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# Phytosanitary measures and certifications programs implemented in Florida*

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## Summary

The geographic and climatic conditions of Florida make the state vulnerable to damaging exotic organisms. This risk is compounded by the intense trade of agricultural products arriving through numerous ports of entry in the state and the tourism industry, with at least 115 million visitors annually. For over 100 years, the Florida Department of Agriculture and Consumer Services' Division of Plant Industry (FDACS-DPI), known as the Florida State Plant Board from 1915-1960, has implemented regulatory programs to protect Florida's diverse agricultural industries from damaging exotic organisms (Tissot *et al.*, 1954). These unwanted organisms include phytoparasitic invertebrates such as arthropods, mollusks, and nematodes, and, also, plant pathogens and invasive plants. Many of these programs have been effective in preventing the establishment of or eradicating severe pests such as the Mediterranean [*Ceratitis capitata* (Wiedemann)] Oriental [*Bactrocera dorsalis* (Hendel)] and West Indian [*Anastrepha obliqua* (Macquart)] fruit flies, boll weevil [*Anthonomus grandis* Boheman], cotton seed bug [*Oxycarenus hyalinipennis* (Costa)] and the giant African snail [*Lissachatina fulica* (Bowdich)], which, at present, is under eradication in central Florida. Florida remains free from some pests through a permanent monitoring system, which, in the case of the fruit flies, is based on traps, baits, and mass release of sterile flies. When eradication is not feasible for a newly introduced pest, the spread of these exotic organisms is limited or controlled by certification programs designed to maintain pest-free propagative plant material and the release of

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biological control agents. These programs are very costly and require the commitment and dedication of regulatory officials, the support of growers, and public awareness of the risk that damaging exotic pests pose to agriculture and the state's economy.

**Keywords:** *Boll weevil, Burrowing nematode, Eradication programs, Fruit flies, giant African snail, Invasive plants, Regulatory legislation.*

### Riassunto

### *Misure fitosanitarie e programmi di certificazione effettuati in Florida*

Le diversificate condizioni geografiche e climatiche della Florida rappresentano circostanze favorevoli per l'insediamento di organismi esotici nocivi. A questo si aggiungono l'intensificazione degli scambi commerciali di piante attraverso i numerosi porti e i flussi turistici quantificabili in non meno di 100 milioni di visitatori per anno, fattori che amplificano il rischio di introduzioni accidentali di organismi esotici potenzialmente dannosi all'agricoltura e all'ambiente. Per oltre 100 anni, la Division of Pant Industry (DPI) del Dipartimento dell'Agricoltura della Florida in cooperazione con il Dipartimento dell'Agricoltura degli Stati Uniti, ha condotto programmi fitosanitari miranti alla protezione delle aziende agricole della Florida da organismi esotici nocivi (Tissot *et al.*, 1954), con riferimento ad artropodi, molluschi, nematodi, microrganismi fitopatogeni e piante infestanti invasive. Molti di questi programmi sono risultati efficaci nel prevenire l'insediamento di importanti fitofagi come la mosca mediterranea della frutta (*Ceratitis capitata*), la mosca orientale (*Bactrocera dorsalis*) e la mosca delle Indie occidentali (*Anastrepha obliqua*), la cimice dei semi del cotone (*Oxycaremus hyalinipennis*) e il punteruolo delle capsule del cotone (*Anthonomus grandis*). A questi si aggiunge la lumaca gigante africana (*Lissachatina fulica*), attualmente in fase di eradicazione nella Florida centrale. L'attuale situazione della Florida basata su di uno stretto controllo delle specie aliene nocive alle piante è resa possibile dal mantenimento di programmi permanenti di monitoraggio e controllo che ad esempio nel caso delle mosche della frutta, prevedono l'uso di trappole, esche attrattive e rilascio massivo di individui sterili. Nei casi per i quali l'eradicazione non risulta più praticabile, il contenimento è basato su programmi di controllo integrato che includono sistemi di certificazione mirati alla produzione di piante indenni da fitofagi e patogeni. A questo si aggiunge ove possibile il rilascio massivo di agenti di controllo biologico prodotti in appositi allevamenti massali curati presso la predetta DPI. I programmi di prevenzione e controllo hanno costi elevati e richiedono per la loro realizzazione un forte impegno da parte del personale addetto ai servizi fitosanitari, a cui si affianca dando un contributo di rilievo il supporto degli operatori agricoli e la partecipazione dei cittadini per evitare introduzioni accidentali legate ai flussi commerciali e turistici, attraverso il trasporto di piante e loro parti.

**Parole chiave:** *Cimice dei semi del cotone, Legislazione fitosanitaria, Lumaca gigante africana, Mosche della frutta, Nematodi fitoparassiti, Piante invasive, Programmi di eradicazione, Punteruolo delle capsule del cotone.*

## 1 Introduction and historical considerations

Human migrations have occurred for thousands of years, resulting in the movement of plants, their parasites, and other associated injurious organisms. The intensification of plant trade after the discovery of the Americas dramatically increased the movement of exotic organisms that have adversely interacted with crops grown in many geographical areas. Therefore, the protection of agricultural industries and the environment has become a crucial issue in many countries and has prompted the implementation of phytosanitary measures to prevent or retard the arrival and establishment of damaging exotic organisms. The first phytosanitary measures against an exotic organism were enacted in 1878 to prevent the spread of an insect, the American vine phylloxera, *Phylloxera vastatrix* (the former name of the grape phylloxera *Dactulosphaira vitifoliae*), that arrived in Europe from the Americas and devastated vineyards and the European wine industry (Anonymous, 1914). These phytosanitary measures developed for this insect included the essential principles of the modern phytosanitary legislation that became uniform and agreed upon by the nations participating in the International Plant Protection Convention (IPPC) held in Rome, in 1951, under the patronage of the Food and Agriculture Organization (FAO) of the United Nations (UN). A glossary containing phytosanitary terms, updated periodically by the Commission of Phytosanitary Measures (CPM), was made available to the countries participating in the IPPC. The definition of quarantine pest was included to indicate "a pest of potential economic importance to the area endangered thereby and not present there, or present but not widely distributed and being officially controlled".

## 2 Phytosanitary legislation in the United States

Each country delegates a local National Plant Protection Organization (NPPO) to enact phytosanitary measures within the framework of the international phytosanitary legislation. Among the NPPOs, we mention the United States Department of Agriculture's Animal and Plant Health Inspection Services (USDA-APHIS) and the Animal and Plant Health and Inspection (SDA), which carry out phytosanitary actions for the United Sates and Brazil, respectively. Other regional and inter-regional organizations (RPPOs) include the European and Mediterranean Plant Protection Organization (EPPO), which develops plant health regulations for the European, Mediterranean and some Asian countries (Ebbels, 2003; Hockland *et al*., 2013; FAO, 2023). The USDA-APHIS was established in 1912 when the USA Congress passed the first Plant Quarantine Act. In addition, in the USA, each state has the prerogative to promulgate phytosanitary legislation to protect local agricultural interests and the environment. Florida has carried out the country's most vigorous, effective, and costly phytosanitary programs for over 100 years. These programs are implemented by the Florida Department of Agriculture and Consumer Services (FDACS), and specifically

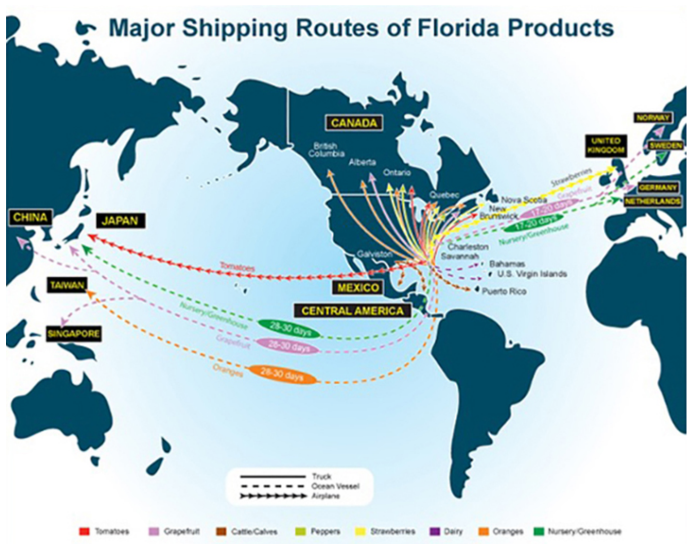


Figure 1: Major shipping routes of Florida agricultural products (after FDACS, 2022).

by the Division of Plant Industry (DPI), which deals with all aspects of protecting Florida's agriculture by providing plant pest and disease diagnostic services, pest surveillance programs, regulation of the movement of plants, responding to new exotic pests and enacting state quarantine functions.

## 3 Phytosanitary programs in Florida

The main objective of these services and regulations is the protection of Florida's diversified agricultural industries and their products, which are an essential component of the state's economy. Sales revenue alone is over US$ 10 billion annually, but when processing, manufacturing, and distribution of agricultural products are included, Florida's agricultural industry is valued at US$ 150 billion. The geographic position of Florida, numerous (29) international ports of entry receiving large consignments of agricultural products, one-third of all plant material entering the country, and 91% of the cut flowers entering the US make the state vulnerable to the arrival and establishment of many exotic organisms (FDACS, 2022) (Fig. 1). Furthermore, a climate gradient encompassing temperate, subtropical and tropical conditions and the tourism industry with over 115 million visitors per year compound this risk. The cooperation between FDACS-DPI and USDA-APHIS-Plant Protection and Quarantine (PPQ) has resulted in implementing regulatory programs to eradicate or contain damaging exotic organisms to prevent their spread in Florida and outside the state. Some programs have reached their objectives and either prevented the establishment and dissemination of targeted exotic pests or have successfully mitigated the impact of said organisms. In contrast, others have been discontinued due to difficulties in implementing feasible and adequate phytosanitary measures to stop the establishment and spread of quarantinable organisms. The damaging exotic or-

Figure 2: An adult female of medfly. (Courtesy of J. Clark, Univ. California).

ganisms targeted by these programs in the past and present include noxious phytoparasitic invertebrates such as arthropods, mollusks, and nematodes, as well as plant pathogens and unwanted invasive plants. The results of some of these costly programs are discussed in the following sections.

### 3.1 Selected programs to eradicate or contain exotic damaging arthropods

#### 3.1.1 Fruit flies

Numerous pest fruit flies threaten Florida agriculture. At present, FDACS-DPI, in cooperation with USDA-APHIS-PPQ, conducts year-round surveillance for exotic fruit flies using up to 56,000 traps depending on the season. Nearly half of these traps are baited with trimedlure for detection of Mediterranean fruit fly (medfly) *Ceratitis capitata* (Wiedemann) (Insecta: Diptera: Tephritidae) (Fig. 2) and other *Ceratitis* spp. The remaining traps are baited with methyl eugenol, which attracts *Bactrocera* spp; cuelure, which attracts primarily cucurbit-infesting dacine fruit flies (*Anastrepha* spp., *Bactrocera* spp., and *Dacus* spp.); and "multi-lure" traps containing synthetic nitrogen-containing compounds, which are attractive to females of several pest genera.

Florida has a long history of fruit fly invasions, and the regulatory response has evolved dramatically over the past nearly 100 years. This history began when the Mediterranean fruit fly was detected for the first time in Florida in 1929. An eradication program was enacted by federal and state authorities in 20 infested counties using over 12,000 McPhail fruit fly traps to detect the presence of flies, stripping and burying potential host fruits, and spraying insecticides up to 10 miles around each infested citrus grove. Eradication was declared after about 18 months for US$ 7.5 million. This was the first successful medfly eradication anywhere on Earth (Tissot *et al.*, 1954). A second medfly outbreak in Florida occurred in 1956. The insect was eradicated again by delimiting the

Figure 3: An adult female of oriental fruit fly on a fruit of litchi. (Courtesy of G. Steck, FDACS).

population with up to 54,000 McPhail traps, the establishment of quarantine zones, fruit stripping and destruction, and ground and aerial insecticidal spraying at a total cost of US$ 11 million (see Clark *et al.*, 1996). Numerous smaller eradications took place from 1962 to 1990, culminating in another large-scale medfly outbreak and eradication campaign in multiple locations in 1997–1998 that cost approximately US$ 35 million. This program led to the establishment of Florida's medfly Preventive Release Program which incorporates Sterile Insect Technique (SIT) into the overall fruit fly safeguarding program within the state. This joint state and federal program involves the aerial release of approximately 80 million sterile male medflies weekly in the most vulnerable areas of the state. When the overflooding ratio of sterile males to sexually mature wild males is high, most or all females mate with sterile males, producing inviable eggs, which cause population crashes. The most recent outbreaks of this fly occurred in 2010–2011.

Of equal or greater concern to Florida agriculture is the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Insecta: Diptera: Tephritidae) (Fig. 3), which has begun to displace the medfly worldwide as a stronger and more effective invader. It has been detected and eradicated in Florida numerous times, beginning in 1964. However, the largest and most serious colonization occurred in a major agricultural production area in South Florida in 2015–2016. The eradication program relied on many elements used in earlier medfly eradication programs (e.g., quarantine, bait spray, fruit stripping) and included a potent male annihilation technique (MAT). This method disrupts population growth by killing males, which are highly attracted to baits containing methyl eugenol combined with an insecticide. A detailed description of the 2015–2016 Oriental fruit fly eradication program and a general overview of exotic fruit fly surveillance and eradication in Florida is available in Steck *et al.* (2019).

Figure 4: An adult female of West Indian fruit fly. (Courtesy of J. Lotz, FDACS).

Another fruit fly that represents a constant threat to Florida is the West Indian, *Anastrepha obliqua* (Macquart) (Insecta: Diptera: Tephritidae) (Fig. 4) as it is widespread in the Caribbean basin, and many of the infested islands are geographically very close to Florida. An outbreak of this fly was first discovered in Florida in 1930, and after a large-scale survey effort, it was determined that the infestation was limited to the Florida Keys and the extreme southern tip of mainland Florida. In 1934 an eradication program began and continued through to its successful conclusion in 1936. This program included widespread fruit removal and destruction and biweekly insecticidal sprays in South Florida, where the insect was localized. The campaign was very effective and resulted in the eradication of this fly; however, this pest is still frequently intercepted in mangos and other fruits imported into Florida from various countries (Steck, 2001).

There are instances in which pest fruit flies have invaded and successfully established in Florida and are a continuing challenge to this day. One is the papaya fruit fly, *Anastrepha curvicauda* (Gerstaecker), established in Florida in about 1905. There are no area-wide management programs to contain this pest, and commercial and residential papaya growers rely on cultural practices and proper pesticide applications to protect their crops. A second example is the Caribbean fruit fly (caribfly), *Anastrepha suspensa* (Loew), which is indigenous to the West Indies. It was detected in South Florida in 1965, and at the time of discovery, the population was already large and widespread. Eradication was deemed unfeasible; therefore, extreme mitigation measures were implemented that allowed Florida growers to continue exporting fruit. Unfortunately, it is thoroughly established in southern and central peninsular Florida, where it infests over 80 different tropical and subtropical fruits, including citrus, disrupting their trade in national and international markets (California, Texas, Japan, and others) that regulate this insect. Because of the caribfly's broad host range, the Caribbean Fruit Fly Protocol Program was established to enable citrus export to markets regulating this fly. This protocol requires that citrus fruits for export originate in certified, fly-free areas, where the preferred hosts of the caribfly (guava, loquat,

Figure 5: An adult female of Asian citrus psyllid feeding on a tender sprout of citrus. (Courtesy of J. Lotz, FDACS).

Surinam cherry, and rose apple) are removed from the environs of commercial citrus production areas, and the absence of the fly is monitored using traps and bait spray applications during the harvest season (Riherd, 1993; Simpson, 1993). This program, which was developed in cooperation with Florida fruit growers and funded by the participants, is administered by FDACS-DPI and USDA-APHIS-PPQ.

#### 3.1.2 Asian citrus psyllid

The Asian citrus psyllid, (*Diaphorina citri* Kuwayama) (ACP) (Insecta: Hemiptera) (Fig. 5), was detected in Florida in 1998 and has become established throughout the state, where it transmits a serious citrus disease called Huanglongbing (HLB) also known as citrus greening disease. This insect distorts the leaves by depleting the sap of the tender sprouts and vectors the phloem-restricted bacterium *Candidatus* Liberibacter asiaticus, the causal agent of the devastating citrus diseases. No effective eradication methods of this psyllid are available. The impact of biological control agents of ACP, such as the parasitoid, *Tamarixia radiata* (Waterstone) that was introduced into Florida to suppress the psyllid populations and, indirectly, the disease, is still under evaluation. To contain this disease and ensure clean citrus nursery propagative material production, FDACS-DPI enacted regulations that moved all production of citrus nursery stock indoors. The guidelines of this program require that citrus propagative material is produced in sealed greenhouses, impervious to ACP, and where young citrus trees are grown on raised benches in sterile conditions. This system allows the production of citrus free from psyllids and, therefore HLB. Unfortunately, the control of this disease in the field is very challenging. Once transplanted under field conditions, these healthy trees produce fruit for a limited number of years until the

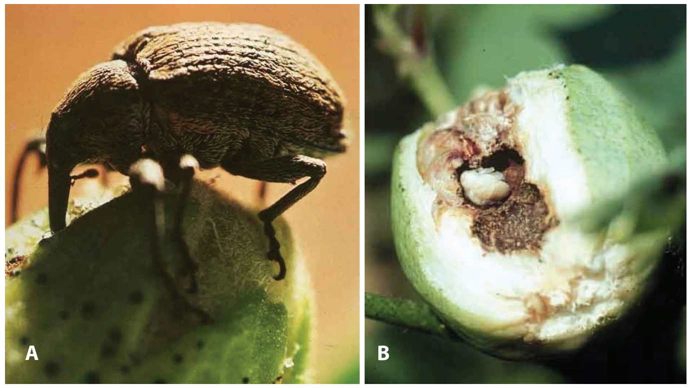


Figure 6: Cotton boll infested by cotton boll weevil. A: A cotton boll weevil adult feeding on a boll of cotton. B. A sectioned cotton boll showing a large necrotic cavity partially filled with organic detritus induced by the feeding activity of a weevil larva, which has metamorphosed into a pupa. (Courtesy of FDACS).

ACP infestations and the vectored bacterium HLB will prematurely debilitate the plants, shortening their production cycle. At present, area-wide ACP control and the use of exclusionary individual protective covers (IPCs) for the first few years of the tree's life in the field is the most effective way of suppressing the pest/disease complex. The search for an HLB-tolerant tree continues.

### 3.1.3 Boll weevil

The boll weevil, *Anthonomus grandis* Boheman (Insecta: Curculionidae) (Fig. 6), is native to Mexico and Central America where it develops and feeds on native cotton species. After its detection in Texas in 1892, the weevil quickly spread in the United States and, within 30 years, had infested all cotton-producing areas of the United States (Dickerson *et al.*, 2001). Weevil females lay a single egg in the cotton squares or bolls. When larvae hatch, they feed on the tissues of squares or bolls, which may then drop from the plant. Fifty percent losses or complete crop failure have been observed in weevil-infested cotton fields (Sorenson and Stevens, 2019). An eradication program of the boll weevil was initiated by USDA-APHIS and most cotton-producing states in 1978 and, subsequently, expanded to other states, including Florida encompassing over 15 million acres in the US at the height of the program. The use of effective pheromone-baited traps led to an extremely accurate surveillance program for emerging populations of this pest and allowed for the swift treatment of infested areas. Eradication of the boll weevil in Florida was achieved through planting practices designed to discourage pest establishment, stripping and burying of potential hosts, sanitation of harvesting equipment, and area-wide insecticidal spray programs over a four-or-five-year period. By 1987, the boll weevil was effectively eradicated from Florida. Occasional outbreaks occurred up until 1996 however, each of these reintroductions was quickly dealt with. The sanitation of machinery used in cotton production and harvesting is still practiced today, and an active pheromone

Figure 7: An adult of cotton seed bug. (Courtesy of J. Lotz, FDACS).

trapping program continues in all cotton fields in the US. Implementing these precautionary practices have so far prevented new infestations of this pest in Florida, where cotton is an important industrial crop in the northern areas of the state with a cash value of US$ 52.5 million annually in 2017 (Leonard, 2020). This is a cost-share program, with 70% funded by the growers and the remaining 30% by USDA-APHIS (USDA-APHIS, 2007).

### 3.1.4 Cotton seed bug

The cotton seed bug, *Oxycarenus hyalinipennis* (Costa) (Insecta: Hemiptera) (Fig. 7), is a Mediterranean species that damage cotton in parts of Africa, Asia, and the Americas. The primary plant hosts of this species include cotton and species in the Malvaceae family; however, in searching for moisture during certain times of the year they will feed on apple, avocado, pear, and other fruits and vegetables.

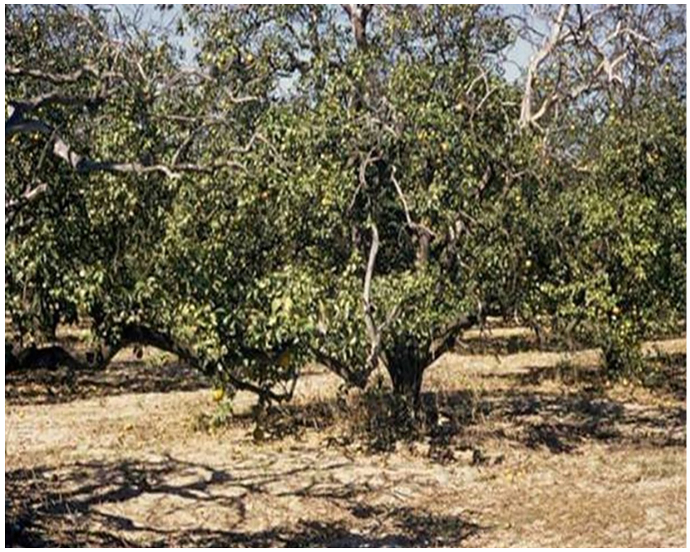

Figure 8: A stunted grapefruit tree showing Spreading decline symptoms. (Courtesy of R. N. Inserra, FDACS).

This insect develops inside the cotton boll and feeds on the seeds causing reduction of seed weight and germination (Halbert and Dobbs, 2010). This pest can indirectly affect cotton lint quality by staining the harvested cotton when insect life stages are crushed during cotton harvesting (Sharma *et al.*, 2017). Cotton seed bug was detected in South Florida in 2010 and eradicated by 2014 (USDA-APHIS, 2014; UF/IFAS, 2014). This successful program consisted of targeted surveys, removal and destruction of infested plants, and regulatory programs to ensure that potential host plants were not moved out of the program area. This eradication campaign was implemented by FDACS-DPI and led by the Florida Cooperative Agriculture Pest Survey (CAPS) soon after the cotton sed bug outbreak was detected. Risks of reintroduction of this pest into Florida are very high because it is well established in the Caribbean Basin (Smith and Brambila, 2008). Continuous monitoring has prevented new infestations of this cotton pest in Florida.

### 3.2 Selected programs to eradicate or contain exotic damaging nematodes

#### 3.2.1 Burrowing nematode

The phytosanitary programs to prevent the dissemination of damaging plant parasitic nematodes in the state of Florida were prompted by the outbreak of a devastating citrus disease called 'spreading decline' (Fig. 8), which was caused by the burrowing nematode, *Radopholus similis* (Cobb, 1893) Thorne, 1949 (Fig. 9) in the early 1950s. At that time, *R. similis* and other nematode parasites of citrus, such as *Tylenchulus semipenetrans* Cobb, 1913, had been disseminated with infested propagative material into Florida's new and old citrus-growing areas where these nematodes were not native. At first, quarantine measures were enacted, and an eradication program of the nematode was attempted. This

Figure 9: Burrowing nematode female and male. (Courtesy of R. N. Inserra, FDACS).

eradication program was discontinued quickly because the chemicals used were harmful to the environment. The current program called the citrus nursery certification program, was concomitantly enacted. This program aims to produce citrus propagative material free from nematode parasites for citrus growers. This program has been combined with the clean citrus budwood program to exclude ACP. This program has eliminated plant-parasitic nematodes from the citrus nursery industry. Combining the initial eradication measures and the citrus nursery certification program has drastically reduced the number of nematode-infested orchards. The benefit of preventing the spread of *R. similis* in susceptible areas of Florida has been estimated at US$ 1.4 billion for 35 years (Dwinell and Lehman, 2004). Unfortunately, *R. similis* consists of two races, banana, and citrus, which have different trophic habits and are not distinguishable morphologically and currently, not even with molecular techniques. The banana race is widely distributed in many geographical areas. It parasitizes bananas but not citrus, whereas the citrus race inducing the citrus disease 'spreading decline' has been found only in Florida and parasitizes both bananas and citrus. Both races infest many ornamental plants in the Araceae, Laurantaceae, Marantaceae and Musacee families. The lack of reliable diagnostic tools to separate the two races has resulted in the adoption of phytosanitary measures by citrus-producing states in the USA and other countries banning consignments infested with either race to protect their citrus industries. To avoid a collapse of the Florida ornamental industry, a certification program of ornamental plants, like the citrus nursery certification program, has been implemented to produce ornamental plants free from regulated nematodes and meet the phytosanitary requirements for export to national and international markets. This program requires the adoption of strict phytosanitary practices in the nurseries and the use of clean growing media, containers, and propagative stocks, and it is also

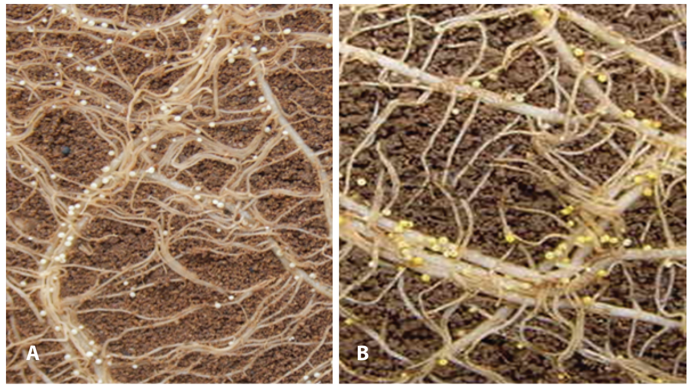


Figure 10: Potato roots infested by females of the pale and golden cyst nematodes. A) White females of the pale potato cyst nematode; B) Golden females of the golden cyst nematode. (Courtesy of N. Greco, CNR, Bari, Italy).

recommended that all nursery stock be placed on raised benches, cement slabs or sites protected by tarps to avoid contamination with nematodes from soil and other sources. Plants produced in these programs are inspected annually to verify their phytosanitary condition and the absence of regulated nematodes in their roots, canopy, and growing media. The nematode certification program for the ornamental industry, initially implemented for the burrowing nematode, excludes many other damaging nematodes occurring in Florida that are regulated in national and international markets. The high market values of ornamental plants justify the high cost of these nematode certification programs (Dwinell and Lehman, 2004; Inserra *et al.*, 2005).

### 3.2.2 Potato cyst nematodes (PCN)

Potato cyst nematodes *Globodera pallida* (Stone, 1973) Behrens, 1975 (Fig. 10A) and *G. rostochiensis* (Wollenweber, 1923) Behrens, 1975 (Fig. 10B) are rigorously regulated in the USA. The first phytosanitary measures to limit the spread of *G. rostochiensis* were enacted by the Golden Nematode Act, passed by the US Congress in 1948 after the introduction of this nematode from Europe with military equipment contaminated by the cysts of this pest. These regulatory actions have restricted the spread of PCN in the state of New York. However, a limited infestation of *G. pallida* was detected in 2006 in the state of Idaho, where strict quarantine actions were implemented. PCN is a menace to the potato industry worldwide. In Florida, regulatory measures are enforced by conducting surveys at 5-year intervals to monitor variation in the composition of nematode species in Florida's potato growing areas. Seed potatoes originating from states free from PCN have played a pivotal role in keeping Florida free from PCN. Estimates of the benefits of these costly phytosanitary programs for the USA were calculated at US$ 300 million annually at 1995 values (Dwinell and Lehman, 2004).

Figure 11: Specimens of the African giant snail. (Courtesy of FDACS).

### 3.3 Programs to eradicate or contain exotic damaging mollusks

One of the most damaging exotic mollusks to cultivated and wild plants of Florida is the giant African snail (GAS), *Lissachatina fulica* (Bowdich) (Mollusca: Gastropoda) (Fig. 11). This invasive snail, native to Southeast Africa has been introduced and established in many tropical and subtropical regions. GAS damages plants by feeding on all above-ground parts, including leaves, stems, and flowers, but it is also an indirect threat to humans as a vector of the rat lungworm (RLW), *Angiostrongylus cantonensis* (Chen, 1935), a nematode parasite of rats, which can infect humans and other mammals. In humans, RLW induces eosinophilic meningitis and can be fatal. The RLW completes its development in the definitive host in the pulmonary arteries. Females lay eggs that hatch in the terminal branches of the pulmonary arteries. First-stage juveniles (J1) migrate to the pharynx, are swallowed, and then passed in feces, which are ingested by the snail, their intermediate host. Once inside the snail's digestive system, J1 migrate into the tissues of the mantel, where they molt twice into the infective and coiled third-stage juveniles (J3). Rats prey on nematode-infested snails and acquire the J3, which migrate to the brain where they develop into young adults. The young adults migrate to the venous system and then the pulmonary arteries, where they become sexually mature. Other intermediate hosts of the RLW include freshwater shrimp, crayfish, and crabs that can vector the nematode when consumed by rodents and humans (Smith *et al.*, 2015). Humans may acquire the RLW by consuming undercooked snails or vegetables contaminated with slime secreted by nematode-infested GAS. Recently, RLW has been detected in frogs in Florida (Walden, 2022). Frogs are paratenic hosts, which are not conducive for nematode development but transmit the infective J3.

In the last 30 years, the movement and establishment of invasive snail species have increased in many tropical and subtropical areas. Usually, GAS is transported or smuggled long distances by persons who use them as pets or for special religious rites. Santeria practitioners occasionally use these snails in rituals or for ceremonial purposes. In Florida, the introduction of GAS has reoccurred intermittently over the last 40 years. The first introduction occurred in South Florida, in locations scattered around the periphery of Miami in 1969 (Sturgeon, 1971). A seven-year eradication program was enacted successfully at an equivalent 2022 cost of US$ 7 million (Poucher, 1975). Another introduction occurred in South Florida in 2011, requiring an 11-year eradication program that relied on manual collection and destruction of GAS specimens and the application of an approved chemical treatment for US$ 24 million. Some specimens collected during this program were found to be infested by the RLW for the first time in the state (Smith *et al.*, 2015). Unfortunately, soon after this eradication was completed in 2021, another detection of the snail occurred in Central Florida in 2022. This infestation was connected to the pet trade as the phenotype found in the new location is an uncommon mutation found in GAS sold for pets. A new eradication program, which is still in progress, was implemented, and similar to the successful 2011-2021 program, public outreach is one of the critical components of this program. The outreach strategies used in this program go far beyond information sheets and newspaper articles and include radio ads, podcasts, social media messaging, television interviews, and, of course, door-to-door communication directly with homeowners in and near the infested area. This educational campaign is focused on making people aware of the biology of GAS and the risk posed to the residents in the snail-infested areas by the potential transmission of the RLW. The GAS-infested areas are divided into survey and treatment grids and monitored by specialized survey teams with detector dogs to collect visible snails and debris potentially harboring GAS specimens. These inspected areas are then treated with molluscicides containing metaldehyde. The decommissioning of the program and complete eradication of GALS from the infested sites will be achieved after a rigorous process requiring no less than 17 months of surveys and chemical treatments, followed by 19 months of surveys with no treatments and detector dog inspections and special night surveys when GAS exit hidden nests and move around in large number to forage. This eradication program will continue for the next few years for US$ 1.5 million annually. At the writing of this paper, a second population of GAS was detected in Southwest Florida and is also under eradication.

### 3.4 Selected programs to eradicate or contain exotic damaging pathogens

#### 3.4.1 Citrus canker

Citrus canker (Fig. 12) is a citrus disease that originated in South-East Asia and is caused by the bacterium *Xanthomonas campestris* (Pamm) Dows. pv. *citri* (Hasse) Dye, which induces lesions on citrus leaves, stems, and fruit. The rind lesions make the fruit unmarketable. Under high humidity and rainy conditions, citrus canker causes defoliation, shoot dieback, and fruit drop. This disease is highly

Figure 12: Symptoms of citrus canker. (Courtesy of T. Schubert, FDACS).

contagious and spreads rapidly with rain and wind. Citrus canker was detected for the first time in Florida in 1912. In 1915, DPI (then known as the Florida State Plant Board) embarked upon an 18-year eradication campaign. By 1933, citrus canker had been eradicated from Florida for the first time; this was the first time a citrus disease had been eradicated anywhere in the world. A little over fifty years later, citrus canker was again detected in Florida in 1986. An eradication program based on removing infected citrus trees was similarly successful in eliminating the disease from Florida, and eradication was declared for the second time in 1992. However, in 1995 citrus canker was detected again in residential areas around Miami. As a result, a third eradication program was enacted. This program had successfully removed most infected trees from the state by 2000. A tiny area of less than 80,000 infected trees remained to be removed when a court injunction forced the program to stop cutting trees from 2002-2004. After overcoming the legal injunctions, the program resumed in 2004. Unfortunately, Florida was hit by five hurricanes in 2004, four of which went directly over the remaining area of infection. These tropical events spread citrus canker throughout Florida's citrus production areas, reversing much of the progress made in the program's first six years. The gargantuan and costly efforts in implementing this program would have been successful if legal actions had not stalled the program from 2000 to 2004. Today the impacts of citrus canker are mitigated by the previously mentioned clean citrus nursery stock certification program, where all citrus nursery material must be grown in sealed greenhouses, and growers conduct aggressive chemical control strategies in the field.

### 3.5 Programs to contain exotic invasive plants

Numerous exotic invasive aquatic and terrestrial plants have arrived and established in Florida. As with other exotic organisms, plants come into Florida through a number of human activities and natural disturbances. Plants may be introduced intentionally as ornamentals or accidentally as contaminants of seeds, soil, food, stowaways in ship ballast, packing materials, and the tropical fish pet trade. Florida offers a welcoming climate for exotic plants from temperate to subtropical regions and habitats ranging from arid, sandy scrublands to wetlands and navigable waterways, making it likely to find numerous exotic plants becoming established within the state. Chemical and mechanical methods for removing these pest plants are costly and usually continuous. An evaluation of plant management expenditures in Florida found that an average of US$ 45 million annually is spent to control invasive plants (Hiatt *et al.*, 2019). Despite the cost, these measures may be insufficient to control the rampant growth of resilient pest plants, especially those with persistent reproductive structures such as underground tubers or long-lived seed banks in the soil. Chemical controls may also impact non-target species and cause additional environmental damage. Biological control agents can offer a more cost-efficient and environmentally friendly alternative for reducing infestations. FDACS-DPI participates in biological control programs to suppress the vigor and dominance of these plants. The Division has specialized in the areas of techniques for breeding biocontrol agents, including the establishment of a Biological Control Rearing Facility. Other areas of expertise include mass rearing, release, and post-release monitoring as part of biocontrol programs (FDACS, 2023). Early detection and surveillance programs occasionally discover outbreaks of exotic pest plants before they become widely established. FDACS-DPI, in collaboration with the Cooperative Agricultural Pest Survey (CAPS) program, monitors state lands for pests as part of Florida's early detection and rapid response programs. In addition, FDACS-DPI has focused on communication through collaborative efforts with other agencies and public information campaigns related to the release of biocontrol agents. Several projects (described below) illustrate the role of the Division in controlling these threats to Florida's native and commercially grown plants.

*Alternanthera philoxeroides* (Mart.) Griseb. (Amaranthaceae) or alligator weed (Fig. 13) provides an early example of the potential success and cost-effectiveness of biocontrol programs. This program, using *Agasicles hygrophila* Selman and Vogt (Coleoptera: Chrysomelidae) as the biocontrol agent, provided a model for research and collaboration as the first insect introduced for control of an aquatic weed (UF/IFAS, 2023). *Alternanthera philoxeroides,* known as alligatorweed, is native to coastal areas of South America from Venezuela to Argentina and likely arrived in the United States accidentally from a ship's ballast in about 1894 (Simberloff *et al.*, 1997). As of 2023, the plant has been documented in 55 Florida counties from the state's northwest corner to its extreme southeastern tip (ISB, 2023a). This species grows rampantly, rooting at the edges of waterways,

Figure 13: A thick mat of alligator weed in a Florida lake. (Courtesy of G. R. Buckingham, USDA, ARS).

then spreading over the water as floating mats, hindering navigation. Shade created by these dense vegetative blankets can inhibit the growth of submerged vegetation and reduce oxygen availability in the water. By 1901, this aquatic weed was recognized as a problem. In 1959, after struggling to clear the plant from navigable waters, the US Army Corps of Engineers asked the US Department of Agriculture (USDA) to assist in efforts to control the weed (Coulson, 1977; Coulson *et al.*, 2000). USDA staff searched for the plant's natural enemies and found several from its native range in South America (Buckingham, 2002). *Agasicles hygrophila,* the alligatorweed flea beetle, was among the most promising of these insects. Classical biocontrol testing of the host range was conducted, and mass rearing of the insects provided a sufficient supply to help control the weed. In 1965, USDA was permitted to release this insect in the southeastern United States. Populations of the plant declined, US Army Corps of Engineers budgets for removal of the weed were reduced, and the alligatorweed flea beetle became a Florida resident (Buckingham, 2002). Most of the quarantine work for this project was done at the FDACS-DPI invertebrate quarantine laboratory. This program's success led to many more aquatic weed biological control collaborations between the two agencies.

*Dioscorea bulbifera* L. (Dioscoreaceae) or air potato (Fig. 14), a rampantly growing herbaceous vine native to Asia and Africa, can reach lengths of 65 feet in a single growing season. The plants reproduce asexually using bulbils (aerial tubers), so similar to potatoes, the common name is air potato. One to four bulbils can be produced at each leaf axil, and a single plant can produce up to 200 bulbils in a growing season. A persistent underground tuber is also sometimes produced, limiting the success of traditional herbicides. The vines die in winter but resprout or produce new plants from fallen bulbils in spring. *Dioscorea bulbifera* was introduced as an ornamental in 1905 (Nehrling, 1944). By the 1980s, air

Figure 14: Herbaceous vines of air potato. (Courtesy of J. Lotz, FDACS).

potato was recognized as a problem plant for several Florida habitats in South and Central Florida, where it produced a dense overstory, shading trees and native herbaceous plants, covering fences and invading disturbed areas (Bell and Taylor, 1982). This species spreads rapidly, especially after storms, and by 2023 had extended its range to 59 of Florida's 67 counties, from the extreme northwestern corner to the Florida Keys (ISB, 2023b). USDA researchers discovered a potential biocontrol agent in Nepal in 2002, later found again in China. USDA subsequently conducted host range testing at their Invasive Plant Research Laboratory in Fort Lauderdale, Florida, on the species eventually identified as *Lilioceris cheni* Gressitt and Kimoto (Insecta: Coleoptera: Chrysomelidae: Criocerinae), also known as the air potato leaf beetle (Pemberton and Witkus, 2010). FDACS-DPI, USDA, and the University of Florida (UF) mass-reared this skeletonizing leaf beetle for release throughout the state. FDACS-DPI distributes the beetle, uses a georeferenced database to keep track of release locations, and follows up with observations of damage to air potato infestations. In the first six years of the program, over 600,000 beetles were released (Kraus *et al.*, 2022). The air potato leaf beetle has significantly reduced the size and number of bulbils produced by damaged vines and, therefore, the number of vegetative propagules. A bulbil-feeding beetle [*Lillioceris egena* (Weis)] was approved for release in 2021. These beetles are also being mass-reared and released. The two beetles working in conjunction should further reduce the air potato vine to manageable levels (Rayamajhi and Dray, Jr., 2022).

*Solanum viarum* Dunal (Solanaceae) or tropical soda apple (Fig. 15), a small shrub found in dense patches in pastures and natural areas, provides another example of the utility of biocontrol for managing invasive plants. *Solanum viarum* was first documented in Florida in 1988 with a herbarium specimen, likely having arrived earlier as an accidental contaminant in other plant material (Simberloff *et al.*, 1997). By 1993, this species was recognized as a problem for Florida

Figure 15: A tropical soda apple bush bearing fruits resembling apples. (Courtesy of J. Lotz, FDACS).

agriculture and was found on over 150,000 acres of ranchland, pastures, and natural areas (Coile, 1993). By 2023, the species had been documented in 53 of Florida's 67 counties (ISB, 2023e), but it has been primarily a problem for cattle and cattle ranchers. The plants form dense thickets that reduce available grazing area (the leaves are not appetizing for cattle) and hinder the movement of cattle to better food sources, resulting in increased costs to cattle producers (Diaz *et al.*, 2014). Because of this direct cost to agriculture, FDACS-DPI invited a group of interested parties, including staff from the USDA and UF, as well as land managers and cattle owners and eventually the Florida Department of Environmental Protection, the Florida Fish and Game Commission, and other concerned groups, to develop a strategy to control this new pest plant. The recommendations included herbicides and research on biocontrol organisms (Diaz *et al.*, 2014). The pursuit of natural enemies in the plant's in its native range began soon after (Medal *et al.*, 1996). This research and the invaluable assistance of South American collaborators led to the identification of several potential control agents, but host range testing eliminated candidates other than *Gratiana boliviana* Spaeth (Coleoptera: Chrysomelidae), the tropical soda apple beetle. FDACS-DPI, along with UF and USDA, engaged in the mass rearing of this beetle on plants grown in screen houses, and in 2003, releases began. These releases were led by FDACS-DPI and involved the cooperation of public and private property owners, UF, county extension services, Florida Forest Service, Florida Wildlife Conservation Commission, and several water management districts, to name just a few of the stakeholders. To facilitate coordination and communication among partners, a database of release information was maintained from 2003–2011 (Diaz *et al.*, 2014). The records in this database document 250,723 insects released in Florida, with smaller additional releases in neighboring states. Studies of pastures after the releases began found that *G. boliviana* reduced the

Figure 16: Twigs of Brazilian pepper with leaves and bunch of berries. (Courtesy of F. & T. Starr).

area covered by *S. viarum* significantly in less than one year. In areas where the plants were not completely eliminated, their numbers were drastically reduced, and a combination of herbicides and mowing on remaining vegetation was effective at a lower management cost (Overholt *et al.*, 2010).

*Schinus terebinthifolia* Raddi (Anacardiaceae) (Fig. 16), or Brazilian pepper, is a shrub or small tree growing up to 45 ft (13.7 m) tall. The shrubby plant has multiple stems, and a dense tangle of branches form its canopy. As the species spreads, it forms dense, woody thickets in natural areas, pastures, and along roadways. *Schinus terebinthifolia* can cause dermatitis, respiratory inflammation, or intestinal distress for sensitive individuals, but the major impact of this plant is the loss of habitat for native species (Morton, 1978). Although the plant was introduced as an ornamental in the 1890s, it was recognized as an invasive species in the 1970s (Morton, 1976; Simberloff *et al.*, 1997). Although initially appearing only in southern and central areas of Florida, the species now persists in 39 counties, as far north as Nassau County, on the Atlantic coast bordering Georgia, and Franklin County on the northern Gulf Coast (ISB, 2023d). In 2007, a potential biocontrol agent, *Pseudophilothrips ichini* (Hood) (Insecta: Thysanoptera: Phlaeothripidae), also known as Brazilian peppertree thrips, was collected in the native range of the invasive species in the state of Minas Gerais, in southeastern Brazil (Williams *et al.*, 2005). Mass rearing of the thrips began at USDA, UF, and FDACS-DPI laboratories. These thrips are now being released across Florida. Research is continuing to explore the successful establishment of the insect in Florida and to determine its impact on weed populations (Wheeler *et al.*, 2017). Between 2019 and 2021, over two million thrips were released (Wheeler *et al.*, 2022) with the goal of providing a safe, effective, low-cost method of controlling the spread of the invasive Brazilian pepper. In addition, FDACS-DPI is working on establishing colonies of a second biological control agent, the Brazilian pep-

Figure 17: Vines of Chinese creeper with inflorescences. (Courtesy of J. Lotz, FDACS).

pertree leaf-galler, *Calophya latiforceps* Burckhardt, that has been approved for release. These leaf-gallers will be mass-reared and released throughout Florida.

*Mikania micrantha* Kunth (Compositae/Asteraceae) (Fig. 17), bittervine, Chinese creeper, or mile-a-minute vine, has long been listed as a federal noxious weed because of its profound impact on agriculture in the Old World tropics, especially tea, oil palm, coconut, cacao, and coffee plantations. The aggressively growing vine creates a dense blanket of vegetation above other plants to block the sunlight and limit their growth. The vine can also invade natural areas with similar consequences for native trees and understory plants (Holm *et al.*, 1977; IUCN, 2023). The seeds are wind dispersed and potentially spread through the movement of seeds of crops, worker clothing, and agricultural equipment. This species was observed in Homestead, Florida, on November 23, 2009, by the Institute for Regional Conservation staff and was documented for the first time in the state (Weaver and Dixon, 2010). In contrast to other examples of weed control projects at FDACS-DPI, the outbreak of *M. micrantha* provides an example of the utility of early detection and rapid response in controlling new invaders. The vine was found in and around abandoned plant nurseries, nearby woodlots, and roadsides. Many nurseries were abandoned due to an economic downturn and remained unoccupied until the financial conditions of owners improved. Fortunately, efforts to extirpate the vines by mechanical and chemical means limited the spread of the species beyond the Homestead area (ISB, 2023c). Surveys to detect, monitor and remove this weedy vine were carried out by FDACS-DPI in collaboration with the USDA, local volunteer organizations such as the Everglades Cooperative Invasive Species Management Area (ECISMA), and the Cooperative Agricultural Pest Survey (CAPS) (Derksen *et al.*, 2010). CAPS is a collaborative program, begun in 1992, between FDACS-DPI and the USDA, focused on early detection of plant pests within the state, but also working with the USDA and US Customs and Border Protection (CBP) to find and shut down pathways for the introduction of pests beyond the borders of Florida (USDA-APHIS, 2023). By 2013, monitoring and removal of plants had been delegated to voluntary organizations, and FDACS-DPI nursery inspectors regularly carried out surveillance of nurseries. The majority of the infested nurseries were no longer abandoned and were cleaned and maintained by the owners (Derksen and Dozier, 2014).

## 4 Concluding remarks

Analyzing the results of some of the regulatory programs listed above provides evidence of the magnitude of financial resources, specialized personnel, equipment, and facilities needed to protect Florida agriculture from exotic damaging organisms. The results of implementing these programs indicate that eradication is attainable for certain organisms such as fruit flies, other arthropods, and snails. However, eradicating fruit flies can only be maintained with a concomitant and costly monitoring system using traps and baits. Monitoring and educational programs are essential to avoid reintroducing GAS and other invasive pests by uninformed travelers who can transport exotic organisms from abroad. Without early detection, established funding sources, and clear eradication strategies already in place prior to an outbreak, eradication programs of exotic pests would not be successful. In cases where eradication is not possible, these pests can be effectively contained if established procedures are in place before their introduction. Commitment, dedication, persistence, and endurance are essential in implementing these programs. However, the support and involvement of the farmers and growers play a pivotal and crucial role in the success of any phytosanitary program.

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