BIOLOGICAL INVASIONS: STEMMING THE TIDE IN FLORIDA

TED D. CENTER[1], J. HOWARD FRANK[2], AND F. ALLEN DRAY, JR.[3]
[1]USDA, ARS, Aquatic Weed Control Research Laboratory, 3205 College Ave.,
Fort Lauderdale, FL 33314

[2]University of Florida, Department of Entomology and Nematology,
Gainesville, FL 32611-0620

[3]University of Florida, Fort Lauderdale Research and Education Center,
3205 College Ave., Fort Lauderdale, FL 33314

ABSTRACT

Invasive, adventive species present a significant challenge to environmental resource managers. Unless this problem is addressed, natural areas face loss of biodiversity and habitat integrity. Traditional control methods are often inappropriate or impractical for use in natural areas. Strategies using biological control, a discipline of applied ecology, offer the best hope for reducing deleterious impacts of invaders. Arguments by some ecologists that classical biological controls contribute to the problem appear unwarranted. These criticisms should not be dismissed out of hand, however. Instead, they should foster in biocontrol scientists a renewed dedication to the safe practice of their discipline and an increased concern for collateral impacts of released organisms on native species.

Key Words: Biological control, invasive species, weeds, insects, Florida

RESUMEN

Las especies adventivas e invasoras presentan un desafío significativo para los administradores de recursos ambientales. A no ser que este problema sea considerado, las áreas naturales encaran pérdidas en la biodiversidad y en la integridad del medio ambiente. Los métodos tradicionales de control son frecuentemente inapropiados o imprácticos para ser usados en áreas naturales. Las estrategias que usan control biológico, lo cual es una disciplina de la ecología aplicada, ofrecen la mayor esperanza para reducir los impactos dañinos de los invasores. Los argumentos de algunos ecólogos de que el control biológico clásico contribuye al problema parecen ser injustificados. Sin embargo estas críticas no deben de ser desechadas de inmediato. En su lugar deben de alentar en el científico dedicado al control biológico una renovada decidicación a la práctica segura de su disciplina y un aumento en su preocupación por los impactos paralelos de los organismos liberados en las especies naturales.

Environmentalists and conservationists have often failed to appreciate the threat posed by invasive, adventive species to biodiversity in natural areas (see, for example, Soulé & Wilcox 1980). In recent years, however, the impact of exotic organisms on biological communities, particularly in natural areas, has become a compelling environmental issue (McKnight 1993). This is particularly true in Florida and a briefing document for the state legislature has recently been prepared on this subject by a delegation of experts assembled by the Florida Department of Environmental Protection. The best documented cases are those evolving from purposeful importations of non-in-

This article is from *Florida Entomologist Online*, Vol. 78, No. 1 (1995).
FEO is available from the Florida Center for Library Automation gopher (sally.fcla.ufl.edu)
and is identical to *Florida Entomologist (An International Journal for the Americas).*
FEO is prepared by E. O. Painter Printing Co., P.O. Box 877, DeLeon Springs, FL. 32130.

digenous plants. The magnitude of this problem cannot be exaggerated. About 456 million exotic plants were imported through the 16 U.S. plant introduction facilities during 1993, with nearly 80% of these coming through the port of Miami (pers. comm. - D. R. Thompson, Operations Officer, USDA-APHIS Port Operation, Hyattsville, MD). These imported plants represent a huge pool of potential invaders, directly through their own escape and naturalization, and indirectly through the insects and other pests that they might harbor.

The number of organisms imported for biological control purposes pales in comparison, yet biocontrol is increasingly being identified as contributing to the problem rather than proffering a cure (Howarth 1983, Simberloff 1992). This viewpoint represents more concern for the “mole hill” than for the “mountain”. Still, the concerns expressed are not altogether unwarranted. It would behoove biological control practitioners, therefore, to take a proactive stance in order to ensure that biological control does not come to be regarded as an ecological pariah.

The Problem

Introduced and immigrant plant species represent a severe challenge for conservationists. Those that successfully invade natural areas may outcompete native species and develop extensive monocultures. These monocultures not only exclude native ecological homologs, but frequently also exclude many associated species. In extreme cases, such invasions can convert a healthy, diverse biological community into a barren monoculture.

The susceptibility of pristine areas to invasion by exotic species is partially related to disturbance and the size of reserves. Disturbed edge habitats presumably function as staging areas from which exotic species invade the surrounding landscape. Other things being equal (see Londsdale 1992), smaller areas with proportionately more edge habitat are more susceptible to invasions than large contiguous conservation areas (see Ewel 1986 for other theories). This suggests that the establishment of large reserves might impede invasions by exotics. However, vast size alone does not preclude problems. Perhaps the best example of a large preserve is Kakadu National Park (13,000 km^2) and adjacent aboriginal reserves in Australia’s Northern Territory. Together, these comprise one of the world’s largest protected natural areas which encompasses the entire Alligator River drainage basin. Yet, the pristine nature of this area is threatened by invasions of adventive species. The weedy legume *Mimosa pellita* Humb. & Bonpl. ex. Willd. (=*M. pigra* L.) now occupies 450 km^2 of seasonally inundated floodplain in nearby areas. The establishment of this species was facilitated by yet another adventive species, the water buffalo (*Bubalus bubalis*), which trampled the floodplains, thereby creating disturbed habitat. These buffalo also browsed competing vegetation. *M. pellita* has now effectively transformed a wide range of structural vegetation types to homogenous tall shrublands, thus causing disastrous consequences to wildlife (Beckman 1990, Londsdale & Braithwaite 1988; Braithwaite et al. 1989). This plant also blocks river and wetland access to local fauna while the floating fern *Salvinia molesta* Mitchell impedes access to seasonal ponds (billabongs). These freshwater habitats are the principal source of water for wildlife during the long dry season, so this transformation has far-reaching impacts. Furthermore, African grasses which are taller with deeper root systems than native species, fuel hotter fires later in the dry season than those typically carried by native grasses. These hotter fires destroy the otherwise fire-resistant sclerophyllous woodlands (Breeden & Wright 1989). Hence, invasive exotic plants are degrading aquatic and upland habitats alike.

Ecological complexity has also been linked to the susceptibility of natural communities to invasions, species-rich communities supposedly being less susceptible than species-poor ones (Ewel 1986). The fynbos of South Africa is one example where this generalization fails, however. This distinct floral kingdom is perhaps the most diverse non-tropical system on earth, harboring as many as 121 plant species within a 100 m^2 area (van Rensburg, undated). Despite this high diversity, the fynbos is threatened by invasive exotic plant species like *Acacia* spp., *Hakea* spp., *Pinus* spp., *Sesbania punicea* (Cav.) Benth., etc. (Taylor 1978). Likewise, rubber vine (*Cryptostegia grandiflora* R. Br.) from Madagascar grows rampant in subtropical and tropical Queensland, another highly diverse region, covering trees up to 30 m tall and choking out native vegetation (McFadyen & Harvey 1991).

An example of an invasion by an exotic species into a species-rich, relatively undisturbed area is provided by *Salvinia molesta*. This South American native was probably released in New Guinea from aquaria. A few plants wound up in aquatic sites on the Sepik River floodplain in about 1971-72. The plant spread rapidly, with nearly disastrous consequences (Mitchell et al. 1980, Thomas & Room 1986a,b).

Exceptions can be found to most generalizations pertaining to factors contributing to site invasibility. This is because invasibility depends upon characteristics of both the invading species and the habitat being invaded. Thus, a particular site might be very susceptible to invasion by one species but resistant to another. Likewise, a single exotic species might easily invade at one site, but be unsuccessful at another. One factor remains paramount, however. Potential invaders must be available. Proximity and availability of a pool of invasive species is a preeminent factor. This factor is ignored by most ecologists who study biological invasions, being either too obvious or perhaps merely biologically uninteresting.

The main source of potential invaders appears to be the commercial importation of plants. As noted previously, vast numbers of plants are imported to the United States each year. This creates a tremendous pool of potential invaders. Obviously, the more exotic species that are present, and the higher the frequency with which they are imported, the greater the likelihood that one or more will invade natural areas.

Ewel (1986) observed that few mammals or trees have invaded the mature forests of the Amazon basin, New Guinea, or Zaire, as compared to Great Britain or New Zealand. He suggested that high species richness and absence of disturbance insulates these communities from invasion. We suggest that lack of economic incentives for the importation of large quantities of ornamental species also explains much of the disparity. In the case of New Zealand, for instance, active "acclimatization" societies have existed since the colonial period (Booz 1991). These societies were dedicated, until the early 1900s, to the introduction of all plant and animal species that they considered desirable. Hundreds of species were thus imported and released. Many of these invaded natural communities. Were it not for these societies, many of these invasions would never have occurred. Although formal acclimatization societies don't exist in Florida, efforts to introduce non-native species (including plants, fish, birds, reptiles, etc.) have been at least as intensive. Florida's biota now includes over 1300 adventive species (U.S. Congress 1993). To our knowledge, no comparable effort has ever been made to introduce species into the aforementioned Amazon basin, New Guinea, or Zaire.

Examples of commercially imported plants "gone bad" are readily available. The paperbark tree (*Melaleuca quinquenervia* (Cav.) S. T. Blake) in Florida (Bodle et al. 1994, Hofstetter 1991), Chinese tallow tree (*Sapium sebiferum* (L.) Roxb.) in the Southeast (Farnsworth 1988), and purple loosestrife (*Lythrum salicaria* L.) in the northern U.S. (Thompson et al. 1987, Malecki et al. 1993) devastate valuable wetlands. Austin (1978), in fact, reported that *M. quinquenervia* reduces biodiversity by 60-80% when it invades wet prairie or marsh communities. It now occupies an estimated 489,000 acres in southern Florida (pers. comm. - A. Ferriter, South Florida Water Management District, West Palm Beach, FL).

Brazilian peppertree (*Schinus terebinthifolius* Raddi) was reported as being common in cultivation but rare in the wild in southern Florida as recently as 1959 (Austin 1978). It now infests 602,000 acres (pers. comm. - A. Ferriter, South Florida Water Management District, West Palm Beach, FL) in a wide variety of habitats, displacing native vegetation in both upland and wetland communities (Myers & Ewel 1990). Acreages would be considerably higher if estimates from the rest of Florida were available. Australian pine (*Casuarina equisetifolia* J. R. Forst. & G. Forst.) interferes with the nesting activities of sea turtles and American crocodiles in coastal communities (Austin 1978) and infests 373,000 acres in southern Florida (pers. comm. - A. Ferriter, South Florida Water Management District, West Palm Beach, FL). This species is also reported to inhibit growth of native plants and to open beaches and dunes to erosion. Austin further noted that as few as a dozen species typically occur in the understory, most of which are adventive. Brazilian peppertree and Australian pine were both introduced as landscape plants.

Cogongrass (*Imperata cylindrica* (L.) Beauv.) was imported into Florida in the 1940s for erosion control and as a source of forage. It failed to be useful for either purpose and now displaces native plants (Coile & Shilling 1993). Another plant introduced for erosion control in Florida and other portions of the Southeast is the notorious kudzu (*Pueraria lobata* (Willd.) Ohwi) (Baker 1986). Like the madagascarine rubber vine in Australia, it blankets tall trees and smothers native vegetation. Other vines cause similar problems in Florida with the Japanese climbing fern (*Lygodium microphyllum* (Cav.) R. Brown), air potato (*Dioscorea bulbifera* L.), and skunk vine (*Paederia* spp.) being good examples. Austin (1978) recorded *L. microphyllum* populations from several counties in southern Florida, and it has recently been reported to infest 26,000 acres, mostly in Palm Beach and Martin counties (pers. comm. - A. Ferriter, South Florida Water Management District, West Palm Beach, FL).

Aquatic habitats seem particularly vulnerable to invasion. The neotropical floating waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.) blankets open water surfaces of lakes and rivers in Florida as well as most other subtropical and tropical areas of the world. Infestations limit access to fishing areas by indigenous peoples in undeveloped countries, increase habitat for disease vectors, reduce the supply of fresh water available to wildlife, and lower oxygen levels in the submersed community. Drifting mats scour native vegetation and destroy nesting sites and foraging areas for rare species (such as the snail kite in Florida). This plant was introduced to decorate garden ponds. The submersed weed hydrilla (*Hydrilla verticillata* (L.f.) Royle) was introduced through the aquarium trade. It invades aquatic sites by growing from the hydrosoil to the water surface where it forms a thick canopy. The resultant dense beds readily displace other submersed aquatic species. As a result, diverse aquatic communities become monocultures. These often lack phytophagous consumers and harbor less desirable detritivore-based faunal assemblages (e.g., Hansen et al. 1971, Dray et al. 1993).

Imported plants threaten the preservation of “pristine” natural areas in other ways. Exotic insects, many of which attack native plants, are often imported on ornamental plants. A recent study estimated that, as of 1992, 271 exotic insect species have immigrated into the state of Florida during the previous two decades. In contrast, only 151 species have been introduced into Florida for biological control purposes *in the past century*. In 1980 over 18,000 immigrant insects were intercepted by the U.S. Department of Agriculture (APHIS) at ports of entry (Frank & McCoy 1992, 1993). These were mostly transported on imported plants, 99% of which are not inspected.

Some of these immigrants (e.g., the gypsy moth in northern areas) have the capacity to reduce biodiversity in native plant communities. A good example is the cactus moth (*Cactoblastis cactorum* (Bergroth)) in Florida, which was purposely released in the Caribbean region during the 1950s for biological control of *Opuntia* spp. Recent evidence (pers. comm. - R. Pemberton, U.S. Department of Agriculture, Agricultural Research Service, Aquatic Weed Control Laboratory, Fort Lauderdale, FL) suggests that it arrived in Florida within exotic cacti, truckloads of which are routinely imported from the Dominican Republic and Brazil. Once here, it began to attack several species of native cacti (Simberloff 1992), including the endangered semaphore cactus (*Opuntia corallicola* (Small) Werdermann in Backeberg).

The weevil *Metamasius callizona* (Chevrolat) arrived in Florida from Mexico in shipments of exotic bromeliads (O'Brien & Thomas 1990). It now infests *Tillandsia utriculata* L., *T. fasciculata* Sw., and *T. paucifolia* Baker, all native bromeliad species (Frank & Thomas 1994), and has nearly extirpated *T. utriculata* from several southern Florida hammock communities (TDC, pers. obs.). A related weevil *M. hemipterus* (L.), first discovered in Florida in 1984, feeds on a wide range of hosts including bananas, sugarcane, and palms (Woodruff & Baranowski 1985, Giblin-Davis *et al.* 1994). It could jeopardize the few native royal palms (*Roystonea elata* (Bartr.) F. Harper) that remain in southern Florida.

A neotropical leaf beetle (*Neolochmaea dilatipennis* (Jacoby)), discovered near Miami in 1975, feeds on the Florida "endemic" *Borreria terminalis* Small (White 1979). It has also recently wiped out ornamental plantings of the beach creeper, *Ernodia littoralis* Sw. (TDC, pers. obs.), a native coastal species listed as of special concern (Craig 1979). A Central American weevil (*Eubulus trigonalis* Champion), recently discovered in Dade Co., Florida (pers. comm. - J. Peña, University of Florida, Tropical Research and Education Center, Homestead, FL), probably arrived in non-indigenous cycads that were imported for the nursery trade. Unfortunately, it attacks native cycads (*Zamia* spp., commonly known as coontie) which are also "threatened" species.

An adventive tortoise beetle (*Chelymorpha cribraria* (F.)) was discovered in Florida in 1993 which feeds on native morning glories (Duquesnel 1994). The little fire ant (*Wasmannia auropunctata* (Roger)) which arrived on Santa Cruz Island in the Galapagos where it displaced several native ant species including two "endemics" (Höll-dobler & Wilson 1990), also occurs in southern Florida. It is apparently adventive throughout both Old and New World tropics (Creighton 1950). The red imported fire ant (*Solenopsis invicta* Buren) displaced the native fire ant (*S. geminata* (F.)) in Texas, perhaps inducing a restructuring of the entire arthropod community (Porter et al. 1988). This species has been naturalized in Florida for some time now. Many more "biological pollutants" have been discussed in several recent publications (McKnight 1993, Van Driesche 1994, U.S. Congress 1993).

Biological Control as a Possible Solution

Traditional control methods (pesticides, etc.) are useful against these invasive species when they occur at an incipient stage. In these cases, the aim is generally towards eradication. Eradication is most likely when the introduced species is already known to be noxious, it is found early, and funds are readily available for an all out assault. However, most invaders of natural systems are not recognized as problems until they've gotten out of hand (this is especially true of insect pests). By then, it's often too late to realistically expect to eradicate or even to contain them using traditional measures. This is due to the inaccessibility of the habitats, the difficulty of detecting unseen infestations, and the associated expenses involved. The identification of **host-specific** natural enemies from within the native range of the target pest, and their subsequent importation into the pest's adopted range, offers considerable promise as an additional control measure in the arsenal of natural resource managers. Australians are introducing host-specific plant-feeding insects and phytopathogens to control *Mimosa pellita* in the Northern Territory (Forno 1992). South Africans have successfully controlled *Sesbania punicea*, *Acacia longifolia* (Andr.) Willd., and *Hakea sericea* Schrader in the fynbos using highly specific insects that destroy plant reproductive tissues (Dennill & Donnelly 1991, Hoffman & Moran 1991, Kluge & Neser 1991). Populations of *Salvinia molesta* in Australia, New Guinea, Sri Lanka, India, Botswana, and Namibia were reduced by 99% within a year after introduction of the weevil *Cyrtobagous salviniae* Hustache (Thomas & Room 1986, Room 1990, Room et al. 1981). Alligatorweed, a notorious mat-forming aquatic species, has been almost totally controlled in many areas by a flea beetle (*Agasicles hygrophila* Selman & Vogt) and a moth (*Vogtia malloi* Pastrana) (Spencer & Coulson 1976). Waterhyacinth is less of a problem in many parts of the world, including Florida, due to the introduction of biological control agents (Center et al. 1990). Prospects for biological control of purple loosestrife appear promising (Malecki et al. 1993, Hight 1993). All of these biological control agents are highly host specific and none exploit native plants as developmental hosts.

How Does Biocontrol Work?

A common belief is that imported species become problems by being introduced into a new area without the repressive forces (i.e., natural enemies) that held them in check in their native habitats (see Ewel 1986). Under this paradigm, biological control represents a remedial attempt to restore some sort of natural balance. This is an erroneous perspective. Biological control programs do not strive to duplicate the population regulatory processes of a pest organism's native environment. When natural enemies hold a species in check in natural conditions, multiple species, including both specialists and generalists, are involved. Biological control relies on the introduction of only a selected few of these species, most often only specialists judged capable of repressing the pest population. Obviously, as Ewel (1986) notes (using Kudzu, *Pueraria lobata*, as an example), many species are just as invasive in their native range as they are in adventive areas. The organisms that might otherwise repress these species are oftentimes themselves controlled by numerous species of natural enemies. However, when these agents are introduced into new areas for biological control purposes, their natural enemies are excluded. In theory, at least, higher populations are thereby attained in their adopted range thus resulting in better control than in the homeland.

In many cases, biological control agents are sparse in their native range, but become abundant when introduced into their host's adventive range. For example, parasitism and competition prevent the bud-galling wasp *Trichilogaster acaciaelongifoliae* Froggatt from becoming highly abundant on its host *(Acacia longifolia*) in Australia (Neser 1985). Released from these regulators, however, this wasp became an abundant and effective biocontrol agent in South Africa (Dennill 1985). This is just one of many examples that could be cited demonstrating that successful biological control agents are not necessarily effective regulators in their native habitats. Of course, obvious effectiveness in their homeland is always a good sign.

In general, potential biocontrol agents are released into a pest's adventive range only if the possibility for collateral damage to native species is negligible, as demonstrated through intensive host range trials. However, it may at times be prudent to accept modest levels of collateral damage to native species in order to prevent more extreme levels of habitat destruction by an immigrant or introduced pest. Australian government scientists, for example, are introducing plant-feeding insects and phytopathogens from Madagascar to control the aforementioned rubber-vine (McFadyen & Harvey 1991). They released one of the insects, the moth *Euclasta whalleyi* Popescu-Gorj & Constantinescu, with the knowledge that it would also feed on a related native vine, *Gymnanthera nitida* R. Br. They reasoned that the possibility of reducing the abundance of one native species was a small price to pay for the sake of preserving many others.

Future Considerations

Environmental problems caused by adventive species in Florida are among the most severe in the United States (U.S. Congress 1993). Invasive plant species are the most obvious problem, and are particularly easy to track after they achieve nuisance proportions. Populations of introduced vertebrates are also relatively easy to follow. Adventive invertebrates (e.g., insects) are much harder to assess, however. Limited knowledge of many native invertebrates, together with the sheer volume of species present in Florida, make monitoring for effects of adventive species a daunting and expensive proposition. Further, problems with invader species are exacerbated by the increasing pressure on public lands caused by Florida's rapidly growing human population. The Florida Department of Environmental Protection recently assembled a statewide panel of biologists and ecologists to assess these problems and develop recommendations for remedial actions. These recommendations are still pending. However, a few points are already apparent.

If the source of the problem is the wanton introduction of exotic species for economic gain, then the ultimate solution is largely dependent on political processes. The importation of exotic species is economically lucrative, so legislative attempts to regulate this practice are bound to be met by stiff opposition. It is ironic that about the only activity involving the introduction of exotic species (aside from prohibitions against use of plants on the federal noxious weed list) that is routinely subjected to intense scrutiny is the introduction of biological control agents. Just about anyone can introduce anything, provided that their intent is not to use that organism for biological control purposes.

All importations of living organisms should be intensively regulated, but such regulation is unlikely to be implemented in the near term. Inspectors are already unable to meet APHIS' goal for examining 2% of the plants passing through Miami's ports of entry, so increased levels of inspections are unlikely. Restricting importations to seeds might provide some relief, but would be strongly contested. Routine fumigation of all plant shipments might eliminate invertebrate stowaways, but the costs and logistics of such a program would be overwhelming. Public education campaigns encouraging use of native plants and advocating patronage of nurseries providing only native species have yet to be initiated on any substantive scale. In any event, changing consumptive habits of the general populace is a slow process. These realities dictate that we deal with the symptoms of the problem, rather than the cause.

Biological control would seem to offer the best strategy for dealing with these symptoms. Concurrently, integrated control methods must be developed and natural areas must be managed to maintain the integrity and health of native ecosystems. Together, these offer the best hope for dealing with invasive, adventive species. We hasten to add that biological control is not a panacea and that legitimate criticisms should be addressed. The impacts of biological control agents on native species, for example, have often not been appraised during the screening process. Fortunately, this is rapidly changing and possible effects of introduced biological control agents on noneconomic native species are now routinely considered.

In order for biological control to develop fully as a pest control alternative, safety must not be compromised. Even one unwise introduction could set all biological control programs back many years, resulting in even greater regulation and slower progress. This places onerous responsibility on each and every biological control scientist. However, the increased demand that we are now experiencing for biological control agents could easily compromise safety. For example, if increased funds become available on a competitive basis and are thinly distributed among many laboratories, the end result might be the creation of many poorly-funded projects. The associated competition and demand for productivity with inadequate funding could force compromises that would not favor safety. A wiser approach would be to develop a few, well-funded projects based at "first-class" facilities so as not to jeopardized objectivity in the reckless pursuit of research dollars (Drea 1993).

The increased demand for biological controls could also result in pressure to develop programs more quickly, thus compromising the care and caution normally employed. Researchers oftentimes perceive (whether justified or not) the potential loss of funds if a biological control candidate that has undergone research for several years must be abandoned. This insecurity could lead to attempts to introduce agents that might not otherwise be considered. This should not be allowed to happen. Researchers should have the security of knowing that their budget will not be affected by these decisions. This again points to the need for adequate and stable funding. The lure of new funding tends to make experts out of dilettantes. This could be problematic if novices begin to introduce biological control agents without following proper protocol (Drea 1993). It might therefore become necessary to develop certification procedures for biological control specialists. Safety still depends on the integrity and honesty of the research scientists, even though the release of a biological control agent is dependent upon review by state and federal agencies.

CONCLUSION

Florida is a major point of entry for non-native species into the United States. Many become permanent residents in Florida, whether by design or by accident. Further, some demonstrate an unfortunate propensity for invading natural areas. These invasive adventive species can reduce biodiversity, thereby challenging efforts to conserve natural areas. Careful, scientific introduction of biological control agents is an appropriate mitigative strategy. The arguments presented by Howarth (1983) that biocontrol agents might be part of the problem, rather than part of the solution, are not convincing (see Lai 1988). More data are needed, though, on unintended effects of **recent** introductions. This issue must be resolved in a manner that avoids the creation of crippling, bureaucratic regulatory institutions. We must proceed with the development of environmentally sound pest management practices to protect the integrity of both natural and agricultural ecosystems in Florida. Classical biological control typically represents a solution that has no market profit, so public funding is required. The recognition of biological control as applied ecology and development of specialized curricula heavily weighted towards ecology in the training of future biological control specialists would help. Also, research leading to the release of new agents should be focused at a few "first-class" facilities and priority projects should be provided with adequate, long-term public funding.

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