Biological control of weeds in waterways and on public lands in the south-eastern United States of America

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Summary

The management and use of water for agricultural and urban needs in a manner that will preserve vital wetlands and recharge areas will constitute one of the most challenging problems to south Florida in the coming decades. Invasive exotic plants are compounding water management problems and have become so omnipresent, that traditional control methods can only be used in local situations. Biological controls are desperately needed for weeds of waterways and public lands like *Hydrilla verticillata* and *Melaleuca quinquenervia*. The USDA-ARS Aquatic Plant Control Laboratory, in collaboration with the U.S. Army Corps of Engineers and other federal, state, and local agencies, is currently addressing these problems. Four host-specific insects have recently been released for hydrilla control and one, the Asian hydrilla fly, *Hydrellia pakistanae*, is established. Surveys for potential biological control agents of *M. quinquenervia* have been undertaken in Australia and several promising species have been found. Additionally, the water lettuce weevil, *Neohydronomus affinis*, and the water lettuce moth, *Namangana pectinicornis*, which have been used effectively in Australia and Thailand respectively, have been released in Florida. The weevil has proven to be very effective at test sites but the moth is not yet established.

Background

During the past 30 years our laboratory has focused on research directed at the control of aquatic weeds. More recently we have become involved with weeds of public lands, especially those associated with wetland habitats. However, the importance of aquatic and wetland weeds is sometimes questioned and the required response is both complex and simple. The simple answer is "water". Society is dependent upon the supply and management of water. Aquatic weeds interfere with irrigation and flood control and thereby directly affect agriculture. Further, a great deal of commerce takes place by way of water-related transport, so elimination of navigational obstructions is critical to the transport of many commodities. The well-documented associations of mosquitoes with aquatic weeds and related human and animal health problems are also of considerable importance.

The more complex answer to the above question is also "water". The situation in south-eastern Florida illustrates the complexity of this answer. Virtually all of the water available to south-eastern Florida is supplied from Lake Okeechobee and the Kissimmee River drainage basin through a network of canals. These canals were made possible by the creation of the Everglades Drainage District in 1907 and the passage of the General Drainage Act of 1913. The original purpose of the Everglades Drainage District was to reclaim mucklands for agricultural activity. Eventually 58 such drainage districts were created in southeastern Florida. This drainage system was later expanded, after several intense tropical storms, to provide a means of flood control. These canals now supply water and provide flood control for both agricultural and urban needs.

This radical shift in land use during the past 50 years has created environmental problems. Nutrient runoff from agricultural lands into aquatic systems has caused accelerated eutrophication. These nutrients induce algal blooms and enhance the growth of aquatic macrophytes, thus exacerbating aquatic weed problems. Competing demands for water between agricultural and urban areas have reduced water supplies to natural wetlands. This has adversely impacted some unique ecosystems, such as those in the Everglades National Park. Indeed, some have predicted the total demise of this World Heritage Area unless the situation is reversed.

Water quality and quantity are not the only important aspects of the aquatic weed situation. If this was the case, aquatic weeds would merely be symptomatic of a larger underlying problem. An equally critical aspect involves the introduction of exotic plant species with extremely invasive population characteristics. These species, often purposely introduced free of natural enemies, become problematic regardless of anthropogenic disturbances. Water lettuce *(Pistia stratiotes* L.) is a good example. Water lettuce was probably introduced during the early colonization of Florida, possibly in the ballast of ships. It was already widespread well before the disruption of aquatic systems by urban and agricultural activities. It had rendered waterways impassable as early as the mid-1700s when the naturalists John and William Bartram first explored in Florida. This clearly illustrates the capacity of exotic species to invade pristine, undisturbed habitats. The combination of the two factors, presence of invasive exotic plant species without natural enemies plus an excessive abundance of nutrients to support luxuriant plant growth, has caused the explosive growth and proliferation of these weeds.

Invasive exotic plant species are sometimes inadvertently introduced for horticultural purposes. Ornamental horticulture is an agriculturally related activity, so agricultural research is appropriate when ornamental introductions become environmental problems, even though only a small percentage of introduced species become problematic. The alternative, legislative restrictions on the introduction of exotic species, would be politically untenable and could destroy a valuable industry. So, in a way, agricultural research aimed at reducing the threat posed by the inadvertent introduction of invasive exotic plant species protects the integrity of this industry.

The notorious wetland weed *Melaleuca quinquenervia* (Cav.) Blake, is illustrative of many of the situations described above. This plant was first established in south Florida in 1906 by Dr. John C. Gifford, a professor from the University of Miami. Various government agencies distributed this species with the aim of establishing a tree that would thrive in the wet habitats of south Florida, promote the drying of wetlands, and provide a commercially valuable product. It persisted at innocuous levels for many years, then began an explosive expansion in the 1950s. Lowering of the water table by the construction of regional water control systems, including the expansion of the South Florida Flood Control Project during that period, is often cited as one of the probable causes of this rapid increase. The canals traversing the Everglades effectively reduced the ambient hydroperiods. This exposed adjacent marshes to muck fires that were more serious than would otherwise have occurred. As a result, these marshes became more susceptible to invasion by fire-tolerant exotic species like *M. quinquenervia.*

Recently Hofstetter (10) noted a possible connection between the expansion of melaleuca and the coincident importation of honey bees for crop pollination. Also, this species has doubtlessly undergone considerable genetic change, commensurate with its abundant seed production, to become better suited to its adopted habitat. These factors, together with an almost complete lack of natural enemies, have enabled this plant to displace native species and to threaten ecosystem stability in many wetland habitats.

Obviously, agricultural, environmental, and urban interests are intertwined and difficult to separate. Agricultural research can solve many of the problems that affect the general public as well as private interests. It is therefore entirely appropriate that weeds of waterways and wetland systems be the subjects of agricultural research. In keeping with this philosophy, we are actively pursuing biological and integrated control solutions to the aquatic weeds water hyacinth (*Eichhornia crassipes* (Mart.) Solms.), water lettuce (*P. stratiotes*), hydrilla (*Hydrilla verticillata* [L.f.] Royle), and Eurasian watermilfoil (*Myriophyllum spicatum* L.), as well as the aggressive wetland invader *M. quinquenervia*. A review of these projects was published in the proceedings of the International Symposium on Biological Control of Weeds (3), so I will avoid duplicating that information and report on progress made since that time.

Progress towards biological control of hydrilla

Biological control, like most areas of scientific endeavor, strives to be predictive. Generalizations are important because they provide the bases for hypotheses that test the limits of our knowledge. However, when in the hands of policy makers, hypothetical statements are often mistaken for facts. Pessimism about the potential of a project can prevent the attempt. For example, the potential for biological control of woody weeds was once thought to be nil, so few attempts were made. Successful programs have now been developed against several woody plants (e.g., 5). In a like manner, the aquatic weed program has suffered from negative predictions. The use of insects to control submerged weeds was once considered very unlikely. Insects that fed on submerged aquatic plants were thought to lack the host specificity necessary for their safe introduction (1). Indeed, we even encountered skepticism espoused by aquatic ecologists concerning the perceived unimportance of insects as primary consumers in submerged aquatic communities (11). As a result, the biological control program against submerged aquatics was treated tentatively for many years and was slow to get underway.

In the late 1970s, it became apparent that the submerged weed *H. verticillata* was out of control. It had continued to widen its range and was spreading throughout the country. Biological control by means of insects, plant pathogens, or herbivorous fish became regarded as the only hope for a widely applicable, affordable control measure. Hence, despite abundant criticism, a biological control program was instituted.

An earlier attempt had been made to import the Asian ephydrid fly *(Hydrellia pakistanae* Deonier) for evaluation in U.S. quarantine, but permits were denied despite strong evidence of its host-specificity. Use of the herbivorous white amur (*Ctenopharyngodon idella* Valenciennes) was widely opposed because of its polyphagous diet and possible effects on water quality and native fish populations. Classical biological control using pathogens was not feasible at the time because of almost hysterical fears about releasing exotic plant pathogens.

The later restructuring of the interagency committee that then regulated the importation of biological control agents provided for a more reasonable petitioning process. As a result, the idea of classical biological control of *H. verticillata* using plant-feeding insects was rejuvenated after a decade of inactivity. Two of the insects studied in Pakistan during the 1970s were subsequently allowed into quarantine. Both were later approved for release. Ironically, one of these was *H. pakistanae*, the fly earlier disapproved for entry into quarantine. The other was the tuber-feeding weevil (*Bagous affinis* Hustache).Both of these were released during 1987. Two Australian insects have now also been released. These are the stem weevil (*Bagous* n. sp.) and a second ephydrid fly (*H. balciunasi* Bock).

We released *B. affinis* at several Florida sites, but proper funding was never allocated for a full-scale attempt to establish it, so we abandoned our efforts. Consequently, we don't know the outcome of our limited release program.

Buckingham (personal communication) documented temporary persistence following releases at a reservoir during a drawdown, but water levels were restored before it was determined whether the population would have endured. Because this insect requires dry soil, it probably can't survive in Florida but might be useful in other regions. Researchers in California have recently begun experimental releases of *B. affinis*. Because it is adapted to monsoon climates, it should do well in the more distinct wet and dry seasonality of the west coast.

Hydrellia pakistanae was first released in Florida during October 1987. The insects released were from colonies that had been maintained in quarantine for two years. This source also was used to develop stock colonies at our field laboratory which produced insects released until August 1990. Thereafter, we also collected adults from field sites to redistribute to other sites. By December 1990 we had made 92 releases at 23 locations totalling 136,340 eggs, 62,848 larvae, 4,073 puparia, and 16,212 adults.

Initial attempts to establish this insect failed. These were usually single releases comprising small numbers of eggs placed on open hydrilla mats in large water bodies. After several unsuccessful attempts, we abandoned this approach. Instead, we selected small, nearby sites that we could visit frequently. Field colonies finally established at three locations from multiple, frequent releases of large numbers of late instar larvae into small, floating cages. Field-collected adults from these sites then readily established at larger sites. We also released flies obtained directly from India and Pakistan that had been exposed to only two or three generations of captive rearing. Despite the small numbers available, the Pakistan strain established quickly. By late 1990 populations existed at several sites in south Florida and at one site in north Florida. Additional collaborative attempts with personnel from the U.S. Army Corps of Engineers (COE) Waterways Experiment Station (WES) to establish this species in other states have not yet been successful, but are continuing.

Surveys conducted during 1991 revealed the presence of *H. pakistanae* populations throughout south Florida. These have persisted for over two years and have now widely dispersed. We have therefore concluded that *H. pakistanae* is established and we are planning to evaluate its effects.

The Australian *H. balciunasi* was released in south Florida between February and July 1990. It seemed to establish quickly, but after initial recoveries of a few *H. balciunasi*, later collections provided only *H. pakistanae*. This was traced back to contamination of stock cultures. After acquiring new, pure colonies we released about 5000 *H. balciunasi* eggs and larvae at a remote, isolated site 100 km from the nearest known *H. pakistanae* population during May 1991. Before releasing these, we collected flies from the water surface above the hydrilla beds. To our surprise, most proved to be *H. pakistanae*. We continued to recover *H. balciunasi* from the site for several weeks, but when samples were collected in August 1991, only *H. pakistanae* was represented. Thus, it appears that *H. balciunasi* did not persist, although it may still be present in low numbers.

We have now obtained new *H. balciunasi* stock from Australia. After brief rearing in quarantine, we released the entire consignment at a site in central Florida. No *H. pakistanae* were found in pre-release samples, so we feel confident that we will be able to evaluate this release without being overwhelmed by *H. pakistanae*. Personnel from the WES at Vicksburg, Mississippi are releasing *H. balciunasi* at a site in Texas and have established vigorous laboratory colonies to support this activity. Consequently, establishment of this species in Florida is not critical, although we do intend to continue the release program.

The most recent species released against hydrilla is the Australian hydrilla stem weevil (*Bagous* n. sp.). The adults chew on the leaves and stems. Females insert single eggs into the stems, often in or near a leaf node. The larvae burrow within the stem. The combined feeding activity of adults and larvae should be quite destructive to beds of hydrilla, particularly those that have grown to the water's surface (2). However, a portion of the life cycle of this species may be dependent upon contact with the soil. After the larvae attain full size, they sever a stem segment and float with it to the shore. Larvae pupate after becoming stranded on the shoreline. Drier conditions during this period and dry, sandy soil might favour survival of the pupa.

This weevil has been released at two sites in Florida. Recently, two adults were recovered at one site two months after the last release, so we are hopeful that a population has established. Wet, humid conditions may not be conducive to the survival of this species. Also, the extensive littoral zones of emergent vegetation that typically surround water bodies in Florida may obstruct the formation of strandlines composed of hydrilla. If so, this could seriously hamper the establishment of this species. However, because of the potential value of this insect, we are fully committed to the attempt.

Hydrilla is becoming increasingly problematic in temperate portions of North America, whereas the biological control agents that we are releasing have originated from warmer climates. An attempt to discover new organisms that would fare better in cooler climates has been initiated. Dr. Gary Buckingham and Dr. Joe Balciunas have been surveying in China as part of a Sino-American co-operative program. Several promising species have been found that will be evaluated over the next few years. The work in China also includes surveys for potential biological control agents of Eurasian watermilfoil (*M. spicatum*), probably our most serious North American aquatic weed.

Progress towards biological control of water lettuce

Two species have been released in Florida for the biological control of water lettuce. The first, the South American weevil *(Neohydronomus affinis* Hustache syn *N. pulchellus* Hustache), was released in 1987 and is now well established (6). The second was the Asian noctuid moth, *N. pectinicornis.* It was first released during early 1991 but has not yet established.

We released *N. affinis* in Florida during April 1987 at Kreamer Island on Lake Okeechobee (6). Weevil populations remained low until January 1989. By April 1989 numbers had increased to over 900 individuals m^{-2} and water lettuce coverage of the site decreased to below 5%. A similar, but less rapid, reduction occurred at a second, nearby site. The weevils were released at Torry Island beginning in July 1987. Populations remained low until summer 1989. By August the population had grown to 800 individuals m^{-2} but it declined during the autumn without having severely affected the plant population. Then, in January 1990, weevil numbers again began to increase. The weevil population attained 1400 individuals m^{-2} by March and, as a result, only a small percentage of the water surface remained covered with water lettuce during May.

We also released the weevils at a canal during July 1987 and, although populations persisted, average densities never exceeded about 30 individuals m^{-2}. In March 1991 we failed to find *N. affinis*, so we assume that the population died out. Hence, it appears that this insect will not be universally effective.

N. affinis has now spread throughout southern Florida and has even been found as far away as Louisiana (Grodowitz, personal communication). Many water lettuce populations manifest abundant damage from weevil feeding. Frequently, the severity of attack is comparable to that at study sites prior to, and coincident with, the collapse of the water lettuce populations. We therefore expect widespread control of water lettuce by this insect. However, Harley *et al.* (8) noted that *N. affinis* seemed more effective in tropical regions of Australia. If this holds true in the U.S., *N. affinis* might not be as effective in northern areas as in south Florida.

Namangana pectinicornis effectively controls water lettuce, even within its native range (7). In Thailand, water lettuce is controlled by augmenting *N. pectinicornis* populations. Because we are using a classical inoculative approach in Florida, populations should be less affected by parasites and pathogens and results could be even more striking.

Progress towards biological control of *Melaleuca quinquenervia*

In the past, support for our program came mainly from the U.S. Army Corps of Engineers Aquatic Plant Control Research Program (APCRP). Because aquatic weeds directly cause economic losses, funds were available from public revenue. However, broad-leaved paperbark (*M. quinquenervia)* and other invasive weeds that infest parks, conservation sites, and other wildlands have little direct impact on economic interests. The lands affected by these species generally are in the public domain, so their tangible value is difficult to assess. As a result, no comprehensive programs exist in the U.S. to deal with these non-aquatic, non-cropland, non-pastureland weeds. Instead, local, state, federal, and private interests typically manage these problems in a piecemeal fashion.

In an attempt to resolve this "orphan" weed dilemma in Florida, we formed an Exotic Pest Plant Council (EPPC). This council constitutes a coalition of environmental groups, private interests, and representatives of local, state, and federal government agencies. This organization has effectively focused attention on the problem of invasive exotic plants and, in some cases, has initiated action against them.

Because this project was conceived solely for the public good, we initially encountered funding problems. Most biological control projects provide no profit motive and develop no exploitable commodity and are therefore of little interest to private concerns. Instead, the benefactors, i.e., the general public, must bear the support costs. However, the general public usually misunderstands or knows very little about biological control and, if anything, is wary of it. Thus, the development of biological control approaches often suffers from a lack of user group and public support. This necessitates public education.

Educational efforts initiated by the EPPC have paid off. Environmental groups as well as the general public are recognizing invasive species as environmental problems. On the whole, this has increased the demand for biological control research, but not the funding for it. As a result, we continue to solicit backing from user groups, primarily other federal, state, and local agencies, that will benefit by reduced control costs. Harris (9) discusses how critical this type of sponsorship is to programs in Canada, and he notes that programs lacking user-group partners are being terminated. We, too, have found this sponsorship to be critical. In fact, without the support of the EPPC and its member agencies, a biological control program on *M. quinquenervia* would never have been possible.

In 1986, a small sum was provided by the Jacksonville District of the U.S. Army Corps of Engineers to conduct preliminary surveys for potential biological control agents of *M. quinquenervia*. The funding was increased the following year and was supplemented by the National Park Service (NPS). Ultimately, a consortium was formed that included the COE, NPS, the Florida Department of Natural Resources (FDNR), the Florida Department of Environmental Regulation (FDER), the South Florida Water Management District (SFWMD), as well as Dade and Lee Counties. In addition, several U.S. congressmen now support the project and additional funds have been provided through an Energy and Water Appropriations Bill. We now temporarily have the resources necessary to conduct a proper biological control project, although most funding is available only on an annual basis.

Dr. Joe Balciunas will provide detailed information about progress on this project in his presentation, so I will be brief. From among numerous candidates, two insect species have now been sufficiently screened to request their importation into U.S. quarantine facilities. These are a defoliating sawfly *(Lophyrotoma zonalis)* and a tip-feeding weevil (*Oxyops vitiosa).*

The melaleuca project is coming in direct conflict for quarantine space with the aquatic weed program and other projects. Additionally, agencies within Florida are interested in initiating projects on *Mimosa pigra* L., *Casuarina* spp., *Rhodomyrtus tomentosus*, and other weeds of public lands. We expect the lack of quarantine space to forestall progress on biological control of many of these species.

Conclusion

Harris (9) rightfully emphasizes that biological control is more than a science, because of its unique political and administrative aspects, which must be balanced against its scientific aspects. He also notes that the success of a biological control program hinges on giving these three aspects appropriate levels of attention. His statements are extremely insightful and should be considered seriously. We, too, have found it necessary to develop a network of collaborators and co-operators that support our projects both politically and financially. Without them, our projects would be impossible. With them, our chances of success are greatly enhanced.

While it is interesting to try to predict the outcome of a project, care must be exercised so as to not prejudice these projects by prognostication. The trend in the past has been to select projects from among an array of possible targets. Projects selected have not necessarily been those with the greatest need for biological control, but rather those with the greatest perceived chances for success. Predicting success is a tricky business, however. Follow-up studies provide feed-back on how frequently projects with high perceived potential for success actually fail or are, in fact, successful. However, because projects with low perceived chances for success are avoided, there is little opportunity to judge the accuracy of the opposite prediction. These unbalanced designs are often inherent in *a posteriori* hypothesis testing, which illustrates why resultant conclusions should be viewed cautiously.

The merits of a biological control approach should be considered relative to the merits of other control approaches for a specific target, rather than solely against other targets. Hydrilla is a good example. No other effective controls exist, yet the problem is enormous. Despite negative prognoses, the lack of alternatives justified the attempt. Contrary to expectations, preliminary indications now suggest that biological control of hydrilla might succeed.

The introduction of a biological control agent follows years of study and requires considerable expense. However, the successful implementation of these bioagents depends upon their release and subsequent establishment. Our experience has shown that initial attempts to establish field colonies often fail. However, it is a mistake to give up too easily. The old adage about trying and trying again is particularly apropos. Harris (9) notes that newly introduced biocontrol organisms might require as long as 15 years to adapt to local environments. Likewise, establishment of organisms that are poorly adapted to local conditions might be somewhat serendipitous and require numerous attempts. About half of all failed projects are probably attributable to failure to establish the biological control agent (9,4). One must wonder, then, how many failed projects might have been successful, if attempts to establish the biocontrol organisms had persisted.

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***Figure 1** The west side of the Torrey Island study area a) in April 1989, two years after the release of **Neohydronomus affinis** and b) in March 1990 after an explosive increase in the weevil population eliminated the water lettuce. The plants remaining in the background are water pennywort (**Hydrocotyle** sp.).*