2,000,000 acres of rangeland in 30 California counties, crowding out range grasses. Livestock men suffered financial losses, because cattle and sheep feeding on the toxic weed lost weight and because land values decreased, making it hard to get loans for improvements. Chemical controls, applied against a mere trace of the total infested acreage by state and local governments, cost as much as $300,000 a year.

As early as 1922 Professor Harry Scott Smith, head of biological control work in California, proposed the importation of insects that fed on the weed in Europe. In 1944 Smith finally was authorized to import four kinds of beetles and a gall-forming fly from Australia and

Europe. After careful testing to ensure the beetles wouldn't attack desirable plants, the four beetles—*Chrysolina hyperici*, *C. quadrigemina*, *C. varians*, and *Agrilus hyperici*—and the gallfly were released. All except *C. varians* became established; *C. quadrigemina* was the most successful species.

From a single colony of 5,000 *C. quadrigemina* beetles released in 1945-46, more than three million beetles were collected for redistribution in California in 1950. The beetles also were sent to Washington, Oregon, Idaho, Utah, Nevada, and Montana, where they became established.

By 1955 Klamath weed virtually disappeared as a pest. Chemical control costs dropped from $300,000 to less than $300 a year. Land values went up again. As range grasses reappeared, animals stopped losing weight. UC scientists estimate that savings to the livestock industry plus savings in control costs have been $3,500,000 per year, totaling about $80,500,000 through 1976.

In California, only Siskiyou County, with its very cold winters, still has a Klamath weed problem. Improved control has been obtained recently by the introduction of a more cold-resistant *C. hyperici* beetle and the root borer, *Agrilus hyperici*, and by an apparent adaptive improvement of *C. quadrigemina*.

Puncture vine effort

Attempts to control puncture vine (*Tribulus terrestris*) have been less successful than the Klamath weed project.

The control of puncture vine (long a major pest around houses, roadways, ginning mills, vacant lots, and sometimes on croplands) by chemical or cultural means has been difficult and costly. Its thorns and seeds are picked up and spread by tires and bare feet.

In 1961, UC and USDA bio-control scientists imported two weed-attacking weevils from Italy: *Microlarinus lareynii* and *M. lypriformis*. The former infests puncture vine fruits and destroys the seeds; the latter attacks the stem and crown. The two weevils were fairly successful in attacking the ground-hugging weed, but they soon ran into trouble from native American insects. Two tiny wasps attacked and destroyed about one-quarter of the young weevils in test plots; two other native insects destroyed the weevil eggs. As a result, weevil destruction of puncture vine was cut in half. Seeds of puncture vine can live in the soil, where weevils can't get at them for 20 years or more. Even if two-thirds of the seeds are destroyed before they mature, the remaining third can present a control problem.

Despite these problems, the reservoir of puncture vines seeds has diminished over the last decade. In the presence of the imported weevils, now spread throughout California, puncture vine plants produce only about one-sixth as many spiny burs as they otherwise would..

In another attack on weeds, on the Channel Islands off Santa Barbara, UC scientists released a mealybug that sucked the juices out of prickly pear cactus, largely ridding the islands of this rangeland pest.

Two recent successes

The two most successful applications of biological control in recent years have been against olive scale and the walnut aphid.

Discovered near Fresno in 1934, the olive scale, *Parlatoria oleae* (Colvee), soon threatened many household and parkway plants as well as olive and deciduous fruit trees. By 1960, more than 200 types of ornamental plants, 28,000 acres of olive orchards, and thousands of deciduous fruit trees in 26 counties in the Central Valley and parts of southern California were infested. Olive scale not only attacks leaves, twigs, and limbs, but also infests olive fruits, causing heavy losses. The olive industry spent millions of dollars fighting the pest.

In the late 1940s, UC scientists introduced natural enemies of olive scale. Only an *Aphytis* parasite from Egypt survived, but in small numbers. Other enemies of olive scale were sought in Spain, Pakistan, India, and the Near East. Of four *Aphytis* strains imported, the most successful was a "Persian" strain of *Aphytis maculicornis* from Iran and Iraq. Over the next eight years, more than 27 million parasites of that strain were colonized at hundreds of olive orchard sites in 24 counties. Thousands were also released on deciduous fruit trees, ornamental trees, and shrubs.

Olive scale densities declined dramatically, but scientists sought a higher degree of control than could be achieved with the Persian *Aphytis* alone. Although the Persian parasite often attacked and killed more than 90 percent of the olive scales in a given area in spring, it failed to follow up in summer because of an intolerance to hot, dry weather and because of the absence of host (scale) stages during the late spring.

Two new species of aphelinid parasites were introduced from West Paki-

Adult seed weevil *(Microlarinus lareynii)* on a seed pod of the puncture vine, *Tribulus terrestris*. 10 times lifesize

Stem of puncture vine plant showing damage caused by the stem weevil, *Microlarinus lypriformis*.

stan in 1957. *Coccophagoides utilis* Doutt thrived; the other species gradually disappeared.

By 1964, UC scientists found that establishment of both *A. maculicornis* and *C. utilis* gave extremely effective biological control of olive scale. *C. utilis* took over from *A. maculicornis* in late spring and attacked whatever scales the latter had missed.

Only 11 percent of California's 28,000 acres of olive trees were treated between 1971 and 1974. Currently, biological control of olive scale is so thorough that it is almost impossible to find enough of the pests to satisfy requests of foreign entomologists asking for stocks of the scale's parasites. The ravages of the scale on many species of shade and fruit trees and ornamentals also have been eliminated.

The cost savings? Over a 12-year period, UC scientists estimate, the olive industry saved $7,260,000. The homeowner, nurseryman, park keeper, and roadway superintendent probably have saved even more.

The walnut aphid

The walnut aphid, *Chromaphis juglandicola*, invaded California about 1900 and soon spread through all the walnut-growing areas of California. Frequently it covered the trees, exuding honeydew on which a black, sooty-mold fungus grew. Years of insecticide war against the aphid produced the usual upsets, resurgences, resistance, and drift of toxic materials outside treated areas. Biological methods seemed the only way to achieve real control.

In the 1950s a UC researcher combing southern France for an effective parasite found a wasp with "high host specificity"—that is, it went after the walnut aphid and no other insect. He imported the French wasp (*Trioxys pallidus* Haliday), which spread rapidly through coastal areas of southern California, laying its eggs inside the walnut aphid's larvae. Hatching wasp larvae then devoured the aphid larvae.

Although it wiped out a high percentage of aphids in southern California, the French wasp couldn't stand the heat and dryness of central and northern California. A strain of *T. pallidus* from hot, dry Iran, was imported in 1968. Small releases of the new wasp developed into abundant populations that spread rapidly and drastically reduced walnut aphids throughout California.

The walnut aphid has been essentially eliminated as a pest of commercial walnut groves. Streetside and garden trees also have benefited. A UC report warns however:

"It is now most important in California walnut production that care be taken to avoid or prevent any factors or practices which might disrupt the activity of *T. pallidus* during summertime, since interference with the parasite may lead to explosive outbreaks of the aphid. The disruption is likely to result from insecticidal treatments directed toward such pests as codling moth or walnut huskfly. The Argentine ant may also be disruptive."

The report concludes: "Although its activities may occasionally be disrupted by certain largely avoidable factors, *T. pallidus* has singlehandedly effected virtually complete biological control of the walnut aphid in California."

Red scale: a long war

The campaign against red scale, *Aonidiella aurantii* (Maskell), has been the longest in the history of biological control. Since its arrival from the Orient in the 1870s, red scale has been the chief pest of citrus and has caused losses of millions of dollars annually from damage

Olive scale parasite, *Coccophagoides utilis,* inspecting an olive scale's suitability to receive her egg.

***C. utilis* perched on its host, top view.**

Adult *Trioxys pallidus,* a walnut aphid parasite, top view.

A female *T. pallidus* thrusts her ovipositor into a walnut aphid, implanting an egg which will develop into another tiny wasp, killing the host aphid.

to trees, loss in fruit quality, and cost of insecticidal treatment.

For 60 years, the biological control effort against red scale was considered a failure. The parasite *Aphytis chrysomphali* Mercet did a fair job of controlling red scale in California's mild coastal areas if not interfered with by chemical treatments or by honeydew-seeking ants. But, since there usually were ants or chemicals—or both—in citrus orchards, *A. chrysomphali* was not highly regarded as a natural enemy of red scale. In addition, there was a misconception about other *Aphytis* species that were available. All known forms were assumed to be the ineffective *chrysomphali* type. Inadequate taxonomy (identification) of the genus *Aphytis* caused a delay of some 50 years in the introduction of the most valuable parasites into California and elsewhere.

Between 1941 and 1957, UC scientists imported four species of parasites from India, West Pakistan, south China, and Formosa. In order of effectiveness these were: two *Aphytis* species, *A. melinus* DeBach and *A. lingnanensis* Compere, and two red scale host races of *Comperiella bifasciata* Howard and *Prospaltella perniciosi* Tower.

Parasitization by these four natural enemies has been highly destructive of red scale. Although it is still a major citrus pest and still requires chemcial control treatments in most areas, its biological control can be considered substantial. Many thousands of acres now go untreated each year, with enormous savings to the citrus industry.

Woolly whitefly

The woolly whitefly, a recent invader from Mexico, has been so well controlled by UC-imported parasites that it has not had a chance to become a pest in California's commercial citrus. This is probably the first instance of prophylactic (advance) biological control of pests.

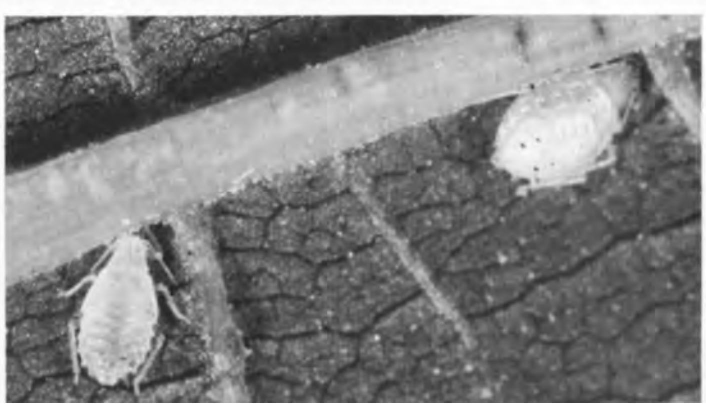
When uncontrolled, the whitefly sucks sap from leaves and secretes a waxy filament (with a woolly appearance) that covers the bodies of the nymphs clustering thickly on the underside of leaves. The nymphal and pupal stages of the insect exude a sticky honeydew in which sooty mold fungus grows. The filaments and the fungus restrict the tree's photosynthetic action. The tree goes into a decline and fruit quality is lowered.

Three wasps, *Amitus spiniferus*, *Eretmocerus paulistus*, and *Cales noacki*, were imported from Mexico, Chile, and El Salvador by UC scientists. Colonized and spread throughout southern California, the wasps laid eggs inside the immature nymphs of the woolly whitefly. The eggs hatched and grew into adults, eating the whitefly in the process.

Whitefly populations in release areas dropped by 90 to 99 percent. UC scientists are able to stop new infestations by releases of parasites.

Robert M. Boardman is Communications Specialist, University of California, Riverside. Sources of information and authorities consulted: Paul DeBach, Professor of Biological Control and Entomologist, University of California, Riverside; Richard L. Doutt, Professor of Entomology, Emeritus, Biological Control, Parlier; Richard L. Goeden, Associate Professor of Biological Control, UC, Riverside; Kenneth S. Hagen, Professor of Entomology, UC, Berkeley; Carl B. Huffaker, Professor of Entomology, UC, Berkeley; Charles E. Kennett, Specialist, Biological Control, UC, Berkeley; Robert van den Bosch, Professor of Entomology, UC, Berkeley; and the late James K. Holloway, U.S. Department of Agriculture entomologist. DeBach's Biological Control by Natural Enemies *(Cambridge University Press, 1974) also provided valuable historical and statistical information. Special close-up photography by Jack K. Clark, Visual Aids, UC Davis.*

***C. utilis* implanting an egg into its host. 80 times lifesize**



***Left,* normal walnut aphid nymph; *right* mummified nymph containing a developing *T. pallidus*.**

Parasitized olive scale [*Parlatoria oleae* (Colvee)] showing small holes where adult wasps have emerged after development within the scale host.