Classical Biological Control: A Critical Review of Recent Programs Against Citrus Pests in Florida

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ABSTRACT Classical biological control is often considered a cornerstone of integrated pest management, although the introduction of exotic natural enemies can have unpredictable and wide-ranging impacts on native ecosystems. In this article, I question the wisdom of using the classical approach as an automatic first response to invasive pests. I critically evaluate some classical biological control programs recently implemented against invasive pests of citrus in Florida including: *Lysiphlebia japonica* Ashmead and *Lipolexis scutellaris* Mackauer (Hymenoptera: Aphidiidae) introduced against the brown citrus aphid, *Ageniaspis citricola* Logviniskaya (Hymenoptera: Encyrtidae) against the citrus leafminer, and *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) against the Asian citrus psyllid. I advance the following contentions: (1) Not all invasive pests are appropriate targets for the classical approach, especially those that lack natural enemies specific to, or effective against them. (2) Some invasive pests may be effectively controlled by generalist predators within a time frame similar to that required for evaluation of introduced parasitoids. (3) The contributions of native species are often ignored when postrelease evaluations focus on introduced species. (4) Parasitism is a highly apparent phenomenon in the field, while predation is less apparent and far more difficult to quantify, an empirical disparity that may generate an undue bias regarding the perceived importance of introduced parasites relative to indigenous predators in biological control. (5) Classical programs have immediate political appeal to agricultural sectors seeking quick solutions to new pest problems, and to the government agencies seeking to respond to their demands for action. Thus, funding incentives for research may be biased toward ‘rear and release’ classical programs and away from other, ecologically sound approaches to pest management such as conservation biological control. I conclude that classical programs are typically employed as a reflexive response to invasive pests, often without adequate evaluation of the pest as a potential, rather than automatic, target for this approach, and without prerelease surveys to document indigneous natural enemies. A classical program may be embarked on regardless of whether or not suitable candidate species for introduction can be identified, and often without objective postrelease evaluations. The net result is a prevailing tendency to underestimate the potential ecological resiliency of established insect communities to invasive pests.

KEY WORDS *Ageniaspis citricola, Diaphorina citri, Maconellicoccus hirsutus, Phyllocnistis citrella, Tamarixia radiata, Toxoptera citricida*

CLASSICAL BIOLOGICAL CONTROL, the introduction of exotic natural enemies for purposes of suppressing populations of an invasive pest species, has been described in different ways from various viewpoints. It has been termed a process of “renewing links between pests and their natural enemies” to “restore population balance” in ecosystems (Bellows 2001). Conversely, it has been criticized as a pest control tactic that has, in extreme cases, “caused both catastrophic declines of common species and . . . pushed rarer species closer to extinction” (Howarth 2000). Numerous case studies can be cited that document both the social and economic benefits of classical programs, as well as wide-ranging undesirable side effects, now collectively referred to as ‘nontarget’ effects (Follet and Duan 2000). A significant number of invasive insect species enter the continental United States through Florida, via natural dispersal through the Caribbean basin, and international airline traffic (Florida Pest Exclusion Advisory Committee 2001). Classical biological control programs are increasingly relied upon as a first response to invasions of agriculturally significant pests in Florida. In this article, I critically review some of the recent classical programs implemented against invasive pests of citrus in Florida, the rationale and assumptions underlying our reliance on this approach, the reasons

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for its political appeal to both agricultural interests and government agencies, and its various impacts on entomological research and ecological persepectives.

Brown Citrus Aphid – A Revealing Case Study. It has been more than 5 yr since the brown citrus aphid, *Toxoptera citricida* (Kirkaldy), invaded Florida and forced citrus growers to abandon sour orange, *Citrus aurantium* L., as a rootstock. This was due to the efficiency of the brown citrus aphid in vectoring citrus tristeza virus (CTV), the causal agent of citrus 'quick decline.' Even before its arrival in Florida, the brown citrus aphid was selected as a target for a classical biological control program. In a review of 184 research publications (Michaud 1998), I concluded that no parasitoid specific to brown citrus aphid had ever been discovered, and that no classical biological control program had ever proven successful against it. All ecological studies that have assessed brown citrus aphid mortality factors throughout its range indicated that biological control is broad-based and brought about by various combinations of generalist predators – *not* parasitoids. However, this lack of precedents and suitable candidates for introduction did not deter state and federal agencies from a commitment to implement a classical biocontrol program against brown citrus aphid with an introduced parasitoid. Based largely on a single laboratory study from Japan (Takanashi 1990) the parasitoid *Lysiphlebia japonica* Ashmead was selected, introduced, and released at >30 locations throughout Florida during the initial years of peak brown citrus aphid abundance in commercial citrus. To my knowledge, no published record of these introductions is available for citation, likely because *L. japonica* never established in Florida, and subsequent releases in Puerto Rico and Belize also failed.

Subsequent developments offered an important lesson in biological control. In 1997, brown citrus aphid infestations were extensive and widespread throughout commercial citrus, providing the opportunity for extensive observations on sources of mortality. Hundreds of hours of field observations on thousands of aphid colonies revealed just how many different generalist predators were feeding on brown citrus aphid (Michaud 1999a, Michaud and Browning 1999). Other studies provided insights into brown citrus aphid behavior, ecology and survival strategies that were relevant to its effective management in Florida, largely via conservation biological control (Michaud 1999b, 2001a; Michaud and Belliure 2000). By 1998, large populations of brown citrus aphid became harder to find, although substantial infestations occurred in some groves during the fall growth periods. From 1999 to date, biological control of brown citrus aphid continued to improve, although occasional localized outbreaks still result if biological control is disrupted. The last infestation in which mortality factors were assessed occurred in October of 1998. From a total of 328 brown citrus aphid colonies followed from initial colonization to extinction, only one survived to produce the winged migrants of economic importance in transmitting CTV, a colony success rate of only 0.3% (Michaud 2001b). Thus, over a period of several years, the brown citrus aphid was brought under good biological control by a combination of generalist predators already present in Florida citrus, primarily certain species of ladybeetles (Coleoptera: Coccinellidae) and hoverflies (Diptera: Syrphidae) that were capable of successful development on a brown citrus aphid diet (Michaud 1999a, 2000; Belliure and Michaud 2001). It is, therefore, a matter for concern that funding from growers and state authorities is still being directed toward the introduction of more unproven parasitoid species, especially when aphid populations of adequate size to support parasitoid establishment no longer exist. Granted CTV is still a problem, but growers no longer spray pesticides for aphids in established citrus groves.

The Classical Approach without Suitable Candidates. Although a body of literature has been generated on the effectiveness of existing predators against brown citrus aphid, it apparently has been ignored by those who would further pursue a classical program by introducing parasitoids against this pest, regardless of need. Despite the failure of an expensive program to establish *L. japonica*, and despite clear guidelines for maximizing existing biological control of brown citrus aphid (Michaud 1999c), yet another exotic parasitoid, *Lipolexis scutellaris* Mackauer, is currently being released against brown citrus aphid in Florida citrus (Hoy and Nguyen 2000). Although it has been reported to parasitize brown citrus aphid in Guam from whence it has been imported, there has been no quantitative assessment of its impact on brown citrus aphid on this island. A search of the Commonwealth Agricultural Bureau database yielded only eleven references to *L. scutellaris,* seven from India, and one each from Bangladesh, Korea, Viet Nam, and Malaysia. No reference mentioned *L. scutellaris* in association with brown citrus aphid and none were ecological studies that quantified its impact on aphid populations. Only one reference speculated that *L. scutellaris* might be useful as a biological control agent (Stary and Zeleny 1983), although the authors did not specify a target aphid species. Observations of *L. scutellaris* in the laboratory reveal that adults have poor dispersal ability and are extremely short-lived even under low temperature conditions that maximize their lifespan (A. Chow, personal communication). Although larval development of *L. scutellaris* in brown citrus aphid is reasonably good, this aphid is far from being an ideal host; only the smallest brown citrus aphid nymphs are susceptible to attack and, once parasitized, they tend to drop from the plant before mummification (A. Chow, personal communication). This dropping behavior has been construed as a pathological response indicative of a nonadapted parasitoid-host relationship (Chow and Mackauer 1999) and is likely to result in significant parasitoid mortality in Florida citrus groves due to high soil surface temperatures and ant predation. There is no published evidence that *L. scutellaris* has any impact on brown citrus aphid populations even in its countries of origin and, therefore, no reason to expect it to have any impact on brown citrus aphid in Florida, should it become established.

More importantly, the introduction of *L. scutellaris* is not even necessary given current levels of brown citrus aphid biological control.

In my view, the term 'biological control' should not become synonymous with the classical approach. Biological control is not simply the displacement of beneficial species from one region to another, it includes any cultural interventions or management considerations that preserve, enhance, or otherwise favor the activities of beneficial insects, native or introduced. The need is for more comprehensive ecological studies to elaborate community-level interactions among natural enemies already present and established in agricultural ecosystems. Such studies would provide insights to further improve the effectiveness of indigenous natural enemies, and might also improve our ability to predict the ecological 'fit' of exotic natural enemies whose introduction might be required for supplementary control of particular pests. Why then are we so inclined to employ the classical approach as an automatic response to invasive pests, rather than treating it as one of many potential alternatives that may or may not be advisable in a particular situation?

'Silver Bullet' Species and the Political Appeal of the Classical Approach. Whenever agricultural producers are confronted with an invasive pest that poses a threat to their livelihood, policy-makers in government agencies are inundated with demands for action to be taken. A policy of 'let's study the situation first' is not likely to be well received by lobbyists representing the interests of organized commodity groups, even if it could be shown to be the best scientific course of action. However, the classical approach has great public appeal on the surface because it avoids the hazards of pesticide use and holds out the promise of lasting agricultural benefits from a one-time investment, although only a small fraction of such projects are ever truly successful. Proponents of the classical approach quickly point to the classic, textbook examples of dramatic pest control achieved with the introduction of a single exotic species, often without placing these in an appropriate perspective of the vast number of failures (Greathead and Greathead 1992). The quest for the 'silver bullet' species that will solve the problem all by itself becomes analogous to the search for the Holy Grail. As Greathead and Greathead (1992) pointed out, even large databases that attempt to objectively summarize volumes of information on classical programs are biased to an indeterminate degree by the fact that failed programs are less likely to be reported in the literature than are successful ones. There is no published record of the failure of *L. japonica* against brown citrus aphid, despite the fact that the program was conducted in at least three different countries. Collectively, these elements contribute to an unjustified political bias toward the classical approach. This, in turn, results in grants and funding opportunities that provide incentives for exotic species introductions that are often little more than exercises in rearing and releasing insects, rather than ecological studies of indigenous natural enemy communities that are ultimately the foundation on which biological control rests. A 'wait and see' approach may often be a more rational course of action than multiple introductions of unproven species, especially when scientific knowledge is lacking. This was certainly true in the case of brown citrus aphid.

The Classical Approach: Historical Successes in Citrus. The classical approach has historically had some great successes in the Florida citrus industry. Examples include the introduction of *Rodolia cardinalis* (Mulsant) against cottony cushion scale, *Icerya purchasi* (Maskell) (Browning 1994), *Aphytis holoxanthus* De Bach against the Florida red scale, *Chrysomphalus aonidum* L. (Clancy et al. 1963) and *Amitus hesperidum* (Sylvestri) and *Encarsia opulenta* (Sylvestri) against citrus blackfly, *Aleurocanthus woglumi* (Ashmead) (Browning and Stimac 1994). These successes were, for the most part, carefully conceived programs based on a solid background of scientific research, using effective natural enemies with a proven track record in other countries. For example, the use of *E. opulenta* against *A. woglumi* has been successful in Costa Rica (Elizondo and Quezada 1990), Nicaragua (Cano and Swezey 1992), Venezuela (Ferrer 2001), Oman (Al-Mjeni and Sankaran 1991), throughout the Carribean (Browning 1992), in Florida (Dowell et al. 1979, Tsai and Steinberg 1991), and in Texas (French et al. 1990, Summy and Gilstrap 1992). Caltagirone (1981) considered citrus blackfly to be one of the landmark examples of classical biological control. Dowell (1989) elaborated the life history traits contributing to the effectiveness of *E. opulenta* and Summy et al. (1985) demonstrated the direct density-dependent and delayed density-dependent functional responses of *E. opulenta* in the field that enabled it to co-exist with *A. woglumi* at low densities. The studies of Elizondo and Quezada (1990) considered the biocontrol contributions of native predators and fungal pathogens as "significant," but concluded that *E. opulenta* was still the key mortality factor in Costa Rica. Cano and Swezey (1992) used a life table approach and similarly concluded that *E. opulenta* was the primary biological control agent of citrus blackfly in Nicaragua. Cherry and Dowell (1980) used exclusion techniques to evaluate predator contributions to blackfly control in Florida and Boscan de Martinez et al. (1982) studied the role of predators and entomopathogenic fungi in contributing to control of *A. woglumi* in Venezuela. Swezey and Vasquez (1991) noted outbreaks of *A. woglumi* associated with inclement weather and pesticide applications, both of which had negative effects on parasitoid populations. This is notable because recent outbreaks of *A. woglumi* in Texas (J. V. French, personal communication) may also be linked to pesticide-induced mortality of *E. opulenta.* Similarly, Rehman et al. (2000) were able to induce resurgence of Florida red scale populations to levels not seen in decades using pesticide applications to eliminate its key parasitoid, *A. holoxanthus,* a strong indication of the importance of this wasp in sustained biocontrol of *C. aonidum.* Thus, there are various independent and pursuasive lines of evidence to indicate that these particular pests are effectively controlled through the introduction of specific natural enemies, making them appropriate targets for classical biological control programs.

The Classical Approach: Weighing Costs and Benefits. More recently, the classical approach has been applied in Florida citrus in a more indiscriminate manner, resulting in the introduction of various unproven species with low probabilities of success. Advocates of the classical approach may argue that the potential costs of uncontrolled pest populations are sufficiently high to warrant acceptance of the potential risks of introducing exotic species, and yet both 'potential costs' and 'potential risks' can be very difficult to estimate (Simberloff 1992). Projections of potential losses resulting from 'no action' typically assume that pest populations will expand unchecked, or continue at postinvasion levels, without the release and establishment of an exotic natural enemy, an assumption that may or may not be justifiable. However, the potential risks are less apparent, typically environmental in nature, and not likely to be weighted as heavily as potential benefits by the agricultural interests and government agencies seeking an expedient solution for an immediate problem.

Many studies have pointed out the potential ecological risks of the classical approach and entire books have focused on the negative impacts of introduced species (Follet and Duan 2000). Although the ecological safety of the classical approach is clearly a matter for debate (Howarth 1991, Simberloff and Stiling 1996), organized agricultural interests often appear to receive disproportionate consideration relative to other socioeconomic segments of society when decisions are made to implement classical programs. The potential of introduced species to have dramatic impacts outside of agriculture is perhaps exemplified in the United States by the introduced ladybeetle *Harmonia axyridis* Pallas. Although *H. axyridis* has become a major predator of brown citrus aphid and other pests in the Florida citrus ecosystem (Michaud 1999a, 2002a), it has also displaced *Cycloneda sanguinea* L. as the dominant coccinellid in Florida citrus (Michaud 2002b), a species that is an equally good predator of brown citrus aphid. Despite its renowned effectiveness as a biological control agent in many annual and perennial crops, this 'invasive biocontrol agent' is displacing multiple native coccinellid species across North America (Lamana and Miller 1996, Colunga-Garcia and Gage 1998) and causing extensive problems in urban developments when large overwintering aggregations enter houses (Nalepa et al. 1996). Although there is little doubt that the benefits of improved pest control by *H. axyridis* are appreciated by growers of pecans (Tedders and Schaefer 1994) and apples (Brown and Miller 1998) as well as citrus, the costs of this classical introduction are clearly being paid by urban communities (Huelsman et al. 2002), and by native fauna (Michaud 2002b). It seems clear that to be truly objective, cost-benefit analyses of classical programs must carefully consider the impacts on all segments of society, not just agriculture.

Implicit Assumptions of the Classical Approach. Those who hasten to import and release exotic species make at least two assumptions that are rarely stated explicitly. These assumptions, while not invariably false, are often unjustified. The first assumption is that native species will not provide adequate control of an invasive pest. The brown citrus aphid example provides evidence of just how flawed this assumption can be. Brown citrus aphid populations subsided to a fraction of their initial magnitude without the establishment of any exotic parasitoids (Michaud 2002c). High initial populations of invasive pests are often taken as an indication that native species are not going to provide sufficient control, and yet few ecosystems are without opportunistic natural enemies that are ready to capitalize on invasive pests as new sources of food. The work of Settle et al. (1996) provides a classic example of how a holistic, ecological approach can provide a permanent solution to major pest problems in a complex agro-ecosystem by maximizing the effectiveness of existing natural enemies, mostly generalist predators, without introducing any exotic species. Further evidence of the potential resilience of native ecosystems can be found in cases where indigenous parasitoids and predators have been factors interfering with the establishment of herbivorous insects introduced for purposes of weed biological control. Native chalcid wasps have been identified as factors potentially limiting the effectiveness of the gall midge *Rhopalomyia tripleurospermi* Skuhravá (Diptera: Cecidomyiidae) introduced into Canada for control of scentless chamomile, *Matricaria perforata* Merát (Asteraceae) (McClay et al. 2002). The herbivore *Dactylopius opuntiae* (Cockerell) (Homoptera: Dactylopiidae), introduced against prickly pear cactus, *Opuntia* spp., only became effective in controling the cactus in South Africa after a native coccinellid predator, *Exochomus* sp., was eliminated with low dosage applications of DDT (Annecke et al. 1969).

As we have seen with brown citrus aphid, several years may be required for the most preadapted native predators to realize numerical responses and exert their maximal impact on a new pest, a period similar to that we are expected to wait before judging the effectiveness of introduced species (Hoy 1998). Unfortunately, exotic natural enemies are typically credited when pest populations decline after their introduction and establishment, and yet postrelease evaluations often fail to account for the contributions of native species in bringing about this decline. Furthermore, classical programs represent large professional investments by those undertaking them and this generates a vested interest in demonstrating their effectiveness, a factor that can lead to the collection of biased data sets that exaggerate the impact of introduced natural enemies and ignore the contributions of native species.

One example from Florida citrus is that of *Ageniaspis citricola* Logviniskaya introduced against the citrus leafminer, *Phyllocnistis citrella* Stainton in 1994. Proponents of the classical program against citrus leafminer implied that *A. citricola* "could be one of the rare "silver bullet" species in classical biological control – a single species capable of providing dramatic pest population suppression." (Hoy et al. 1996). In 1996, leafminer pupae were sampled in 28 Florida counties and parasitism by *A. citricola* was reported to average >90% in some groves (Hoy et al. 1997). The article overtly promoted *A. citricola* to citrus growers as the primary biological control agent of citrus leafminer, a considerable overstatement of the facts (Pomerinke 1999, Amalin et al. 2001). To report percentages of pupal parasitism without considering sources of mortality acting on other life stages is tantamount to selectively sampling only the tip of an iceberg, for predators ensure that only a small fraction of eggs and larvae ever make it to the pupal stage. Subsequent, more objective studies attempted to measure all sources of mortality to all citrus leafminer life stages (Pomerinke 1999, Amalin et al. 2001). These studies concurred in their findings that generalist predators were the primary sources of citrus leafminer mortality and that parasitism by *A. citricola* accounted for no more than about 4–5% population reduction, at least in southern regions of the state. Moreover, the data presented by Pomerinke (1999) indicated that citrus leafminer parasitism by native eulophid wasps in southwest Florida declined from 18 to 2% following the introduction of *A. citricola.* In contrast to *A. citricola* that attacks citrus leafminer in the egg and early larval instars, the native eulophids are ectoparasitoids that attack citrus leafminer larvae in later stages of development and may well avoid those already occupied by the exotic endoparasitoid. Thus, there is evidence to suggest that *A. citricola* may have merely substituted for native parasitoids that were just beginning to respond to citrus leafminer when *A. citricola* was released and began to compete with them for hosts (Browning and Peña 1995). Ironically, those promoting the classical program against citrus leafminer were more concerned about possible interference by the native parasitoids with *A. citricola* (Hoy et al. 1996). The fact that similar levels of citrus leafminer biocontrol have been achieved in Texas and Mexico where *A. citricola* has failed to establish (Legaspi et al. 1999) supports the contention that the establishment of *A. citricola* did not lead to lower equilibrium citrus leafminer populations in Florida than would have been delivered by native natural enemies acting on their own. Thus, there is little evidence that *A. citricola* represents a success for the classical approach, especially considering that citrus leafminer is still a significant problem in Florida citrus, and under weaker biological control than brown citrus aphid against which no introduced parasitoids have yet been established.

The second implicit assumption is that adding more natural enemies to an ecosystem will improve levels of pest control. Apart from this possible outcome, the addition of natural enemy species to an ecosystem has many possible adverse consequences that are difficult, if not impossible, to anticipate (Follet and Duan 2000). Furthermore, there exists a substantial body of literature suggesting that abitrarily increasing the number of species in an ecosystem decreases the stability of the system, largely because co-evolved assemblages of natural enemies are not themselves arbitrary collections of species (Allen 1990, 1996). While federal environmental impact assessments require testing introduced species for prey/host specificity, no consideration is given to possible direct or indirect competitive interactions with other established natural enemies. A prime example of competition between aphid parasitoids can be found in the alfalfa cropping system in the Pacific region. The exotic parasitoid *Aphidius smithi* Sharma & Subba Rao had been established as the primary parasitoid of the pea aphid, *Acyrthosiphum pisum* Harris, for more than 10 yr, and accounted for >90% of the parasitoids recovered from this pest during the 1970s (Kambhampati and Mackauer 1989). It was thought by some that the introduction of another aphid parasitoid, *Aphidius ervi* Halliday, would further improve levels of pea aphid biological control, but in less than five years *A. ervi* virtually eliminated *A. smithi* from the alfalfa ecosystem all along the Pacific coast through competitive displacement (McBrien and Mackauer 1990), although levels of pea aphid biological control remained virtually unchanged (Kambhampati and Mackauer 1989, Chua et al. 1990). A similar scenario ensued in the alfalfa ecosystem in New Zealand where *A. smithi* failed to establish and *A. ervi* ended up displacing another introduced aphidiid wasp, *Aphidius eadyi* Stary, González & Hall (Cameron and Walker 1989). It is also conceivable that an exotic natural enemy could actually result in reduced levels of biological control, either of the target pest or of other pest species, through various mechanisms of competitive interference with indigenous beneficial species. Such complexities of insect community ecology are still being unraveled, and yet the classical approach is typically promoted without any apparent consideration of these potential undesirable side effects.

The 'Shotgun' Approach. In light of the above considerations, the 'shotgun' approach (releasing many exotic species in the hope that one or more will establish and adversely impact pest populations) should be viewed as environmentally unconscionable. Advocation of this approach is a strong indication that no promising candidate species have been identified. An example of the shotgun approach can be found in the program recently mounted against the Russian wheat aphid in the midwestern states in which some 24 species of exotic natural enemies were imported and released (Prokrym et al. 1998). Only four of these species became established and only one appears to have had any measurable impact on the target pest, *Aphelinus albipodus* Hayat & Fatima (Brewer et al. 2001), although russian wheat aphid populations are now insignificant in most regions of the central plains. Once again, objective field observations indicated that most russian wheat aphid mortality was inflicted by generalist predators, primarily native coccinellids (Nechols and Harvey 1998). Recent work in Wyoming has revealed the importance of native dipteran predators (Chamaemyiidae and Syrphidae) for early season control of russian wheat aphid, with parasitoids becoming more important in late season (M. Brewer, personal communication). Unfortunately, the relative contributions of native and exotic parasitoids are proving difficult to disentangle because, in some cases, exotic strains of indigenous species, e.g., *Diaeretiella rapae* (McIntosh), were introduced that are indistinguishable from their native counterparts. It is notable that opinion was initially divided regarding which natural enemies should be introduced and how quickly. One viewpoint favored the rapid introduction of as many species as possible, while the other preferred a more conservative approach that would have required prerelease evaluations of candidate species and releases of only the most promising ones (Prokrym et al. 1998). Not surprisingly, the 'shotgun' camp won out on the grounds that the urgency of the situation warranted immediate action. Unfortunately, whenever we hasten to release a plethora of exotic species indiscriminately into the environment we underestimate the resiliency of native ecosystems to resist and assimilate invasive pests, and reinforce the myth that classical introductions are the only means of achieving biological control.

It should be recognized that releases of exotic natural enemies represent large-scale experiments on the ecosystem, usually without any 'control' that permits meaningful comparison –we cannot know what would have happened to the pest population in the absence of the introduced species unless the releases fail, as in the case of brown citrus aphid in Florida. Although substantial state and grower-supported funding was spent on classical biological control of brown citrus aphid in Florida, the problem essentially took care of itself, albeit with a little advice to citrus growers to avoid pesticide applications. Although the classical programs recently mounted against brown citrus aphid and other citrus pests have been vigorously promoted in trade journals (Hoy and Nguyen 1996, 2000, 2001) peer-reviewed publications summarizing the results of these projects are glaringly absent from the scientific literature, a strong indication that no adequate postrelease evaluations were ever performed.

The 'Apparency' of Parasitism Versus Predation. Current guidelines for the importation of exotic species in classical programs require an Environmental Impact Assessment that ensures a reasonable degree of specificity on the target pest, a criterion that now largely constrains practitioners of the classical approach to import natural enemies with demonstrated specificity for the target pest. Although some effective parasitoids have broad host ranges, they are unlikely to be approved for introduction under current guidelines. Similarly, although predators exist that are reasonably prey-specific (e.g., *R. cardinalis*), there are typically few that are suitable candidates for introduction. Almost exclusively, recent classical introductions against citrus pests in Florida have used parasitoids with narrow host ranges. Unfortunately, the 'apparency' of parasitism is another factor facilitating underestimation of the impact of native natural enemies on invasive pests. Empirically, parasitism is far easier to estimate under field conditions than is predation. Parasitism leaves more evidence and is easier to directly observe and measure, making the contributions of generalist predators easier to overlook, and less recognizable for growers and extension personnel. Estimates of percentage parasitism rank among the most misleading statistics in all of biological control literature when they are obtained through selective sampling or when they are presented without adequate ecological context for meaningful interpretation (van Driesche 1983, van Driesche et al. 1991). For example, assuming a parasitoid kills its host in a late developmental stage, any estimate of percentage parasitism based on samples taken late in the pest's phenology in the crop will tend to over-estimate the importance of parasitism as a mortality factor, an effect that will be further exacerbated if the parasitoid has a longer developmental time than its host.

Practitioners of the classical approach too often focus their attention exclusively on parasitism, despite the fact that there is no real evidence that parasitoids are any more effective overall than generalist predators in suppressing pest populations (Chang and Kareiva 1999). The specialist parasitoid is, by definition, constrained to attacking its specific host and remains in association with its host even at low population densities when generalist predators have switched to feed on more abundant prey. The continued association of a specialized parasitoid with low density populations of its host can, therefore, be viewed as merely a consequence of its specificity, and should not be construed as evidence that the parasitoid is necessarily responsible for maintaining the pest at low density.

The Classical Approach as an Ecological Experiment without Control. A scenario similar to that of brown citrus aphid is now underway with a new invasive pest, the Asian citrus psyllid, *Diaphorina citri* Kuwayama, the primary vector of citrus greening disease in Asia. Partly in response to erroneous reports of the presence of greening in Florida, the citrus industry funded the introduction of two parasitoids, *Tamarixia radiata* (Waterston) and *Diaphorencyrtus aligarhensis* (Shafee, Alam & Agaral) that have now been released at multiple sites across the state over the past two years (Hoy and Nguyen 2001). *Tamarixia radiata* appears to have established and is tracking Asian citrus psyllid populations in central Florida, although rates of parasitism are currently low (Michaud 2002b). The final degree of control *T. radiata* will exert on Asian citrus psyllid populations is not yet clear, but it should now become incumbent on the 'releasers' of this species to perform some objective postrelease evaluations. *Tamarixia radiata* may end up contributing to the control of Asian citrus psyllid, but it is entirely possible that the same final levels of biocontrol would be provided by natural enemies already present, an absence of native parasitoids notwithstanding. Regardless of the outcome, this assertion cannot be refuted with scientific data because the classical 'experiment' had no control. This would have required the establishment and monitoring of control plots as described by van Driesche and Bellows (1996), although how *T. radiata* might be selectively excluded from such plots for any extended period is difficult to imagine.

In this case, it was explicitly stated that "native natural enemies are not expected to suppress the pest populations to a noneconomic level" (Hoy 1998), and yet that is exactly what is happening. A native ladybeetle, *Olla v-nigrum* Mulsant, has undergone dramatic population increases in response to Asian citrus psyllid as a new food source and, in combination with other ladybeetles such as *H. axyridis,* will most likely be the key mortality factor bringing asian citrus psyllid under biological control in the next few years (Michaud 2001c). My field observations in central Florida in the fall of 2001 employed reiterated, nondestructive sampling procedures on 150 infested citrus terminals and indicated a psyllid survival rate (first instar to adult) of ≈7% (unpublished data). Predation, primarily by the assemblage of coccinellids, accounted for ≈90% of juvenile psyllid mortality, abscision of heavily infested terminals almost 10%, and parasitism by *T. radiata* 0.3%. However, since ladybeetles do not consume mummified psyllids, and since the parasitoid requires a longer period than its host to complete development, sampling late in a citrus flushing cycle when only mummified psyllids remain could easily generate a distorted data set indicating rates of parasitism by *T. radiata* approaching 70 or 80%.

It is also noteworthy that *O. v-nigrum* has been used successfully in classical biological control of a psyllid of new world origin, *Heteropsylla cubana* Crawford, throughout southeast Asia and the Pacific area (Chazeau et al. 1991). Evidently, we already had a world-renowned psyllid predator resident in Florida citrus groves, and yet proponents of the classical approach looked immediately to other countries for exotic species to import (Hoy and Nguyen 2001). We are frequently told that several years are required before introduced species can be adequately evaluated. For example, Hoy and Nguyen (1997) stated explicitly "Only after three years have elapsed without any evidence that an introduced natural enemy species has established is it considered appropriate to list (the classical program) as a failure." I find it very disheartening that, while we extend such generosity to imported species, we do not afford native species the same probationary period before resorting to the classical approach.

Current work in our laboratory is revealing that Asian citrus psyllid is actually a more suitable component of diet for a wider range of generalist predators in citrus than is brown citrus aphid, supporting the development and reproduction of species that also perform well on brown citrus aphid, and many that do not (Michaud 2002a). Surely this is what research in biological control is really about: quantifying the performance and impact of all natural enemies on a target pest, both native and introduced, both in the laboratory and in the field. We cannot know what would have happened had *T. radiata* failed to establish, but we can be reasonably sure that large populations of Asian citrus psyllid would not have persisted indefinitely.

In conclusion, the cited examples suggest that we need to start applying the classical approach more rationally and more judiciously. We should choose our candidate species and our targets more carefully and base our decisions on ecological data before we take the irreversible step of performing uncontrolled experiments on the ecosystem. Granting agencies should not be fooled into thinking that they are funding scientific research into biological control when they are merely funding the rearing and releasing of exotic parasitoids. If we need to introduce an exotic parasitoid against an invasive pest then so be it, but that decision should be based on a consensus of informed opinion and supported by sound ecological data. An absence of apparent negative side effects should not be considered sufficient grounds to justify the introduction of an exotic species; there should be valid scientific evidence indicating a reasonable expectation of impact on the target. Postrelease evaluations should be an obligatory component of all classical programs and should objectively assess all sources of mortality to all life stages of the pest. We should not assume a priori that one exotic parasitoid will be a 'silver bullet' solution, for this is the exception, rather than the rule. The 'shotgun' approach of multiple introductions in the absence of suitable candidates should be discouraged as an environmentally irresponsible enterprise. The foundation of biological control in perennial crops is typically based on a complex of indigenous natural enemies, species whose ecology and interactions we desperately need to better understand if the integrated pest management approach is to succeed. 'Rear and release' classical programs that fail to generate balanced ecological data sets do little to enhance our understanding of how insect communities function, and may sometimes generate distorted perceptions of how biological control is achieved. The example of brown citrus aphid in Florida has taught us that biological control of exotic pests can succeed without the introduction of exotic natural enemies. We should now recognize the need to evaluate invasive pests as potential, rather than automatic, targets for the classical approach and end the indiscriminate introductions of unproven exotic species. The Florida citrus ecosystem is truly an enviable model of integrated biological control with a myriad of potential pests held at barely detectable levels year-round by a robust complex of natural enemies. However, if we continue to employ the classical approach as an immediate and automatic response to every invasive pest, regardless of need or probability of success, we risk destabilizing these insect communities and disrupting some of the excellent biological control systems already in place.

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