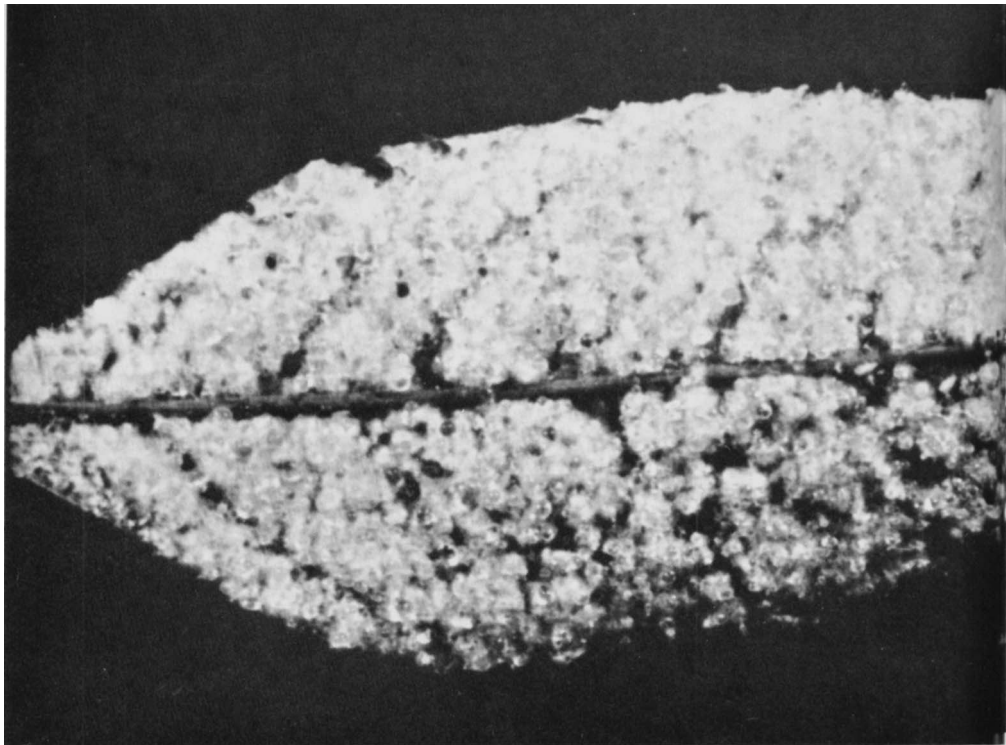


Fig. 1. The lower surface of a citrus leaf is heavily infested by honeydew-producing 4th instar woolly whitefly.



Biological Control of Woolly

PAUL DeBACH • MIKE ROSE

The woolly whitefly, *Aleurothrix floccosus* Mask., first discovered in residential San Diego during November 1966 surveys for the citrus whitefly, has been of deep concern to the citrus industry, the University of California, and various agricultural agencies. In 1968, a study by Harold Lewis for the California-Arizona Citrus League estimated potential losses to California citrus of \$10 per acre for either whitefly or a 17 percent average increase in total pest control costs statewide.

The name woolly whitefly is derived from the white waxy filaments secreted by the nymphal instars which develop on lower leaf surfaces. Like scale insects, the nymphal stages are sessile (non-motile), but adults of both sexes are winged, which greatly enhances dispersal. The adult woolly whitefly is similar to other aleurodids.

The woolly whitefly is very damaging to citrus trees. Theoretically, a single mated female can give rise to 6 million individuals on a tree with 30,000 leaves after four generations (one season). The successive generations have their greatest impact in the fall, with the result that massive defoliation occurs during winter. In its immature stages the woolly white-

fly secretes honeydew on which sooty mold grows and interferes with photosynthesis. (See fig. 1.) Argentine ants are strongly attracted to the honeydew as food, and their presence interferes markedly with the whitefly's natural enemies as well as with those of other pest species. This interference results in increased pest populations.

Discovery of an invading incipient pest insect always evokes questions about dealing with its presence. If eradication appears feasible, it is undertaken. Otherwise, biological control by importation of natural enemies from the native home should be initiated. In this case, the senior author had previously observed woolly whitefly in mainland Mexico, where it may be native, and had noted naturally-occurring biological control by three or more parasitic *Hymenoptera*. Because regulatory agencies had not decided to pursue eradication attempts, three species of parasites, *Amitus spiniferus* (Brethes), *Eretmocerus ?paulistus* Hempel and *Encarsia* sp., were imported and colonized in small numbers in San Diego in 1967. *E. paulistus* was originally described from Brazil. Although closely related, the parasite introduced from Mexico may not be the same species. *A.*

spiniferus became immediately established and reduced populations to low levels within one year on the original release site. *E. ?paulistus* was reimported the following year; it too was successfully colonized. The ready establishment and rapid reproduction of these two species and the knowledge that other natural enemy species existed which could be imported gave promise that biological control could be achieved, at least in San Diego (see fig. 2).

The introduction of various natural enemies, including so-called strains, races or biotypes, from throughout the indigenous range of an invading pest should receive primary emphasis in establishing sound biological control. It is always better to make multiple and rapid importations of all known parasites or predators so that survival of the fittest can determine the best natural enemy complex.

After successful introduction and colonization of the original parasites, the California State Department of Food and Agriculture (CSDFA), in consultation with citrus industry leaders and the San Diego County Agricultural Commissioner's office, decided on chemical eradication in 1969. Ultimate biological control



heavily infested colonization trees by August 1970. Two of the original release trees were selected as "nursery trees" or sources of parasites from which twigs bearing numerous parasitized woolly whitefly nymphs were transferred to strategically located sites throughout Tijuana. Thus, the delicate parasites were allowed to emerge naturally without collection into vials and without other handling which often injures them. New release trees were found in surveys of strategic areas to lessen the probability of movement by woolly whitefly across the border to San Diego after parasites decreased them. Later, all areas of the city were colonized. By this method and from an original source of under 200 parasites released about a year previously, more than 27,000 *A. spiniferus* and *E. ?paulistus* were transferred throughout Tijuana by November 1970 and far more dispersed naturally. This is many more parasites than could have been cultured in a large insectary by several trained persons and at great expense. Additionally, some 12,000 *A. spiniferus* and *E. ?paulistus* were shipped by Mexican Sanidad Vegetal collaborators from Culiacan, Sinaloa, and were also colonized in Tijuana.

Foreign exploration by the senior author in South and Central America during 1970 brought about importation of *Amitus ?spiniferus*, *Eretmocerus ?paulistus*, and *Encarsia* sp. from El Salvador. The *A. ?spiniferus* and *E. ?paulistus*

were successfully colonized, but no recoveries of *Encarsia* were made. A new parasite, *Cales noacki* De Santis, imported from Chile, readily became established; although it did not look impressive in its native home, it has become of major importance in Baja California Norte and San Diego County. The "nursery tree" method of twig transfer was used to distribute all newly-established parasites throughout the infested area in Baja California Norte to assure rapid dispersal, optimal increase, and survival in a habitat most suited to them.

The biological control project in Baja California Norte was organized to lessen possible return dispersal by woolly whitefly to San Diego during and after the eradication program there (assuming its success) and to evaluate in advance the relative efficacy of the various parasite species in biological control in case eradication failed. By late 1970 the firm establishment of three exotic parasite species and probably two "biotypes" (with resultant rapid reduction of woolly whitefly populations on release sites), the demonstrated utilization of "nursery trees" to provide abundant parasites for transfer, and natural dispersal by parasites in Baja strongly indicated that biological control would be achieved.

Meanwhile, chemical eradication attempts, judged a failure, were abandoned in San Diego. Consequently, biological control was reinitiated in January 1971. The known area infested

Whitefly

was problematical, and eradication, if successful, would solve the problem barring reintroductions. The prospect of success did not appear rosy. Attempts to eradicate other aleurodids (citrus blackfly in Cuba and Mexico, spiny blackfly in Japan, and citrus whitefly in California) had failed; on the other hand, biological control of aleurodids historically has been successful. Nonetheless, it was decided to go ahead with chemical eradication. All work on biological control was then transferred to Baja California Norte where woolly whitefly had been detected shortly after its discovery in California.

With cooperation from Mexico's Sanidad Vegetal, a few *A. spiniferus*, *E. ?paulistus*, and *Encarsia* sp. were again imported from Sinaloa, Mexico, during July 1969 and colonized on selected sites in Tijuana. In September, just before chemical eradication was started, *E. ?paulistus* also was collected in San Diego and transferred to Tijuana. By mid-October, biological control in San Diego was terminated. Limited time and a restricted budget resulted in a total of only 30 *A. spiniferus* and 169 *E. ?paulistus* being colonized in Tijuana.

These few parasites had reproduced by the tens of thousands on the original

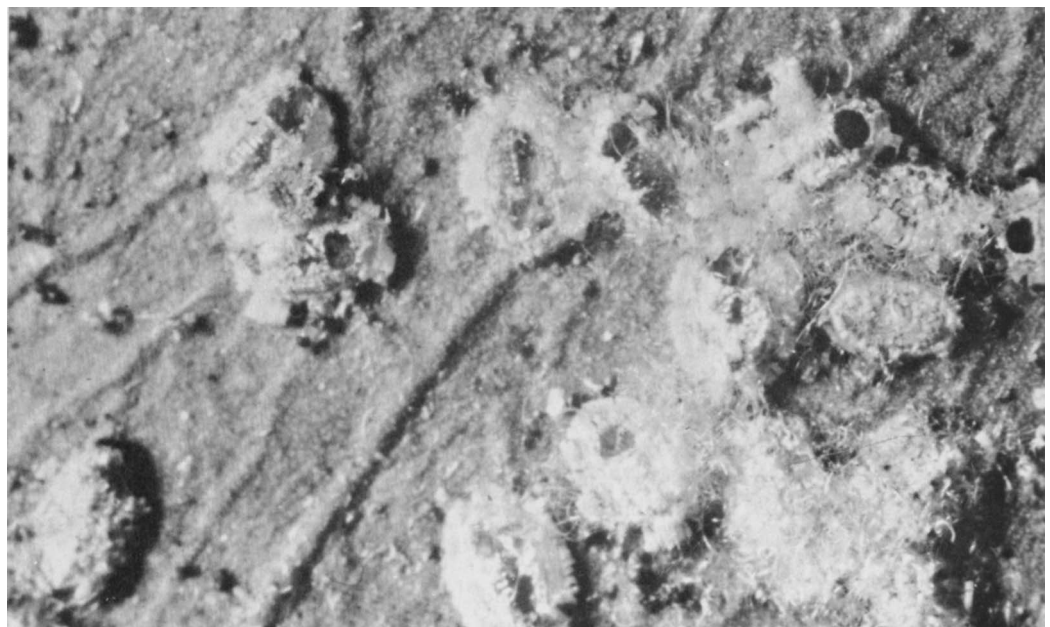


Fig. 2. Exit holes in 4th instar woolly whitefly have been chewed open by emerging *Amitus spiniferus*.

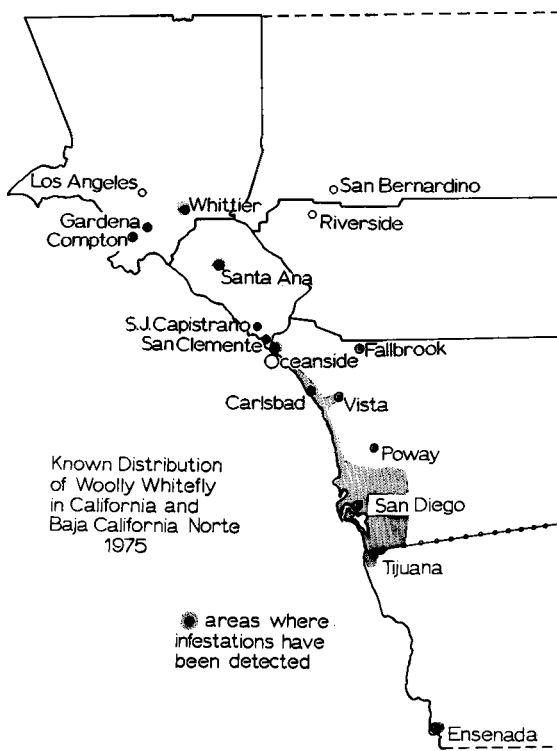


Fig. 3. This map notes the areas in southern California and Baja California where woolly whitefly infestations have been detected.

by woolly whitefly exceeded 200 square miles, but populations were low because of the earlier eradication treatments. Later in the year, however, large infestations became common. A quarantine line was established, and within it natural enemies of woolly whitefly were colonized. Outside the quarantine area chemical eradication was continued as infestations were found. To hasten parasite dispersal, the CSDFA surveyed for release sites and colonized the parasites provided by the University.

Preferred release sites were those with high levels of infestation, best assuring initial parasite colonization, rapid increase, and sustained parasite production. Ideally, the sites chosen were widely enough separated to take advantage of natural dispersal by parasites into surrounding neighborhood trees and were free from interference from such factors as ants, dust, or insecticides.

During the first recolonization season of 1971 in San Diego, more than 20,000 parasites were colonized on over 100 sites located strategically throughout infested areas. The parasites comprised primarily *A. spiniferus*, *E. ?paulistus* and *C. noacki*. They were either collected from sites in Tijuana or, in the case of the first two species, imported with the aid of

Mexican collaborators. With assistance from collaborators in Chile, the authors again imported *C. noacki* to assure their firm establishment in the entire infested area. In addition, *E. paulistus*, *Prospaltella* sp. and *Signiphora* sp. were imported from Brazil and *E. paulistus* was successfully established. By this time the very rapid spread of woolly whitefly in Spain and France, where it was also a new invader, was becoming known, indicating that the spread could be rapid in California. This, combined with the known distribution of the woolly whitefly in diverse climates in various Western Hemisphere countries, made it seem inevitable that all California citrus areas would be invaded eventually.

The 1971 colonizations in San Diego resulted in parasites becoming established on virtually all release sites. These sites provided "nursery trees" during 1972, the system thus offering a surplus of parasites which was utilized to inoculate new infestations.

In principle, by adding additional species and "biotypes" to this complex of previously established parasites the effectiveness of the natural enemy complex could be enhanced. To accomplish this, new parasites have been introduced from many parts of the Americas since 1971, and the following parasites additionally

have been successfully colonized in California: *E. ?paulistus* from Florida, *A. ?spiniferus* and *E. ?paulistus* from Baja California Sur, *Amitus*, new species from Peru, and only recently a *Prospaltella* sp. from mainland Mexico was recovered. Although this represents a large number of species and "biotypes," we know there are still various parasites throughout the indigenous range of woolly whitefly which have not yet been established in California.

Transfer of natural enemies following the establishment of such a large complex is complicated. We must assure that *each* species has a chance to become established in all newly detected infested areas. For example, *E. ?paulistus*, along with *A. spiniferus*, was initially a predominant parasite species in Baja California Norte and San Diego. Yet, today, it is nearly non-existent, and *C. noacki* has forged into the predominant position (along with *A. spiniferus*). Such competitive displacement represents survival of the fittest, and the winner is the parasite(s) best suited to that particular environment. Further, we know that *E. ?paulistus* is the dominant parasite in various areas of Mexico; in the future it may be the most important parasite in a different climatic area in California—Riverside, for instance. The crux is that as



Fig. 4. Citrus leaves with woolly whitefly show the general level of infestation and occurrence of sooty mold before reduction by parasites was employed in coastal San Diego County.

habitats differ even slightly, so, too, may natural enemy complexes. To assure that competition determines the best natural enemy composition in a given habitat, *all* introduced natural enemies should be colonized and hopefully established throughout the range of the pest, at least until completely effective biological control has been achieved in a given habitat. For these reasons all available parasite species have been carefully identified and colonized in all newly found infested areas since the project was initiated. To date some 200,000 parasites, representing the species, races, strains or biotypes previously mentioned, have been colonized throughout the range of woolly whitefly in California and Baja California Norte and have reproduced by the countless millions in the field.

The range of woolly whitefly has changed dramatically since 1966. In 1971 the known area infested around San Diego was more than 200 square miles; by 1972 this area had more than doubled and included Carlsbad and Fallbrook to the north. In 1973, when it was discovered in San Clemente and near San Juan Capistrano in Orange County, it became obvious that detection teams could not find all new infestations. By 1974 woolly whitefly was known to exist in virtually all the coastal and several key inland citrus areas in San Diego County, such as Vista, and large infestations were found for the first time in central Los Angeles County. By January 1975 large infestations were also detected at Santa Ana in Orange County. Chemical eradication/suppression treatments outside the San Diego quarantine area were then stopped, as it was obvious that they were impractical because of the rapidity and extent of dispersal. Today, woolly whitefly thrives in large residential areas of Los Angeles and Orange counties where parasites have been introduced too recently to effect biological control. In San Diego County and Baja California Norte woolly whitefly still exists in low numbers and always will, but because of the effects of imported parasites the general population has been greatly reduced. (See map, fig. 3.)

In contrast to the current situation, populations of woolly whitefly in San Diego and Baja California Norte before parasites were established commonly exceeded an average of 100 or more live whitefly nymphs per leaf (see fig. 4). Conversely, it is now estimated that parasites, particularly *A. spiniferus* and *C. noacki*, have reduced woolly whitefly populations in Tijuana and Ensenada and in coastal and southern San Diego County



Fig. 5. The tree shown in fig. 4 appears healthy about one year after *Amitus spiniferus* and *Cales noacki* were established.

by more than 95 percent of the original peak population levels (see fig. 5). This has been demonstrated by experimental comparisons involving woolly whitefly populations having parasites absent or excluded versus ones having them normally active. In many cases the reductions have been even more spectacular. On sites where trees are environmentally optimal (free of interference from ants, dust, insecticides, and isolation) reductions of 99.95 percent of the average original high population are observed, even during peak whitefly activity, July through November. In fact, in many parts of San Diego during August and September 1975 it was necessary to inspect 1,000 or more leaves per tree to find any live whiteflies. However, wherever parasites were interfered with—for example in the Japanese beetle eradication area in San Diego where chemicals were applied to citrus trees and in new infestations where parasites were absent, as in Los Angeles and Orange counties in 1974-75—woolly whitefly populations increased exponentially during the season and reached extremely high densities.

Because parasite success is not always the same in different climatic zones, we cannot be certain that biological control can be achieved in citrus areas of the San Joaquin Valley or in interior and desert areas of southern California. We do

feel certain that the present parasites will effect a high degree of biological control in coastal and intermediate citrus areas. They also may do well in the more extreme areas—we think the probability is good. If they do not, additional species remain to be imported. This, again, leads us to emphasize the need to match environmental diversity with the biological diversity of different natural enemy species and “biotypes.” Continuing foreign exploration and colonization of parasites in environments relatively free of adverse factors will greatly favor the potential overall success in the biological control of woolly whitefly in California.

Paul DeBach is Professor of Biological Control, and Mike Rose is Staff Research Associate, Division of Biological Control, U. C., Riverside.

Their research has been funded in part by the California State Department of Food and Agriculture (CSDFA) and the California Citrus Advisory Board (CAB). Cooperation has been extended by other agencies, especially by the Mexican SAG--Sanidad Vegetal; the U. S. Department of Agriculture, Plant Protection Division; the County Agricultural Commissioner's Offices of San Diego, Orange, and Los Angeles, and the entomologists of the California Fruit Growers Exchange. They have been assisted in this work by Doug McEnery, Steve Olson, Marilyn Reynolds, Larry Ritchie, and Mike Thornton.