CLASSICAL BIOLOGICAL CONTROL OF CITRUS PESTS IN FLORIDA AND THE CARIBBEAN: INTERCONNECTIONS AND SUSTAINABILITY

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ABSTRACT

Beginning in 1993, Florida's citrus industry has been invaded by citrus leafminer (*Phyllocnistis citrella* Stainton, Lepidoptera: Gracillariidae), brown citrus aphid (*Toxoptera citricida* Kirkaldy, Homoptera: Aphididae), and the Asian citrus psylla (*Diaphorina citri* Kuwayama, Homoptera: Psyllidae). The source(s) of these pests remain unknown but other countries in the Caribbean, as well as Central and South America, also have suffered invasions by these pests. Brown citrus aphid and Asian citrus psylla are vectors of serious citrus diseases (citrus tristeza virus and greening disease, respectively), while citrus leafminer damage provides openings for invasion of the citrus canker pathogen into the foliage. All three pests were considered suitable candidates for classical biological control. Dr. Ru Nguyen (Division of Plant Industry, Gainesville, Florida) and I have collaborated on importing, evaluating, rearing and releasing parasitoids for each pest into Florida's 860,000 acres of citrus between 1993 and the present. Two parasitoids (*Ageniaspis citricola* Logvinovskaya, Hymenoptera: Encyrtidae and *Cirrospilus quadristriatus*, which was subsequently determined to be *C. ingenuus* Gahan, Hymenoptera: Eulophidae) of the citrus leafminer were imported from Australia, Thailand, and Taiwan with the assistance of several scientists. Both parasitoids have established in Florida, and *A. citricola* has become the dominant parasitoid while *C. ingenuus* has had no apparent effect. *Ageniaspis citricola* has been supplied to colleagues in the Bahamas, Bermuda, Brazil, Chile, Mexico, Honduras, and several other countries from our rearing program. In all cases, *A. citricola* was provided free of charge along with information on rearing methods, as well as the risk assessment that we developed prior to obtaining release permits from the Florida Department of Agriculture and Consumer Services and the U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS). Such information assisted the recipients in obtaining local release permits, thus reducing the costs of importation and release for these agencies.

Two other parasitoids were imported for control of the Asian citrus psylla: *Tamarixia radiata* Waterston (Hymenoptera: Eulophidae) and *Diaphorencyrtus aligarhensis* (Shafee, Alam and Agarwal) (Hymenoptera: Encyrtidae). The parasitoids were obtained through the kind assistance of colleagues in Taiwan. Again, we have made both parasitoids available to coun-

tries in the Caribbean, upon request, along with rearing methods and our risk assessment data.

Finally, the parasitoid *Lipolexis scutellaris*, which was later designated *L. oregmae* Gahan (Hymenoptera: Aphidiidae), was imported from Guam for a classical biological control program directed against the brown citrus aphid. This parasitoid and our data have been provided upon request from colleagues in several locations (Hoy and Nguyen 2000c).

Classical biological control historically has had an ethos that fostered cooperation, interconnections, and sharing of resources and knowledge. This ethos must be maintained if classical biological control is to be sustained as a viable pest management tactic. A few governments recently have behaved as if their natural enemies are national resources that require extensive financial remuneration; this attitude will threaten the sustainability of classical biological control. We must share information and resources in order to win our struggle to manage invasive pests.

INTRODUCTION

The objective of this paper is to provide an overview of three classical biological control projects directed against invasive citrus pests in Florida. In addition, I will provide a personal perspective on several issues limiting the sustainability of classical biological control, and make a plea that communication needs to be improved if classical biological control is to be sustainable in the region.

Beginning in 1993, Florida's citrus has been invaded by three significant pests: the citrus leafminer (*Phyllocnistis citrella*), the brown citrus aphid (*Toxoptera citricida*), and the Asian citrus psylla (*Diaphorina citri*). These invasions have created serious disruptions to the integrated pest management program, which is based on biological control of scale insects, mealybugs, mites, and whiteflies (Browning and McCoy 1994; Hoy 2000; McCoy 1985). The majority of citrus pests prior to 1993 were under substantial biological control and Florida citrus growers could manage diseases and most arthropod pests with the use of oil and copper sprays once or twice a year, especially if their crop was destined for juice production (because cosmetic damage is not an issue).

PEST STATUS OF INVADERS

After each new invasion, the introduced pests multiplied and spread rapidly throughout Florida's citrus, causing economic damage. For example, the citrus leafminer colonized 860,000 acres within a year after its detection (Heppner 1993; Hoy and Nguyen 1997). Population densities were often extremely high, despite the presence of generalist natural enemies such as spiders, lacewings, ants, and eulophid parasitoids (Browning and Peña 1995). Densities of the citrus leafminer were so high that fruits and stems, in addition to foliage, were attacked (Fig. 1) (Heppner 1993). Growers repeatedly sprayed their trees, especially nursery trees and young groves, in a futile effort to suppress the leafminer populations. Subsequently, the citrus leafminer has been implicated as exacerbating the spread of citrus canker in south Florida, where this disease is the target of an eradication program (Gottwald *et al.* 2001).

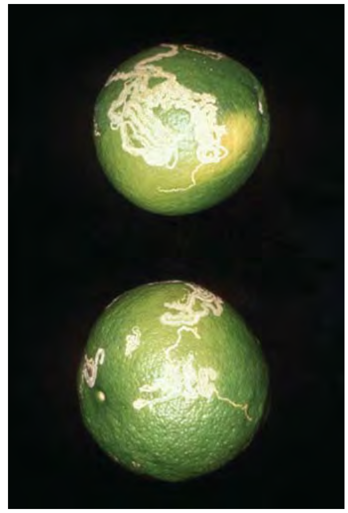

Figure 1. Citrus leafminer damage on citrus foliage (left) and fruits (right). An operational economic injury level is estimated to be less than 1 leafminer per leaf. UGA1390033, UGA1390034

The brown citrus aphid can be a direct pest of tender new citrus foliage (= flush) (Fig. 2), causing shoot deformation and production of sooty mold. The aphid completes one or two generations before the flush hardens off and then alate aphids are produced. However, the concern over the invasion of the brown citrus aphid was the fact that this aphid is a very efficient vector of *Citrus tristeza virus* and accentuated by the knowledge that approximately one-fourth of Florida's citrus was planted on rootstock susceptible to the disease caused by the virus (Yokomi *et al.* 1994). This acreage has had to be replanted on tristeza-tolerant rootstock at great expense.

Figure 2. Brown citrus aphids develop on tender new shoots of citrus. The ephemeral aphid populations make it difficult to sample for parasitoids. UGA1390035

The Asian citrus psylla is a vector of the bacterium that causes greening, one of the most serious diseases of citrus in Asia (Gottwald *et al.* 2001; Halbert *et al.* 2000; Knapp *et al.* 1998; Whittle 1992). Psyllids also can cause direct feeding damage to young shoots (Fig. 3). The pest apparently invaded Florida without the greening pathogen (Hoy *et al.* 2001), but Florida's citrus is vulnerable to the disease now that the insect vector is well established (Knapp *et al.* 1998).

Figure 3. Asian citrus psylla: orange eggs on tender flush (left) and adults feeding on mature foliage (right). Adults can survive over the winter on mature foliage, which leads to a lag in populations of their host-specific parasitoid, *T. radiata*, in Florida in spring. Psyllid nymphs, which are hosts for the *T. radiata*, can develop only on tender new growth. UGA1390036, UGA1390037

The citrus leafminer, Asian citrus psylla, and the brown citrus aphid all feed on tender new growth (flush), which can potentially reduce tree growth or yield, although economic injury levels for these pests have not been determined for all citrus cultivars in Florida. Because Florida citrus receives rainfall all year, management of pests that attack the flush is especially difficult because populations can be high between March and October each year due to the production of four or five major flush cycles.

HOW DID THESE PESTS INVADE?

The method by which these pests invaded Florida remains unknown, although it is likely that the increased trade and tourism has made invasions more frequent (Enserink 1999; Frank and McCoy 1992). It appears that Florida, and other tropical and subtropical regions are especially vulnerable to invasions and the apparent inability of quarantines and regulatory agencies to stem the flow of pest arthropods into new regions from around the world will continue to create new opportunities for classical biological control (York *et al.* 2005). Because the IPM program in Florida's citrus is so heavily dependent on biological control, I believe we are on a 'biological control treadmill', rather than the more common 'pesticide treadmill', because new pests need to be controlled in a compatible manner with the long-established biological control of our exotic pests (Hoy 2000).

CLASSICAL BIOLOGICAL CONTROL

All three invaders were considered suitable candidates for classical biological control and Dr. Ru Nguyen (Division of Plant Industry, Gainesville, Florida) and I have collaborated on importing, evaluating, rearing and releasing parasitoids for each pest into Florida's 860,000 acres of citrus from 1993 to the present.

CITRUS LEAFMINER

Two parasitoids (*A.* and *C. quadristriatus*, now *C. ingenuus*) of the citrus leafminer were imported from Australia, Thailand, and Taiwan (Hoy and Nguyen 1997, Hoy and Nguyen 2003). The first collections were made possible through the kind assistance of Dan Smith, of the Queensland Department of Primary Industries in Australia. Both parasitoids had been imported into Australia and undergone risk assessment there (Neale *et al.* 1995). Because the climate of Queensland matches that of Florida relatively well, we chose to collect parasitoids there first. Dan Smith generously provided me with field assistance and data that facilitated our efforts to obtain rapid permission to release *A. citricola* in Florida.

The release of *A. citricola* in Florida may have achieved a record for least time from importation into quarantine until release; I returned from Australia on a Monday (April 25, 1994) with large numbers of adults and pupae of *A. citricola*, and Dr. Nguyen and I recognized that we would 'waste' many of these adults due to a lack of space and hosts in our quarantine facilities. Because we had written a draft request to release *Ageniaspis* prior to my travel to Australia, based in part on the information provided by Australian scientists from their risk analysis, we were able to submit our request to release *A. citricola* to the Division of Plant Industry for review on Tuesday, which immediately submitted it to the USDA-APHIS for review. Permission to release *A. citricola* was facilitated by John LaSalle at the British National Museum, who confirmed the identity of the parasitoid after we sent specimens to him by overnight shipment. The Division of Plant Industry of the Florida Department of Agriculture and Consumer Services assisted in a rapid review, as did the USDA-APHIS, and Dr. Nguyen and I had permission to make the first releases of adults of *A. citricola* into populations of citrus leafminers by Friday (April 29) (Hoy and Nguyen 1997).

Ageniaspis citricola pupae are produced within the pupal chamber of the citrus leafminer; this encyrtid is polyembryonic and females typically deposit two eggs per oviposition event, one of which develops into a male. The second egg twins, producing two daughters (Zappalà and Hoy 2004); this reproductive strategy may contribute to its success when host populations are low. *Ageniaspis citricola* and *C. ingenuus* have both established in Florida, with *A. citricola* now the dominant parasitoid of the citrus leafminer (Hoy and Nguyen 1997; Hoy *et al.* 1995; Hoy *et al.* 1997; Peña *et al.* 1996; Pomerinke and Stansly 1998; Smith and Hoy 1995; Villanueva-Jimenez and Hoy 1998a; Villanueva-Jimenez *et al.* 2000) (Fig. 4).

Cirrospilus ingenuus has had no apparent effect in reducing citrus leafminer densities, although this eulophid has established in south Florida (LaSalle *et al.* 1999). In retrospect, however, Dr. Nguyen and I regret releasing this ectoparasitoid because we discovered, after the release, that it could hyperparasitize *A. citricola* (Hoy and Nguyen 1997).

Figure 4. *Ageniaspis citricola* pupae.
UGA1390038

Ageniaspis citricola has many of the attributes of an effective natural enemy (Rosen and Huffaker 1983). It is host specific (Neale *et al.* 1995), able to locate low-density leafminer populations and to discriminate between previously parasitized hosts (Edwards and Hoy 1998; Zappalà and Hoy 2004), although it is not able to perform well in regions with low relative humidity (Yoder and Hoy 1998) and lags behind citrus leafminer populations in the spring in Florida (Villanueva-Jimenez *et al.* 2000). Citrus leafminer populations decline to very low densities over the winter when there is no new flush and typically only a very few citrus leafminers are found in the first flush cycle in spring. Since *A. citricola* is host specific and polyembryonic, populations of *A. citricola* increase from very low densities to detectable levels by the second flush cycle in Florida and, if not disrupted by drought or pesticide applications, become the dominant parasitoid, capable of parasitizing up to 100% of the leafminer pupae by the fall, which decreases the number of citrus leafminers able to overwinter (Villanueva-Jimenez *et al.* 2000; Zappalà *et al.*, unpublished). A second population of *A. citricola* was imported from Taiwan, and this population appears to be a cryptic species (Alvarez and Hoy 2002; Hoy *et al.* 2000). Although it was released in Florida, we have no evidence of its establishment (Alvarez and Hoy 2002).

During 2000 and 2001, Florida suffered a drought that was especially serious in the spring, leading to a greater lag between populations of *A. citricola* and the citrus leafminer than before. This led us to consider release an additional parasitoid that would have the potential to suppress citrus leafminers early in the season when *A. citricola* densities are very low and a long list of potential candidates was reviewed (Heppner 1993; Schauff *et al.* 1998). Such a parasitoid ideally would tolerate lower relative humidities than *A. citricola* and might have an alternative host on which it could overwinter. With the assistance of Dr. G. Siscaro of the University of Catania in Italy, we imported the eulophid *Semielacher petiolatus* Girault (Hymenoptera: Eulophidae) (Fig. 5) for evaluation in quarantine (Hoy *et al.* 2004). This parasitoid had established in citrus in the Mediterranean and promised to have a greater tolerance of low relative humidities (Ateyyat 2002; Lim *et al.* unpublished). It was also reported

Figure 5. *Semielacher petiolatus* female.
UGA1390039

to use alternative hosts, including a dipteran leafminer in the genus *Liriomyza* (Massa *et al.* 2001), which could provide hosts for *S. petiolatus* during the winter when citrus leafminer populations are extremely low in Florida.

After importing *S. petiolatus* into quarantine we demonstrated that it could develop on the citrus leafminer, but that it often superparasitized (Lim and Hoy 2005). Additional research confirmed that *S. petiolatus* does not discriminate between unparasitized and parasitized hosts with its own progeny or with the endoparasitoid *A. citricola* and could potentially disrupt the substantial control provided by the host-specific *A. citricola* (Lim *et al.* unpublished). Also, it did not parasitize *Liriomyza trifolii* Burgess (Diptera: Agromyzidae), a common and abundant leafminer pest of vegetables during the winter in Florida (Lim *et al.*, unpublished). After this risk analysis in quarantine, we recommended against releasing *S. petiolatus* in Florida because of the information previously mentioned and also because there was no evidence that it would provide control of the citrus leafminer during the spring when populations of *A. citricola* lag behind those of its host. Although it is difficult to predict with any certainty the outcome of potential releases of *S. petiolatus* in Florida, the potential benefits do not appear to justify the potential risk. In regions where *A. citricola* is not an effective parasitoid, it is possible that releases of *S. petiolatus* are appropriate, but independent risk analyses should be conducted in each country.

Ageniaspis citricola has been supplied to colleagues in the Bahamas, Bermuda, Brazil, Chile, Mexico, Honduras, and several other countries (including Morocco, Italy, Spain) from our rearing program (Hoy and Jessey 2004; Villanueva-Jimenez *et al.* 1999). In all cases, *Ageniaspis* was provided free of charge along with information on rearing methods (Smith and Hoy 1995), studies of its biology and susceptibility to pesticides (Alvarez and Hoy 2002; Edwards and Hoy 1998; Hoy *et al.* 2000; Villanueva-Jimenez and Hoy 1998b; Yoder and Hoy 1998; Zappalà and Hoy 2004) and the risk assessment data that we developed prior to obtaining release permits from the Florida Department of Agriculture and Consumer Services and the U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS). Such information was intended to assist the recipients in obtaining permission to make releases, thus reducing the costs of importation, evaluation and release for local regulatory agencies.

ASIAN CITRUS PSYLLA

Two host-specific parasitoids were imported for control of the Asian citrus psylla: *T. radiata* and *D. aligarhensis* (Fig. 6) (Hoy and Nguyen 1998). Both parasitoids were obtained through the kind assistance of P. K. C. Lo of the Taiwan Agricultural Research Institute and had shown efficacy in Taiwan and on Reunion Island (Aubert and Quilici 1984; Chien 1995; Chien and Chu 1996; Chu and Chen 1991). Before we could obtain permission to release these parasitoids we had to 'prove a negative', namely that they did not harbor the greening pathogen. This led us to develop a polymerase chain reaction (PCR) test with a known level of sensitivity for the greening pathogen (Hoy and Nguyen 2000a; Hoy *et al.* 1999; 2001). Both parasitoids appear to be host specific and were mass reared and released throughout Florida, where *T. radiata* is now widely distributed (Hoy *et al.* 2000; Hoy *et al.* unpublished; Skelley and Hoy 2004). The status of *D. aligarhensis* is unclear because only a few recoveries have been made (Hoy *et al.*, unpubl.).

Again, we have made both parasitoids available to colleagues in the Caribbean, upon request, as well as our rearing methods, information on the parasitoid's biology (McFarland and Hoy 2001; Skelley and Hoy 2004) and our risk assessment data.

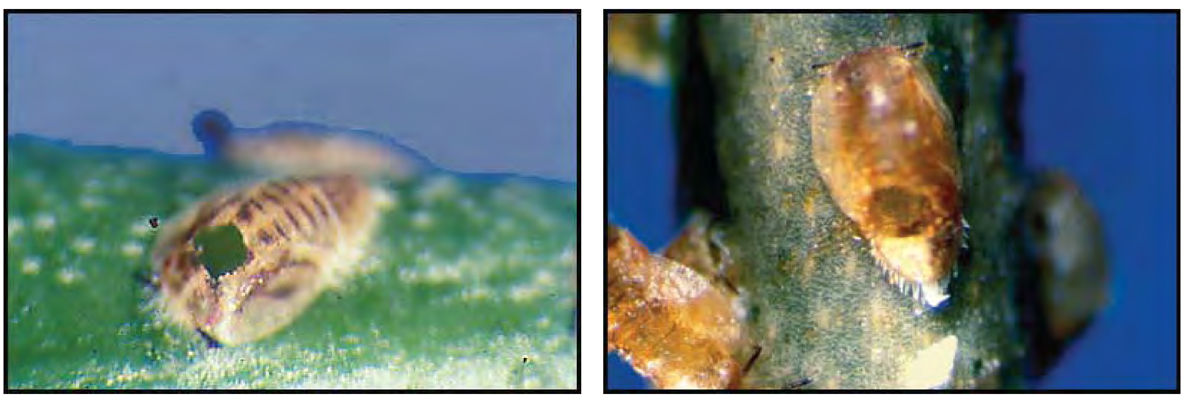

Figure 6. Asian citrus psylla nymphs parasitized by *Tamarixia radiata* (left) and *Diaphorencyrtus aligarhensis* (right). Exit holes for *T. radiata* and *D. aligarhensis* are on the thorax and abdomen, respectively, making it easy to discriminate parasitism by the two parasitoids in the field. UGA1390040, UGA1390041

BROWN CITRUS APHID

The parasitoid *Lipolexis scutellaris*, which was later designated *L. oregmae* by Miller *et al.* (2002), was imported with the assistance of Ross Miller in Guam for a classical biological control program directed against the brown citrus aphid (Hoy and Nguyen 2000b,c). Petr Stary provided taxonomic identifications and other information, and Susan Halbert, of the Florida Department of Agriculture and Consumer Services, provided expert advice on preparing the application to release *L. scutellaris* in Florida (Hoy and Nguyen 2000c).

This parasitoid was easy to rear on the brown citrus aphid on citrus trees after the discovery of its unusual behavior of causing parasitized aphids to walk off the tree to mummify in the soil at the base of the trees (Hill and Hoy 2003). We treat the soil in the potted trees with a 2-3% sodium hypochlorite solution prior to exposing the trees to aphids and parasitoids to control fungal pathogens of the parasitoid mummies (Hill and Hoy 2003, Persad and Hoy 2003a,b; Walker and Hoy 2003b).

Laboratory analyses indicated that *L. oregmae* and *Lysiphlebus testaceipes* (Cresson), a parasitoid already established in Florida and a natural enemy of the brown citrus aphid, are not intrinsically superior to each other (Persad and Hoy 2003a). Beginning in 2000, releases were made throughout the state over several years, and *L. oregmae* seems to have established (Hoy *et al.* unpublished; Persad *et al.* 2004). However, populations of *L. oregmae* are low in Florida, perhaps because this parasitoid is preyed upon by abundant red imported fire ants, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), in citrus groves (Hill and Hoy 2003; Persad and Hoy 2004; Walker and Hoy 2003). Red imported fire ants will feed on mummies in the soil and also will climb into the tree to remove parasitized aphids, leaving behind the unparasitized pests (Persad and Hoy 2004). A PCR test that allows us to sample aphids and assay them for the presence of either *L. oregmae* or *L. testaceipes* allowed us to obtain qualitative data on distribution and spread of *L. oregmae* in Florida (Persad *et al.* 2004). This technique is sufficiently sensitive that we could grind up 500 aphids of which only one was parasitized by *L. oregmae*, yet get a positive PCR product??. Once we know that *L. oregmae* is present in a grove, additional samples can be taken to ascertain the relative abundance of *L. testaceipes* and *L. oregmae*.

Because *L. oregmae* attacks black citrus aphid (*T. aurantii* Boyer de Fonscolombe), spirea aphid (*Aphis spiraecola* Patch), cotton aphid (*Aphis gossypii* Glover), and cowpea aphid (*Aphis craccivora* Koch), on citrus and other crops in Florida, it has alternative hosts that can sustain it when brown citrus aphid populations are low (Hoy and Nguyen 2000c). These aphids also are imported pests of citrus in Florida so there was reduced concern about the nontarget effects of *L. oregmae*.

Releases of *L. oregmae* were also made in Bermuda during the July of 2002, but its establishment has not yet been confirmed. Shipments of *L. oregmae* have been requested by scientists in CARDI for release in Jamaica and permits have been issued by the Jamaica Department of Agriculture.

CONSTRAINTS TO CLASSICAL BIOLOGICAL CONTROL IN THE REGION

Biological control is, in my opinion, at a turning point in its development as a discipline. It could become a more important component of pest management programs if we are able to resolve concerns about potential risks to biodiversity (Howarth 1991; Simberloff and Stiling 1996). If we are unable to resolve those concerns, there could be less classical biological control conducted in the future, rather than more. Several constraints need to be eliminated or reduced.

INTERNATIONAL COOPERATION

International cooperation is crucial to the success of classical biological control programs (FAO 1997). Such cooperation will become even more important in the future because we lack sufficient resources to conduct classical biological control projects in isolation. Scientists in Australia, Taiwan, Thailand and Guam were instrumental in our ability to respond rapidly to the three invasive species in Florida's citrus. They provided assistance, information, and resources that enabled us to respond rapidly to the threat of these invaders. Historically, classical biological control has depended on such generous international cooperation and it needs to be maintained. The belief that natural enemies are national resources that should be sold is detrimental to the continued success of classical biological control. Indeed, biological control scientists may wish to become even more proactive about cooperating in classical biological control of citrus pests and begin sharing information about the natural enemies of potential invaders in advance, perhaps using websites as a repository of information.

THE FUTURE OF CLASSICAL BIOLOGICAL CONTROL

It is ironic that, just when there is an increased focus on and potential role for biological control of arthropod pests, serious concerns about biodiversity could restrict its use. Current constraints also include the deployment of relatively few resources, at least compared to those available to develop new pesticides or transgenic crops. Most of the funding for classical biological control is obtained from public sector sources, which have not had sufficient increases in their budgets to meet the current and potential demand.

The history of biological control of arthropod pests is filled with outstanding examples of successes and a remarkably low number of ecological problems (Frank 1998; Funasaki *et al.* 1998). Despite this, we will have to embrace increased oversight and consideration of ecological issues. The question then becomes: how best can we achieve appropriate oversight without hampering the benefits of biological control?

One solution for biological control practitioners might be to focus more frequently on natural enemy species that are narrowly host- or prey-specific. Scientists working on biological control of weeds already have accepted this constraint, and undergo external reviews of the biology, behavior, and host specificity of the natural enemies they wish to release. It also will be useful to have more thorough scientific peer review before natural enemies are released for classical biological control of arthropod pests (Ewel *et al.* 1999). Despite increased peer review, it may be impossible to eliminate all risk concerns.

Risk analyses are neither simple nor easy. Blanket criticisms of biological control are of little constructive value in the absence of comparative data on the alternatives, including doing nothing (Thomas and Willis 1998). Furthermore, biological control has numerous public benefits, including relatively inexpensive and long-term control, and reduced pesticide applications, which can result in reduced negative effects on ground water, nontarget species, human health, and worker safety.

RECOMMENDATIONS

- Sharing of information is essential if classical biological control is to be cost effective; providing information on risk assessments, unpublished data on biology and ecology, and copies of hard-to-find literature on web sites would be an efficient method of sharing key information that will allow scientists and governmental agencies to evaluate potential introductions of natural enemies for classical biological control in other countries. At present, this form of sharing occurs on an *ad hoc* basis. The University of Florida has provided resources and technical support to assist us in providing information in this manner, but it may be useful to consider developing a centralized and international site where practitioners of classical biological control can deposit such information.

- If possible, scientists and organizations should provide colonies of natural enemies upon request to others at the lowest possible cost. Reimbursements for shipping and rearing costs are appropriate, but tying the request for natural enemies to large-scale funding for the donor could delay or preclude the introduction of key natural enemies in a timely fashion.
- Funding for post-release evaluations is particularly difficult to obtain because most funding is provided for collection, importation, rearing and release. Sharing of information and colonies would produce savings that could be used to obtain needed data on the effects of the imported natural enemies on the target pests subsequent to their establishment. Such studies should occur after equilibrium has developed between the pest and its natural enemies in the new environment. In addition, funding needs to become available for evaluating the impact of key importations on nontarget species. Again, this type of funding remains relatively rare, but is essential if we are to develop the data to understand the long-term costs and benefits of classical biological control.

CONCLUSIONS

Our collective responses to these challenges will determine how effectively classical biological control is maintained as a viable discipline. We have valuable new tools, including molecular genetic methods, which will allow us to answer previously intractable questions in systematics, ecology, behavior and quality control. The use of pesticides no doubt will decline and the ones used may be less hazardous to the environment. The demand for classical biological control could increase in the 21st century, especially if we respond effectively to concerns regarding potential negative environmental consequences attributed to biological control. When risks and benefits are compared appropriately, classical biological control should fare very well in comparison to the risks and benefits associated with other pest management tactics such as chemical control, cultural practices, host plant resistance (including the use of transgenic crops), and genetic control.

The potential risks and benefits of classical biological control must be calculated in a realistic manner because it is not possible to manage pests without any risk. As pointed out by Lubchenco (1998), our world is changing and we now live on a "...human-dominated planet. The growth of the human population and the growth in amount of resources used are altering Earth in unprecedented ways." Lubchenco (1998) concluded that the role of science now includes "...knowledge to reduce the rate at which we alter the Earth systems, knowledge to understand Earth's ecosystems and how they interact with the numerous components of human-caused global change, and knowledge to manage the planet". This change in perception of the status of ecosystems must become widespread among scientists and others if appropriate policy decisions are to be made. To increase awareness of this change in perception, perhaps a new term should be coined to describe our role and responsibilities as 'planet ecosystem management' or 'PEM' (Hoy 2000). Humans are, in fact, remodeling the entire global ecosystem.

Classical biological control historically has had an ethos that fostered cooperation, interconnections, and sharing of resources and knowledge. This ethos must be maintained if classical biological control is to be sustained as a viable pest management tactic. A few governments recently have behaved as if their natural enemies are national resources that require extensive financial remuneration; this attitude will threaten the sustainability of classical biological control. We must share information and resources in order to win our struggle against invasive pests.

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