BIOLOGICAL CONTROL OF ASIAN CITRUS PSYLLID, *DIAPHORINA CITRI* (HEMIPTERA: PSYLLIDAE) IN FLORIDA: A PRELIMINARY REPORT[1]

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ABSTRACT: The Asian citrus psyllid, *Diaphorina citri*, recently invaded the citrus-producing regions of Florida, reaching the northern limits of commercial production in summer of 2001. Preliminary observations indicate a wide range of natural enemies attacking juvenile stages of *D. citri*. The exotic parasitoid *Tamarixia radiata* (Hymenoptera: Eulophidae) was released in previous years and has established, but is not a significant source of mortality for *D. citri* at present. The primary sources of mortality for juvenile psyllids are two coccinellid species, *Olla v-nigrum* and *Harmonia axyridis*. Both species complete development successfully on an exclusive diet of *D. citri*. Other ladybeetles completing development on *D. citri* include *Curinus coeruleus*, *Cycloneda sanguinea*, and *Exochomus childreni childreni*. Other predators observed attacking *D. citri* in Florida include hunting spiders (Aranae: Anyphaenidae, Clubionidae, Oxyopidae, and Salticidae), lacewings (Neuroptera: Chrysopidae, Hemerobiidae), hoverflies (Diptera: Syrphidae), and predatory bugs (Hemiptera: Anthocoridae).

The Asian citrus psyllid, *Diaphorina citri* Kuwayama, is the primary vector of citrus greening disease in Asia (Catling 1970a). Greening is caused by a phloem-limited bacterium, *Liberobacter asiaticum*, that has not yet been reported from the western hemisphere. However, *D. citri* was discovered in Stuart, Florida, in 1998 (Halbert et al. 1998) and subsequently has spread through most commercial citrus plantings in the state. Apart from its importance as a vector of greening disease, *D. citri* feeding damage to growing citrus terminals causes permanent leaf and shoot distortion and may lead to the abscission of young terminals if these are heavily infested in early stages of growth. Heavy populations in nurseries and newly planted citrus groves require chemical control to avert cosmetic damage and maintain normal growth patterns. However, field observations suggest that many generalist natural enemies readily attack juvenile stages of *D. citri* in Florida and eventually may contribute to significant population control of the psyllid. In addition, the exotic parasitoids *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) and *Diaphorencyrtus aligarhensis* (Shafee, Alam and Agaral) were imported from Taiwan and released at various sites throughout the state over the past year (Hoy and Nguyen 2001). However, it likely will be several more years before biological control of *D. citri* is maximal and the relative contributions of the various native and introduced natural enemies can be fully assessed. Although the list of indigenous natural enemies attacking *D. citri* probably will continue to grow, the present paper reports on those species currently attacking *D. citri* in Florida and completing development successfully on a psyllid diet.

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Development and reproduction of *D. citri* requires succulent, newly-expanding citrus terminals and, consequently, population outbreaks are limited to periods of new growth or 'flush' in citrus groves. In summer and winter most adult psyllids enter reproductive diapause and survive by feeding on mature leaves until the next citrus flush; juvenile stages are scarcely found during these periods. The survival rates of adult psyllids during these periods are not known, but anecdotal observations suggest that various web-spinning spiders may be important sources of mortality. However, juvenile stages of *D. citri* appear to represent acceptable prey to a wide variety of generalist predators present in Florida citrus groves.

Aranae. At least four different species of spiders have been observed feeding on *D. citri* nymphs in Florida citrus groves: two sac spiders, *Hibana velox* (Becker) (Anyphaenidae) and *Chiracanthium inclusum* (Clubionidae), a jumping spider, *Hentzia palmarum* (Hentz) (Salticidae), and a lynx spider *Oxyopes* sp. (Oxyopidae). Immature spiderlings of these species typically were observed in association with *D. citri* nymphs; later instars likely switch to larger prey. Laboratory feeding tests conducted with the two most commonly observed species, *H. velox* and *H. palmarum*, revealed that spiderlings of both these species successfully completed early nymphal instars on a diet of *D. citri* nymphs (Amalin, unpublished). These spiders are all dietary generalists and some (e.g. *H. velox*) can be reared on simple artificial diets (Amalin et al. 1999). Moreover, spiderlings of *C. inclusum*, *H. velox* and *H. palmarum* also have been implicated as important sources of mortality for the citrus leafminer, *Phyllocnistis citrella* Stainton, in Florida citrus (Amalin and Peña 2000). It is notable that van den Berg et al (1992) concluded that hunting spiders, particularly species of Clubionidae and Salticidae, contributed to reduction of populations of the African citrus psyllid, *Trioza erytreae* (Del Guercio), in the Transvaal. More work is needed on the role of web-spinning spiders as potential sources of mortality to adult *D. citri* in Florida citrus groves, especially during periods of reproductive diapause.

Coleoptera. Five species of Coccinellidae, subfamily Coccinellinae have been recorded as predators of juvenile *D. citri* in Florida citrus: *Coelophora inaequalis* (F.), *Coleomegilla maculata fuscilabris* Mulsant, *Cycloneda sanguinea* L., *Harmonia axyridis* Pallas, *Olla v-nigrum* Mulsant; and two species of the subfamily Chilocorinae, *Curinus coeruleus* Mulsant, and *Exochomus childreni childreni* Mulsant. Larvae of all species with the exception of *C. inaequalis* completed development successfully on an exclusive diet of *D. citri* nymphs in the laboratory. Both *C. inaequalis* and *C. m. fuscilabris* are relatively rare in citrus and unlikely to contribute any meaningful biological control of *D. citri*.

Curinus coeruleus was imported from Mexico in the 1950's (Gordon, 1985) and its status in Florida was uncertain for many years. It appears to be well established in eastern coastal regions, primarily in the Indian River district and is most abundant during summer months when most other coccinellids are aestivating (Michaud, unpublished). This species has been used in classical biological control programs against a psyllid of New World origin, *Heteropsylla cubana* Crawford, in various countries in Southeast Asia (Chazeau *et al.* 1992, Villacarlos and Robin 1992). However, it is reported to have poor dispersal capability (Follet and Roderick 1996) and is found rarely in citrus groves in southwestern or central Florida.

The blood-red ladybeetle, *C. sanguinea,* is a native species that was formerly the most abundant aphidophagous coccinellid in Florida citrus (Muma 1953a, Michaud 1999) until its recent displacement by the multicolored Asian ladybeetle, *H. axyridis* (Michaud, 2002). However, it is present throughout Florida citrus and is still sufficiently abundant to contribute significant mortality to *D. citri* populations upon which it readily feeds. On the other hand, *E. c. childreni*, another native species, is primarily a scale-feeder that may also prey on aphids (Muma 1953b). Although its larvae develop well on a diet of *D. citri* nymphs, its small size, low voracity, and low relative abundance will likely limit its impact on *D. citri* populations.

The two coccinellid species most frequently observed in association with *D. citri* in citrus groves are *H. axyridis* and *O. v-nigrum*. *Harmonia axyridis* is an introduced species that currently dominates the assemblage of coccinellids in Florida citrus (Michaud 2002). Its abundance is likely due in part to its extremely broad dietary capabilities, and in part to its effectiveness as an aggressive intraguild predator and its ability to displace native coccinellid species (Brown and Miller 1998, Colunga-Garcia and Gage 1998, Cottrell and Yeargan 1998). *Olla v-nigrum* is a native species that occurred at relatively low density in Florida citrus prior to the arrival of *D. citri*, likely because of its inability to complete development on either of the primary species of citrus aphid (Michaud 2000). However, more than any other coccinellid, this species has demonstrated remarkable functional and numerical responses to the presence of abundant *D. citri* as a new food source (Michaud 2001) and appears to be emerging as a key biological control agent. Further work is in progress to assess the relative suitability of *D. citri* for both development and reproduction of these ladybeetles.

Diptera. Hoverflies (Syphidae) have been previously reported as predators of both African and Asian citrus psyllids (Catling 1970b, Mead 1977). The predominant aphidophagous syrphid in Florida citrus is *Pseudodorus clavatus* F. (Belliure and Michaud 2000) and larvae of this species have been observed on psyllid-infested citrus terminals, particularly those with mixed aphid and psyllid colonies. *Pseudodorus clavatus* has been successfully reared on the invasive papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink (Michaud unpublished), but five larvae of this species transferred to a diet of *D. citri* nymphs in the 2nd or 3rd instar failed to pupate successfully. However, another native syrphid, *Allograpta obliqua* (Say) was often observed feeding on *D. citri* in central Florida and eleven of twelve early instar larvae transferred to an exclusive diet of *D. citri* nymphs yielded viable adults. Weems (1971) reported 28 different aphid species as prey for larvae of *A. obliqua* in Florida and noted that it had also been observed feeding on whitefly nymphs. Adults of many other syrphids can be observed and collected in citrus, although the range of prey utilized by larvae remains unknown for most species.

Hemiptera. Several observations indicate that immature assassin bugs of the Genus *Zelus* (Reduviidae) will prey on adult psyllids, but these bugs are tertiary predators and typically seek larger prey as they mature. They are also notorious intraguild predators that generally have an ambiguous impact on pest control because of their propensity to feed on other beneficial insects (Rosenheim et al. 1995). Other observations have revealed predation on *D. citri* nymphs by *Orius* sp. (Anthocoridae), a small predatory bug that has also been reported feeding on the brown citrus aphid, *Toxoptera citricida* (Kirkaldy) (Michaud and Belliure 2000). Bugs of the family Anthocoridae, particularly species in the Genera *Anthocorus* and *Orius* are known to act as predators of psyllids and have even been considered for introduction against *T. erytreae* in South Africa (van den Berg 1985). However, the suitability of *D. citri* as prey for the development and reproduction of these bugs remains unknown, and their comparative scarcity in Florida citrus suggests that they have few suitable prey alternatives and that their potential contribution to biological pest control is negligible.

Hymenoptera. Many ant species tend psyllid-infested citrus terminals, apparently for the purpose of harvesting honeydew. The honeydew produced by *D. citri* nymphs is waxy and viscous, having the appearance of toothpaste squeezed from a tube. Under dry conditions, wind action causes these viscous threads to fall from the bodies of nymphs as they exude it, precluding its adherence to leaves and the subsequent growth of sooty mold. Under wet or humid conditions, the hygroscopic nature of the honeydew causes it to absorb moisture, lose its viscosity, and behave more as the typical honeydew excreted by aphids and scales. Dissolved or not, it is highly attractive to many ant species including *Brachymyrmex obscurior* Forel, *Camponotus floridanus* (Buckley), *Crematogaster ashmeadi* Mayr, *Dorymyrmex bureni* (Trager), *Dorymyrmex reginicula* (Trager), *Monomorium floricola* (Jerdon), *Paratrechina bourbonica* (Forel), *Pseudomyrmex gracilis* (F.), and *Solenopsis invicta* Buren. The impact of these ants on biological control of *D. citri* warrants assessment, but *C. floridanus* and *S. invicta* in particular are large aggressive species known to attack predators in citrus aphid colonies (Michaud and Browning 1999, Michaud unpublished). Many of these ants are also important as sources of mortality for other citrus pests such as citrus leafminer, *P. citrella* (Pomerinke 1999, Amalin et al. 2001) and citrus root weevil, *Diaprepes abbreviatus* (L.). (Whitcomb et al. 1982). In addition to collecting honeydew, I have observed workers of *D. bureni* and *P. gracilis* carrying *D. citri* nymphs to their nests on several occasions, so these species may also act as predators of immature *D. citri*.

The introduced parasitoid *T. radiata* appears to have established in Florida, although it is currently found at very low levels within most *D. citri* infestations. The encyrtid endoparasitoid *D. aligarhensis* does not appear to have established. *Tamarixia radiata* is a eulophid ectoparasitoid that contributes additional mortality to *D. citri* by virtue of the host-feeding behavior of adult females. However, only late instar *D. citri* nymphs are suitable for oviposition and these may be absent for prolonged periods when new flush is unavailable for psyllid reproduction. How the parasitoid population manages to bridge these extended periods of host deprivation is not known. The apparent effectiveness of this parastioid in regions such as Taiwan and Reunion Island (Chien and Chu 1996) may be partly due to the more continuous availability of citrus flush for psyllid reproduction under fully tropical conditions, and possibly to utilization of alternate hosts by the parasitoid. Although *T. radiata* appears to have successfully overwintered in Polk County Fla. in 2000-2001 (no releases have been made locally this year), it is also possible that the parasitoid was redistributed with its host on potted jasmine orange in commercial nursery operations (Halbert et al. 2002). There have been no collections of either native parasitoids or hyperparasitoids from *D. citri* in Florida as yet.

Neuroptera. Larvae of the little brown lacewing, *Micromus posticus* (Walker) (Hemerobiidae) have been observed feeding on *D. citri* nymphs in citrus, although their suitability as prey for the development of *M. posticus* has not been assessed. However, *M. posticus* typically has very low abundance in Florida citrus and offers little promise as a biological control agent. Larvae of both *Chrysoperla rufilabris* Burmeister and several *Ceraeochrysa* spp. (Chrysopidae) have been observed feeding on *D. citri* in citrus groves and a number of specimens have been reared out successfully on an exclusive diet of *D. citri*. The latter species are trash-carriers with cryptic behavior; larvae disguise themselves by attaching the empty cuticles of their prey to hooked bristles on the dorsal surface of their bodies. Larvae of the former species are naked and presumably more vulnerable to intraguild predation when feeding in exposed locations such as citrus terminals. This vulnerability likely favors other types of cryptic behavior such as nocturnal feeding that may lower their detectability and lead to underestimation of their importance as agents of biological control. Although neither species appears sufficiently abundant in citrus to contribute significant mortality to *D. citri* populations at present, their ability to effectively utilize *D. citri* as a food source for development may yet result in some numerical response to psyllid populations in particular circumstances.

CONCLUSIONS

Although relatively high populations of *D. citri* have been observed in many citrus groves over the past growing season, biological control of this pest appears to be developing well in Florida. The complex of coccinellid species is by far the most apparent source of mortality for juvenile *D. citri* at this time. However, *D. citri* apparently is an acceptable and suitable prey for a wide range of generalist predators in Florida citrus, and several years may be required before this broad-base of biological control will be maximal. Predators that are best able to utilize *D. citri* for both development and reproduction are those most likely to increase in abundance in response to *D. citri* infestations. A numerical response already has been noted for *O. v-nigrum* (Michaud 2001). The 2002 growing season represents a unique window of opportunity to make the extensive field observations necessary to objectively quantify the biological control contributions of these various species before *D. citri* populations recede and sources of mortality, particularly predation, become increasingly difficult to observe and assess. Further work is required to evaluate the relative suitability of *D. citri* for the development and reproduction of the various predators, especially ladybeetles. However, given the general acceptability of *D. citri* as prey for so many indigenous natural enemies, and its apparent suitability for larval development, the need for introduction of exotic parasitoids to control *D. citri* is questionable.

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