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Citrus Blackfly

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The management of the citrus blackfly provides an excellent case history of both attempts at eradication and successful biological control. The citrus blackfly, *Aleurocanthus woglumi* Ashby (Homoptera: Aleyrodidae), is a sucking insect that feeds on the foliage of citrus species and other hosts. When present in large numbers the blackfly weakens a plant by lowering the nitrogen levels, thereby reducing the quantity and quality of fruit. It is believed to be a native of the Far East, where it was first noticed by western entomologists in 1910, and has spread throughout most of the citrus-growing regions of the world (fig. 10.1).

Although the blackfly disperses relatively slowly under natural conditions, it is easily transported on leaves of its preferred hosts, *Citrus* species, or on the foliage of such alternate hosts as mango (*Mangifera indica* L.). Incipient infestations are not readily detected because of the small size of all developmental stages of the blackfly and its preference for feeding on the undersides of leaves. The worldwide importance of citrus for fruit production and its popularity as an ornamental in urban plantings make the introduction of citrus blackfly a matter of serious concern. Improved transportation methods in the twentieth century have greatly increased the likelihood of such introductions, either on seedlings or excised leaves in shipments of fruit.

Citrus blackfly first appeared in the western hemisphere in Jamaica in 1913 and spread rapidly throughout the Caribbean region and into Central America. Introductions to the United States have occurred several times.

Early infestations in Florida (1934) and Texas (1955) were eradicated successfully with chemical spray applications. Later infestations in these same two states resisted eradication attempts, however, and were brought under on-going control primarily by the release of parasitic wasps. The success of biological control programs in limiting blackfly numbers to nonpest levels is noteworthy.

We thank R. V. Dowell for reviewing an earlier draft of this chapter.

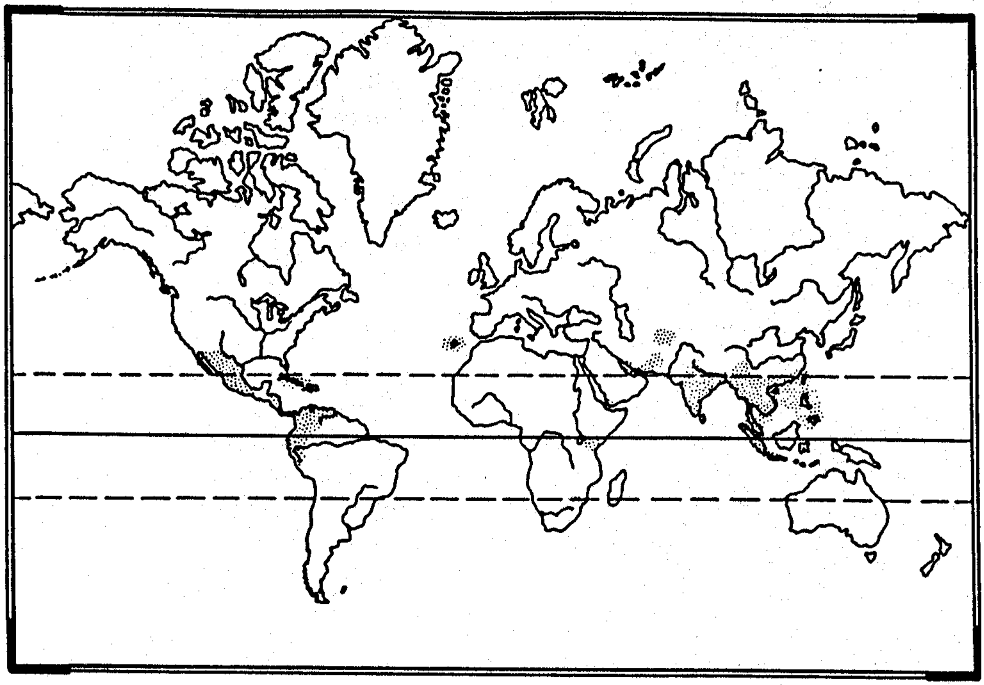

Figure 10.1 Worldwide distribution of the citrus blackfly, *Aleurocanthus woglumi* (adapted from Commonwealth Institute of Entomology 1976).

Life History and Habits

The citrus blackfly, in common with other whiteflies (family Aleyrodidae), has a motile first instar crawler stage, three sessile nymphal instars, and a winged adult stage. Generation time and life history details vary considerably under different environmental conditions (compare Russell 1962; Chavez Torres 1980). Development from egg to adult requires nearly 1000 degrees-days above the developmental threshold of 13.7°C (about two to three months depending on the weather). No development occurs at temperatures below 13.7°C (Dietz and Zetek 1920; Dowell and Fitzpatrick 1978). From two (Afzal Husain and Khan 1945) to six (Dietz and Zetek 1920) overlapping generations per year have been reported under field conditions and a seventh generation is possible under insectary conditions (Clausen and Berry 1932). Three to four generations occur annually in Florida (Dowell et al. 1981).

The female adult citrus blackfly oviposits in a spiral pattern on the underside of leaves. Each female may oviposit several times, with each spiral containing twenty to fifty eggs, for a maximum fecundity exceeding one hundred eggs. Dowell et al. (1981) report the average number of eggs per female to be sixty-five to seventy. Eggs from unmated females develop into male offspring (Dietz and Zetek 1920).

The active first instar nymph, or crawler, is elongate-oval in shape and less than half a millimeter in length. Crawlers usually settle along minor leaf venation within fifteen minutes of emergence (Chavez Torres 1980) but may remain active for several hours (Dowell, Reinert, and Fitzpatrick 1978). Once settled, the insect feeds on plant fluids and grows progressively larger and more ovate through its second, third, and fourth instars. The last nymphal stage is approximately one millimeter in length, and the adult is shorter than two millimeters. Winged adults are initially bright red in color but become covered with a waxy dust within twenty-four hours, producing a general slate-blue appearance (Dowell et al. 1981).

In its native southeast Asian habitat the citrus blackfly is found virtually exclusively on citrus trees (Clausen and Berry 1932). In the western hemisphere, however, *Aleurocanthus woglumi* has been reported on seventy-five different hosts representing thirty families in Cuba, Jamaica, and Panama (Dietz and Zetek 1920) and on at least seventy-five plant species from thirty-eight families in Mexico (Smith, Maltby, and Jimenez 1964). A complete list of hosts on which oviposition has been recorded includes at least one hundred and sixty species in eighty families (Dowell and Steinberg 1979). Female blackflies, like other species of whitefly, apparently orient to plant foliage on the basis of color, responding to reflected light in the 500 to 600 nanometer range (Dowell 1979b), although there is no evidence for long-range chemical attraction. The number of plant species oviposited upon becomes greater with increasing blackfly density (Howard and Neel 1977; Dowell et al. 1979).

Despite the polyphagous oviposition habits of the citrus blackfly, complete development to the adult stage has been reported on only twenty noncitrus species (Dowell et al. 1981), and survival on these alternate hosts is generally low (Clausen and Berry 1932; Smith, Maltby, and Jimenez 1964; Howard and Neel 1977; Dowell and Steinberg 1979; Dowell et al. 1979). Dowell (1978) demonstrated that secondary hosts, including mango (considered the most important), are incapable of supporting citrus blackfly populations without constant immigration from nearby citrus trees.

Biologically and economically, *Citrus* species are the most important hosts, with survivorship greatest and population growth most rapid on lemon, much less on grapefruit, and somewhat intermediate on lime (*Citrus aurantifolia* [Christm.]), orange (*Citrus sinensis* [L.]), tangerine (*Citrus reticulata* Blanco), and tangelo (*Citrus paradisi* Macfad. x *C. reticulata*) (Dowell, Reinert, and Fitzpatrick 1978; Howard 1979). Those noncitrus hosts that are capable of supporting citrus blackfly development from the egg to the adult stage may facilitate spread of the infestation between the more preferred citrus hosts.

Damage and Epidemiology

Feeding by immature citrus blackflies can inflict both direct feeding injury and indirect damage by promoting sooty mold growth. Although there is no evidence that toxins are injected during feeding, insertion of the feeding stylets damages the epidermal cells on the underside of the leaves, resulting in thickened cell walls, loss of cellular contents, and chlorotic patches (Hart, Gausman, and Rodriguez 1976). This cellular damage may be relatively insignificant (Dowell et al. 1981) unless considered in combination with other factors, such as loss of nutrients from the infested tree. Fifty to one hundred blackfly nymphs per leaf can reduce the nitrogen content of that leaf below the 2.2 percent level required by orange trees for successful fruit set (ibid; Dowell 1983).

Indirect damage from citrus blackfly infestation results from the secretion of honeydew by feeding nymphs. Accumulation of honeydew on the leaf surface promotes the growth of sooty mold fungi, impairing respiration and photosynthesis. Damage to leaf cells, nutrient loss, and sooty mold accumulation combine to produce the symptoms characteristic of severe citrus blackfly infestation: reduction in bloom and fruit set, stunting, and defoliation. Branch death or tree kill can occur in severe infestations but is generally uncommon (Ba-Angood 1977; Afzal Husain and Khan 1945). These symptoms can lead to a reduction in fruit yield and quality, although there is little information available regarding the actual economic impact of the citrus blackfly. Most published figures have been offered without supporting data.

Data on economic impact can be difficult to compile, because citrus blackfly infestation is essentially a debilitating condition rather than a direct threat to the fruit itself. Moreover, equivalent densities of nymphs may be associated with quite different effects on tree health because of local differences in edaphic and climatic conditions.

Observers in Panama (Dietz and Zetek 1920) and Florida (R. V. Dowell, personal communication, 1983) were unable to attribute a single case of tree death or loss of vigor to citrus blackfly infestation. Short-term infestations were found to reduce fruit production by up to 50 percent in Mexico (Smith, Maltby, and Jimenez 1964) and Florida, (R. V. Dowell, personal communication, 1983) and infestations of longer than one year frequently resulted in almost complete crop failure. In Pakistan, typical losses due to citrus blackfly have been estimated at 5 to 10 percent with occasional losses as high as 50 to 60 percent (Abbas, Kahn, and Haque 1955). Lotorto (1978) stated that fruit production may be reduced by up to 80 percent in severe infestations. Reductions of this magnitude were not, however, observed in Panama (Dietz and Zetek 1920).

In Florida, the citrus blackfly has been an urban pest, found on dooryard (urban or ornamental) citrus and in nurseries, where it is currently held at low densities by introduced parasites. It has not become a pest in commercial citrus groves. As a result, no economic thresholds have been established (Fitzpatrick, Cherry, and Dowell 1979). Although the emphasis in urban areas has shifted from eradication to containment with biological control, complete exclusion of the citrus blackfly from commercial citricultures is still considered essential.

During the most recent eradication effort in Florida (1976–79), the potential annual costs of chemically controlling the citrus blackfly if it were to become established in commercial groves was estimated to be from $80 million to over $100 million (Cooper 1978; Blackfly eradication program 1976). Such figures do not take into account existing pest management practices. A more carefully documented estimate by Dowell (1980) places a maximum value of $9,288,000 on the additional chemical treatments that would be required annually in Florida to control an established infection without a biological control program.

The citrus blackfly is limited in its distribution by climatic conditions, available host plant material, and its own dispersal capabilities. Warm, humid conditions increase the developmental rate and the number of annual generations; cool, dry conditions retard development. The temperature threshold for citrus blackfly development is 13.7°C, and optimal survival occurs at 26.6°C (Dowell and Fitzpatrick 1978). Dessication of eggs and nymphs under conditions of low humidity can be a major mortality factor, and such conditions also reduce successful adult emergence from the final nymphal instar (Clausen and Berry 1932; Quezada 1974). Adults may also be destroyed in large numbers by heavy rains and wind (Russell 1962).

Adult citrus blackflies do not appear to move great distances on their own. Dowell et al. (1981) report that adults may be capable of flying four hundred to six hundred meters, but very few were caught by yellow sticky traps placed more than fifty meters from an infested tree. First instar crawlers have been observed to walk a maximum distance of only thirty-eight millimeters from the egg spiral (Dietz and Zetek 1920). Although wind dispersal of the crawlers is certainly conceivable, this has not been documented. The possibility of long-range dispersal of adults by wind has also been suggested (Chavez Torres 1980).

Humans are the primary agents of long-distance dispersal of citrus blackfly. *A. woglumi* is thought to have been originally introduced into Jamaica on infested seedlings from its Asian home; live immatures and adults have also been intercepted on boutonnieres, corsages, and excised leaves in fruit shipments (Newell and Brown 1939; Dowell et al. 1981). However, survivorship is low on excised plant parts, and potted seedlings are probably the major means of long-distance dispersal to new areas. Inspection and quarantine are of prime importance in preventing introductions.

Control

Citrus is grown under adverse conditions in much of the citrus blackfly's range in southeast Asia, with seasonal flooding alternating with periods of water stress. In some of these areas, such as Sri Lanka, citrus is largely a casual crop given little or no care after planting (Burke 1967). In other areas citrus has been an important cultivated crop for many years, or its cultivation has been rapidly expanding. Citrus blackfly has been regarded as a serious pest in some of these regions (Abbas, Kahn, and Haque 1955; Afzal Husain and Khan 1945), but in other portions of its range it is scarce, and when it is found, the level of parasitism by natural enemies is often high (DeBach and Bartlett 1951; Rao 1969). Climatic factors and natural enemies prevent citrus blackfly from attaining high populations levels. Several species of parasitic wasps in the genera *Encarsia* (including *Prospaltella* of earlier authors), *Eretmocerus*, and *Amitus* attack citrus blackfly in different parts of Asia (Clausen and Berry 1932; Russell 1962; Smith, Maltby, and Jimenez 1964).

Because humans are a chief factor in the distribution of this pest, plant quarantine and inspection are major means of limiting its spread. Because the blackfly feeds on the foliage and not on the fruit, primary measures are directed at regulating the shipment of citrus seedlings from nurseries. Such quarantine measures can be regionally effective but may be unevenly applied on a worldwide basis.

In the western hemisphere, the initial establishment and spread of *A. woglumi* was unimpeded by its effective natural enemies, which were left behind in Asia. Early chemical suppression techniques involved the use of various oils and sprays applied as emulsions. A spray consisting of paraffin oil, whale oil soap, and water was widely used in the West Indies and in the first U.S. eradication program in Key West, Florida, in 1934 (Newell and Brown 1939). Formulations containing nicotine were also found to be effective in Panama (Dietz and Zetek 1920) and Jamaica (Gowdey 1921).

When citrus blackfly invaded Mexico, extensive chemical trials revealed that rotenone was very effective, as were the relatively new organophosphates, malathion and parathion. DDT was also effective against the blackfly but had the disadvantage of inducing secondary outbreaks of scale insects (Reinert and Neel 1977). Rotenone and malathion were widely used in Mexico during the 1940s and 1950s; they were replaced by carbophenothion early in the 1960s (Enkerlin 1974; Smith, Maltby, and Jimenez 1964). Insecticide trials during the same period of time in Oman and in India also demonstrated the effectiveness of organophosphates for citrus blackfly control (Reinert and Neel 1977).

In the mid-1950s, rotenone and malathion were used successfully in the eradication of small infestations in the Rio Grande Valley in Texas. Following reinfestation of the same area in 1971, they were replaced by dimethoate (ibid). When citrus blackfly was discovered in 1976 for the second time in Florida, malathion was used initially but was replaced by acephate, then unregistered for such purpose, when the Environmental Protection Agency granted an exemption allowing its use. Acephate requires fewer applications and is less phytotoxic than malathion (Lotorto 1978; Selhime 1980).

Biological control has been extraordinarily successful in dealing with *A. woglumi* virtually everywhere it has been used. Concern over its possible introduction into the United States from the Caribbean islands led the United States Department of Agriculture (USDA) to establish a cooperative program with the Cuban government in 1928 to find and introduce natural enemies of the blackfly. Subsequent exploration in Malaysia resulted in the importation and establishment of *Eretmocerus serius* Silvestri in Cuba, Panama, the Bahamas, and Haiti, where this parasite proved very effective in reducing citrus blackfly populations (Clausen and Berry 1932; Clausen 1978).

As citrus blackfly continued to expand its range in the Americas, *Eretmocerus serius* was successfully imported to combat it in Costa Rica, Barbados, and Jamaica (DeBach 1964). *Eretmocerus* was also brought into Mexico but was less successful there, presumably because of an inability to adapt to the more arid environment (Smith, Maltby, and Jimenez 1964). Further exploration in the Far East resulted in the importation and successful establishment in Mexico of *Amitus hesperidum* Silv., *Encarsia opulenta,* (Silv.), and *Encarsia clypealis* (Silv.) (ibid; Flanders 1969). Augmentation of biological control by *Eretmocerus* with *Encarsia opulenta* has since increased the degree of success in Barbados and Jamaica (Clausen 1978). *Encarsia opulenta* alone was successful when introduced into Venezuela (Chavez Torres 1980). *Amitus hesperidum* was reported to be established in Ecuador (Clausen 1978), but no indications of its success are currently available.

In 1959, citrus blackfly was discovered near Durban, South Africa. Eradication was thought to be impractical because of the large number of dooryard citrus trees in the region, the hilly terrain, extensive plantings of mango (an alternate host), and the general lack of commercial and home treatment for scale pests of citrus. Shipments of *Eretmocerus* from Jamaica were subsequently established in South Africa, and the pest potential of citrus blackfly was reduced significantly (Bedford and Thomas 1965). Biological control using introduced parasites against the blackfly was also found to be effective in the Seychelles (Greathead 1971) and in Kenya. Within several years of the initial releases, sooty mold was virtually eliminated from citrus, and commercial control had been obtained without the use of insecticides (Wheatley 1964).

Parasite rearing facilities established in Mexico for the production of

Amitus hesperidum, Encarsia opulenta, and *Encarsia clypealis* were to be important in the eventual biological control of citrus blackfly in the United States as well as in protecting Mexican citriculture.

History of Eradication Efforts

In August 1934, an infestation of citrus blackfly extending over several city blocks was found on the island of Key West, Florida, by State Plant Board inspectors. Various life stages were found on dooryard citrus and on twenty-two other species of plants and trees (Brown 1937). Rapid inspection of the surrounding islands indicated that the infestation was confined to Key West and probably had been introduced from Cuba (ibid). Ironically, the infestation in Cuba had at the time been brought under excellent control by the introduction of parasites. The State Plant Board had commented the previous year that "Florida's horticultural industries are, by reason of the successful introduction (of parasites), greatly protected against danger of introduction of the blackfly, and if there should be such introduction, there is immediately available an effective control measure" (State Plant Board of Florida 1933).

At a meeting in Key West two days after the initial discovery of citrus blackfly, the State Plant Board and the USDA, with the aid of the Emergency Relief Administration, decided upon an immediate eradication campaign. Eradication measures included (1) suitable regulations providing authority for application of eradication measures, (2) enforcement of a quarantine to prevent the movement of uncertified host plants from Key West, and (3) application of an oil emulsion consisting of two parts fish oil soap, two parts oil, and one part water at twenty-one day intervals (Brown 1937). This spray regime was followed for almost three years, from September 1934 until June of 1937 (with a two month interruption in the spring of 1936), although in the final months only citrus and mango were treated (Newell and Brown 1939). No phytotoxicity was noted even though sufficient material was applied with truck-borne power sprayers to drench all parts of the trees (ibid).

The last citrus blackfly in Key West was found on a single leaf in February 1937. The quarantine was suspended on April 13, 1938, and on April 14, the successful outcome of the eradication campaign was reported at the annual meeting of the Florida State Horticultural Society (Brown 1939). The project was reported to have cost $36,000 in federal funds and $161,464 in state funds (ibid).

The isolation of Key West and the established presence of State Plant Board personnel on the island contributed immensely to the success of the eradication campaign. These same factors, however, also created serious problems during the course of the campaign.

Key West was physically isolated from mainland Florida in the 1930s. The overseas railroad bridge was partially destroyed by a hurricane in 1935, and construction of the automobile causeway was not begun until 1937. The five-hour ferry ride and only three airplane flights each week simplified the enforcement of quarantine measures.

But the citizens of Key West were socially isolated as well from mainland Florida. In 1937, the *New York Times* referred to Key West as "problem stepchild of the United States, neglected by the parent mainland, gone foreign in atmosphere, architecture, habit and language" (Berger 1937). There were no commercial citrus groves on the island, and the State Plant Board found residents to be indifferent towards the threat to mainland groves and hostile to the eradication effort.

Opposition to the spray program was encountered almost immediately among property occupants. The personal inconvenience of the program was certainly a major factor in this resistance, since it was necessary to provide access to the spray crews every three weeks in order to "drench" the twenty-three suspected host plants. In some cases, it was necessary to drag great lengths of hose through residents' homes in order to reach yard plantings (Newell and Brown 1939). The possibility of contaminating backyard cisterns (rainwater being the sole source of fresh water on Key West) may have been a contributing fear. This limited availability of fresh water caused supply problems for the Plant Board as well, since their crews used several thousand gallons daily (ibid).

A simultaneous (1933–36) eradication campaign against the West Indian fruit fly (*Anastrepha* spp.) on Key West undoubtedly contributed to citizen inconvenience. This project involved fruit stripping and the widespread application of tartar emetic (antimony and potassium tartrate) at fifteen-day intervals to yard plantings. This eradication attempt was dropped in 1936, when it became evident that the West Indian fruit fly had been present for some time on the mainland without any apparent economic damage (Brown 1937). Because the State Plant Board was an established presence in Key West when the citrus blackfly was first detected in 1934, trained personnel and equipment were already available locally. A somewhat antagonistic relationship with much of the local citizenry also existed.

In May 1935, criminal charges were filed against one objector for violating plant board regulations, but the local jury failed to reach a verdict. Later in 1935 and in 1936, several citizens were found guilty of assaulting plant board employees. In June 1935, the plant board was denied an injunction restraining fifty-five objecting property occupants. However, in December a permanent injunction was granted by the circuit court in Miami. The defendents in the suit appealed to the Florida State Supreme Court, which nullified the restraining order while acting upon the appeal in March 1936. By this time, the number of objectors had increased to approximately one hundred (ibid), and the plant board, "disappointed at its own failure as well as that of interested and public-spirited citizens to reduce opposition, had discontinued spraying and withdrew its inspection force" (Brown 1939).

The interruption in spraying was short-lived. On March 30, 1936, twelve days after operations ceased in Key West, a joint meeting of the State Plant Board and the Florida Citrus Commission was held to advise citrus industry leaders of the situation. Immediately after this meeting, plans were made for resuming operations (Brown 1937).

In May 1936, the supreme court sustained the injunction granted by the circuit court, and spray operations resumed. A deputy sheriff was assigned to each spray truck to protect the crew (ibid). General opposition to the eradication project declined greatly, and only a few individuals were cited for contempt before eradication activities were discontinued in June 1937. Quarantine enforcement was dropped in April 1938. Although this brought the four-year eradication campaign to a successful conclusion (confirmed by an extensive inspection in the fall of 1938), the State Plant Board emphasized that with proper cooperation from property occupants, the operation would have been completed in one year or less (Brown 1937, 1939; Newell and Brown 1939).

In 1947, concern over citrus blackfly infestations in Guaymas and Empalme, Mexico, 270 miles south of the Arizona border, led California and Arizona citrus growers to contribute $25,000 for a chemical control program in these two cities and nearby citrus groves. With the cooperation of the Mexican Dirección General de Agricultura all urban host trees and commercial groves in the area were sprayed two to three times with rotenone in oil between November 1947 and April 1948. In 1948, responsibility for this grower-initiated program passed to the USDA and the Dirección General de Agricultura, and chemical treatments and monitoring were continued (Cooper, Plummer, and Shaw 1950).

As in Key West, spray hoses frequently had to be dragged through residents' homes in Guaymas and Empalme in order to reach enclosed patios with trees (Gunter 1954). No enforcement laws existed, and compliance was at the discretion of the individual property owners. Initially, the urban public was reported to be quite cooperative (Woglum 1948). But several years and many treatments later the lack of enforcement laws was cited as a major stumbling block to eradication of the persistent low-level infestations of blackfly. Where spraying was not permitted, labor-intensive hand stripping of infested leaves was used instead (Woglum, Smith, and Clausen 1952; Gunter 1954).

In early 1950, a small blackfly infestation was found in two trees in Matamoros, Mexico, immediately across the border from Brownsville, Texas. All host trees within a nine-block square area were sprayed four times with rotenone in oil (Berry 1951). The continuing threat of insect encroachments across the Texas border and into the citrus groves of the Lower Rio Grande Valley resulted in the formation of the Mexican Fruit Fly-Citrus Blackfly Control Project in 1951 (Hart et al. 1973). Personnel of the state of Texas, the USDA, and the Dirección General de Agricultura conducted ground surveys, treated and eradicated spot infestations along the Texas-Mexico border, and maintained a blackfly-free barrier zone in northwestern Mexico (Reinert and Neel 1977). South of the barrier zone blackfly was effectively controlled by parasites.

During 1955–56 citrus blackfly began to appear in Texas. By the end of 1956 thirty-three separate infestations had been reported (ibid). These were small infestations on leaves attached to fruit or seedlings brought across the border or small infestations on noncommercial trees growing near the border. The latter were believed to be due to tourists bringing adult blackflies across the border in cars or trailers. A series of localized malathion or rotenone sprays were successful in eliminating these foci.

New blackfly infestations in Texas were reported during 1967 and were attributed to dispersal from Mexico by hurricane winds originating from the Yucatan peninsula six to seven months earlier (Chavez Torres 1980). By 1971, citrus blackfly invasions of Texas had triggered another eradication program, this time with dimethoate sprays applied every three weeks (Hart et al. 1978). Despite repeated applications, with some trees receiving up to thirty treatments, the infestation not only persisted but continued to spread, moving beyond dooryard citrus into several commercial groves. To help combat further spread, federal quarantine regulations were instituted requiring all commercial citrus to be stripped of leaves prior to being packed for shipment. Citrus blackfly was successfully confined to residential citrus in the Brownsville area until 1974 when it moved into commercial groves. A program to treat infested groves with dimethoate was immediately instituted (Citrus blackfly fight 1975).

In 1974, a trial area of heavily infested dooryard citrus was chosen to test the effectiveness of biological control, while the eradication program was continued outside of this zone. Field-collected *Encarsia opulenta* and *Encarsia clypealis* and laboratory-reared *Amitus hesperidum* were released onto residential citrus in Brownsville (Holler and Brazzel 1978). After three years, blackfly populations had been reduced to low levels, and no commercial production losses were reported during the final two years of the study (Ketner and Rosier 1978). The most recent studies have shown that citrus blackfly in the Lower Rio Grande Valley continues to be held at very low population densities by the action of *Encarsia opulenta* (Summy et al. 1983).

At about the same time that *A. woglumi* was coming under satisfactory biological control in Texas, it was discovered anew in Florida. In January

1976, citrus blackfly was found on nursery stock in an urban area of Fort Lauderdale, Broward County. An initial survey of the surrounding area indicated that the infestation covered a minimum of several square miles, and spraying was promptly scheduled (FDACS 1976a). Further surveys were conducted, and within a month the size of the area placed under quarantine had expanded to two hundred square miles. Because the blackfly disperses slowly, the size of the Fort Lauderdale infestation was believed to indicate that the insect had been in Florida for at least four years—possibly even longer—prior to its detection (Hart et al. 1978; R. V. Dowell, personal communication, 1983).

Quarantine regulations went into effect in March 1976, requiring that nurseries in the affected areas be inspected on a regular basis and that all mango and citrus plants transported from the controlled areas be treated and/or certified to be free of citrus blackfly. Fruit shipped from this region was to be fumigated with methyl bromide or certified to be free of all leaves. An official dumping site was designated for the disposal of yard trash and plant clippings.

An urban biometric survey was initiated at this time to provide detailed information on the size and distribution of the infestation (FDACS 1976b). Initially, the USDA contracted with commercial applicators to conduct door-to-door spraying with malathion in the infested portion of Broward County (Blackfly eradication program 1976; FDACS 1976a).

The success of biological control in dealing with citrus blackfly elsewhere and the difficulty in eradicating the pest from Texas led some researchers to conclude that biological control was a preferable method of dealing with the situation. Citrus industry representatives disagreed, however, believing that climatic conditions in Florida were sufficiently different from other citrus growing regions to permit eradication (Hardy 1976; R. V. Dowell, personal communication, 1983). Within two weeks of the initial blackfly discovery in Fort Lauderdale, the board of directors of Florida Citrus Mutual requested that the state department of agriculture and the USDA immediately institute a chemical eradication program (Reitz 1977). As planning for an eradication campaign proceeded, however, arrangements were made to import parasites from rearing facilities in Mexico as part of an integrated management study intended partly as a hedge against an unsuccessful eradication attempt (Dowell 1979a). Releases of *Amitus hesperidum* and *Encarsia opulenta* were begun in April 1976. A third species, *Encarsia clypealis,* was released once at a single location in November but was not recovered again (Hart et al. 1978).

Meanwhile, the size of the infestation continued to grow in proportion to the area examined in the biometric survey. By mid-1976 the regulated area had increased to 480 square miles. In July the state legislature officially authorized a cooperative eradication program to be administered jointly by the USDA Animal and Plant Health and Inspection Service and the Florida Division of Plant Industry. This effort was projected to last five years and cost about five million dollars per year; six dollars per year for every acre of commercial citrus in the state (Lotorto 1978; Reitz 1977).

At the completion of the blackfly survey in August 1976, the infestation covered the southern half of Palm Beach County, most of the inhabited portions of Broward County, and the northern half of Dade County. Both state and federal quarantines were designed to prevent the citrus blackfly from spreading north and west from these urban areas in southeastern Florida to the primary citrus growing regions in central Florida.

Chemical control was initiated in August using six applications of malathion, applied by ground crews at two-week intervals. Sprays were applied in two moving buffer zones, beginning at the northern and southern boundaries of the eradication zone and moving towards each other. In October an Environmental Protection Agency exemption authorized limited use of acephate in place of malathion. Acephate had been found to have both residual and systemic toxicity against the blackfly and was considered to be less phytotoxic and less hazardous to birds and fish than malathion. The numbers of sprays applied per property in the buffer zones was reduced to three with acephate instead of the previous six (Lotorto 1978; Reinert and Neel 1977). Initial hopes for the development of aerial application methods (FDACS 1976b) were never realized. Reitz (1977) attributed this to the preference of the blackfly for the undersides of leaves and to insufficient translocation within plants of the pesticides employed.

An extensive, well-organized media campaign was mounted by the state of Florida to inform the general public about the citrus blackfly and the eradication program (Dowell et al. 1979; Reitz 1977). Perhaps as a result, the blackfly campaign did not experience the negative public reception in the affected areas that occurred in 1934 in Key West.

The state legislature also required basic research on the biology of the blackfly and its chemical and biological control as part of the eradication program. Researchers at the University of Florida cooperated with state and federal workers in producing new information on the biology and host range of *A. woglumi*, efficacy of various control measures, and biology of its parasites (Lotorto 1978; Reinert and Neel 1977; R. V. Dowell, personal communication, 1983).

Funding of the eradication program raised some interesting questions. A state legislature proposal to finance an emergency pest control fund by levying a new tax on agricultural commodities was strongly opposed by agricultural interests on the grounds that additional industry taxes were inappropriate for solving pest problems that may have been caused by the general public (Lavigne 1976). The citrus industry also opposed grower-financed projects to raise money for the eradication program (Hardy 1976).

This opposition by industry succeeded in overriding the tax proposal, and the eradication program was funded from general revenue moneys.

Continued monitoring during 1977 indicated that the infestation centered in Fort Lauderdale actually encompassed 1,250 square miles (Lotorto 1978). The two buffer zones to the north and south of the infested area continued to move inward; affected citrus was treated with acephate every twenty-one days. In October 1977, mango and Surinam cherry were added to the treatment schedule. The addition of these two hosts, together with the increased size of the area to be treated, made continued treatment of both barrier zones economically unfeasible. Therefore, treatment of the southern zone was discontinued in early 1978, and all effort was concentrated in the northern part of the infested area nearest the important citrus-growing regions to the northwest.

Parasite releases were also continued throughout 1977, with great success in establishment and in controlling citrus blackfly. By January 1978, the parasites alone were credited with a 97 percent reduction in the blackfly population (FDACS 1978; Selhime 1979). This led to the incorporation of biological control as an integral part of the eradication effort: parasite releases were used to rapidly reduce blackfly numbers with subsequent acephate applications intended to eliminate the remainder. The opportunity to capitalize on the blackfly reduction resulting from parasites in the northern portion of the infested area was offered as an additional rationale for concentrating the spray operations in that region (Florida expands 1978).

Surveys in late 1978 and early 1979 revealed a persistent low-level infestation throughout the sprayed areas rather than the expected spot infestations which would have indicated local reintroductions (R. V. Dowell, personal communication, 1983). The two parasites, *Encarsia opulenta* and *Amitus hesperidum,* also managed to survive the spray regime and persisted at very low host densities (Dowell 1979a; Cherry and Pastor 1980).

The proven effectiveness of the parasites and their persistence at low densities of the citrus blackfly led the Blackfly Technical Advisory Committee to recommend termination of the eradication phase and full implementation of a biological control program. Despite disagreement by some associates of the citrus industry (Blackfly question 1979), Florida Commissioner of Agriculture Doyle Conner announced in March 1979 his decision to accept a "containment" program with the option of reverting to eradication if necessary (FDACS 1979). The eradication program had not officially failed but simply was no longer necessary.

The containment program provided for continued monitoring of citrus blackfly populations in the area of original infestation, parasite releases, and chemical treatment of isolated infestations. All treatment with acephate was terminated in September 1979 when the specific exemption for its use expired. As of 1988 citrus blackfly is considered under complete biological control in Florida. Occasional local flareups are quickly eliminated by *Amitus*. Both parasite species have become established and are no longer being reared for release (R. V. Dowell, personal communication, 1988).

Thus, the speculation in 1933 by the Florida State Plant Board that parasites could effectively control citrus blackfly in mainland Florida had finally been accepted, though not without two attempts at eradication. The first attempt, in 1933, encountered a great deal of public resistance but proved successful because of the isolated nature of the infested area (Key West). Forty years later, the second eradication effort aroused no public antagonism yet failed to attain its goal. Despite public support for the program, the size of the infested area and its location in a major urban center undoubtedly made thorough treatment and enforcement of quarantines difficult. With citrus blackfly present in Mexico and the Caribbean, the establishment of effective parasites in Florida and Texas serves not only to control existing populations but also as insurance against the ever-present threat of reintroduction.

Evaluation of Eradication Efforts

Successful eradications of *Aleurocanthus woglumi* share several comparable features. In each case the total area of infestation was very small or very isolated at the time of detection. Survey or monitoring techniques used were very extensive or were already established for the blackfly or for other pests. Failure to eradicate citrus blackfly, therefore, was often attributable to late detection. Complicating this was the tendency of the insect to appear first in an urban setting where survey and control measures are labor intensive and thus inherently expensive and less efficient. The resistant nature of the immature stages and their habit of feeding on the undersides of leaves also contributed to the lack of effectiveness of control methods.

Prevention of pest establishment with rapid chemical treatment is often a cost-effective means of dealing with a new introduction if the pest can be detected and eliminated before it spreads throughout a new habitat. With the citrus blackfly, the requirement of early detection has seldom been met and will probably remain a problem in the future.

The continual growth of worldwide travel and trade seems likely to assure new introductions and reintroductions of *A. woglumi*. Localized spot treatments of the pest are desirable in attempting to prevent establishment. But the failures of previous large-scale eradication programs should be kept in mind. Biological control remains an effective management technique, and recent research illustrating the compatibility of natural enemies with the pest management techniques currently practices in citriculture (Fitzpatrick, Cherry, and Dowell 1979; Dowell and Fitzpatrick 1980) should strengthen the acceptance of biological control by the citrus industry. Natural control of citrus blackfly offers a textbook example of effective classical biological control.

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