Terrestial Invasive Plant Management in Florida

The Upland Invasive Exotic Plant Management Program 1997-2017

Preface

People often incorrectly use the word "invasive" interchangeably with nonnative, nonindigenous, or exotic species. However, most nonnative plant species in Florida have not proven to be invasive species, which are those that have spread sufficiently to cause damage to native habitat and species, the economy, or human health. In fact, many nonnative species—including all crop plants—are beneficial, while others—such as most ornamental plants—are harmless amenities. Most commercialized plant species require a level of care and maintenance that would be lacking in nature. Thus, even among plants that escape cultivation, the rate of establishment is low.

On the other hand, there are the estimated 5 to 10 percent of nonnative plants that become invaders, causing serious widespread problems that can prove exceedingly costly to deal with. Invasive species can devastate farms and forests, impede navigation and flow of waterways, degrade lakes and ponds, affect human health, and overtake natural areas and replace native species.Once invasive plants become established in native habitats, eradication is difficult, if not impossible to achieve; therefore, continuous management is needed to sustain wildlife habitat, recreational opportunities, and native plant communities on public conservation land.

The Invasive Plant Management Section (IPMS) is the designated lead agency responsible for coordinating and funding the control of invasive plants in public waterways and on public conservation land. Florida's aquatic plant management activities began in the late 1890s. With the addition of terrestrial plant control in the 1990s, IPMS oversees the largest and most successful invasive plant management effort in the United States.

Invasive plants infested 15 percent of public conservation land at the end of 2017, with levels of infestation ranging between <1% to nearly 100%. However, 47% (705,175 acres) of this area is currently under maintenance control (defined as being maintained at the lowest feasible level). To achieve this success, IPMS expended $175 million over 20 years to conduct operations on 700 federal, state, and local natural areas that comprise over 10 million acres, or ninety percent of all conservation land in the state.

The Florida Fish and Wildlife Conservation Commission (FWC) is legislatively directed to provide oversight and coordination of invasive plant control in the state. The Upland Invasive Exotic Plant Management ("Uplands") Program, a subsection of IPMS, conducts terrestrial operations. The purpose of this report is to provide an overview of the first twenty years of the Uplands Program, 1997-2017.

Invasive plant control is typically performed by private vegetation management companies under contract to to the state. A typical crew consists of one supervisor and eight workers.

28 February, 2020. Ruark L. Cleary, Invasion Biologist, Tallahassee, Florida.

Acknowlegements

Preparation of this report would not have been possible without the assistance of staff from Florida's public land management agencies: Florida Forest Service, Florida Park Service, Florida Fish and Wildlife Conservation Commission, National Park Service, U.S. Fish and Wildlife Service, U.S. Forest Service, South Florida Water Management District, and several county and city natural resource management departments.

The Florida Natural Areas Inventory under contract with IPMS provided historical information on public conservation lands included in this report. The South Florida Water Management District reviewed and provided figures for the Melaleuca Program section. IPMS staff reviewed various sections.

The success of the Uplands Program would not have been possible without the tireless dedication of public conservation land managers and their commitment to protecting Florida's biological diversity, maintaining wildlife habitat, and providing for the use and enjoyment of the state's natural areas by current and future generations.

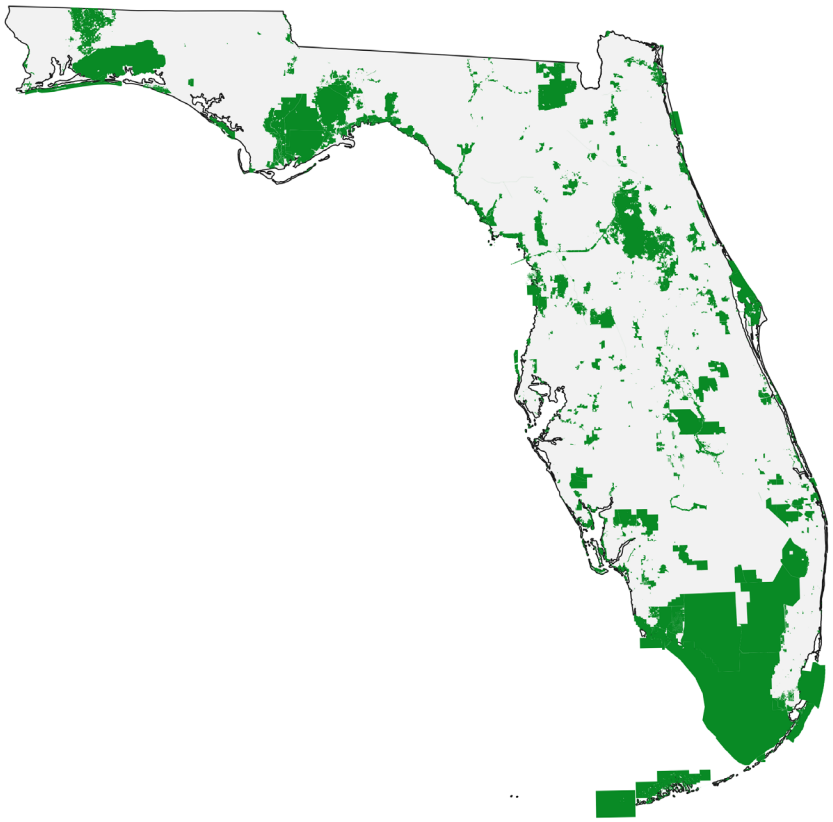

Figure 1. Conservation lands in Florida where invasive plant management has been conducted.

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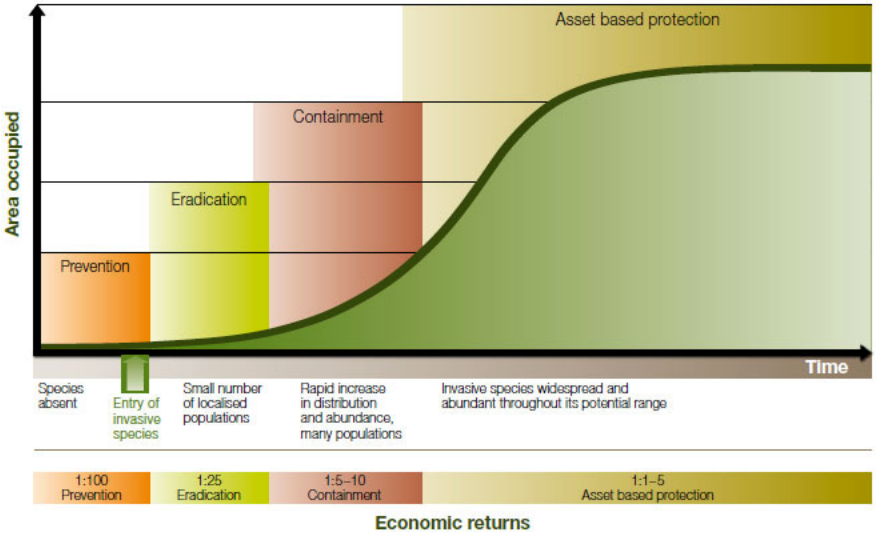


The Invasion Curve (Austrailian version).

The best, cheapest, most effective way to manage invasive species is to not let them into the country in the first place. Billions and billions of dollars later, many have still not learned this lesson.

Introduction

The State of Florida covers 42 million surface acres, of which 34 million acres are land and 11 million of those acres are in public ownership for natural resource protection. Over 1.5 million acres (or 15%) of conservation land has been invaded by nonnative (exotic, alien, nonindigenous) plants such as cogon grass (Imperata cylindrica), melaleuca (Melaleuca quinquenervia), Brazilian pepper (Schinus terebinthifolia), Old World climbing fern (Lygodium microphyllum), and Japanese climbing fern (L. japonicum). However, invasive plants respect no boundaries and millions of acres of agricultural and private land have also been affected. Florida's public conservation land supports a nature-based tourism economy valued at $10 billion annually (total tourism spending in 2015 equaled $89 billion). While South Florida has been hardest hit by this invasion of exotic species, the problem is statewide in scope.

Some invaders change the composition, structure, or processes of native plant and animal communities. One easily observed example is when a plant forms a dense one-species stand (monoculture) where once there was a rich assembly of native species, resulting in a loss of biodiversity. Populations of Florida's rarest plants have been lost in this fashion. Other invaders modify habitat processes by changing water flow regimes or by increasing fire frequency in habitats not adapted to fire. Once invasive plants become established in native habitats, eradication is difficult, if not impossible, to achieve. Thus, continuous maintenance is needed to sustain wildlife habitat and recreational opportunities, while preserving native plant communities.

The 1997 Florida Legislature charged the Invasive Plant Management Section with the task of creating a program to bring invasive exotic upland plant species under maintenance control. A maintenance control program, as defined in Section 369.22, Florida Statutes, is "a method for the control of exotic plants in which control techniques are utilized in a coordinated manner on a continuous basis in order to maintain the plant population at the lowest feasible level." The Upland Invasive Exotic Plant Management ("Uplands") Program was established that same year.

After first conducting an assessment of the current problems caused by invasive plants and identifying the highest priority invasive species that needed to be managed, the Uplands Program then developed a comprehensive interagency control strategy. The 2001 Uplands Program Strategic Plan set forth specific strategies to implement the program's long-term goal, including:

- Implement an integrated program that uses chemical, mechanical, and biocontrol technologies. Modify procedures as appropriate to assure the greatest protection for natural systems;
- Improve general public awareness of the threat to biodiversity from invasive plants by developing a comprehensive education and outreach program;
- Inventory and map with GIS the distribution of invasive exotic plant species; and,
- Research the use of biocontrol agents and provide procedures and facilities for their cultivation, dissemination, and evaluation including monitoring and field assessments.

To implement its statewide cooperative strategy, the Uplands Program divided the state into Regional Invasive Plant Working Groups (Figure 2). Each working group brings together stakeholders in a geographic area for the purpose

of combining expertise, energy, and resources to deal with common weed problems. The expertise within the working groups is relied upon to set regional control priorities based upon severity and potential threat to existing public conservation lands. This is accomplished by the working groups reviewing and ranking project proposals. The eleven working groups are made up of over 500 members representing federal, state, and local government conservation land managers, non-governmental organizations, and private landowners across the state. A liaison is designated for each working group to facilitate proposal review and coordination with Uplands Program staff. A workplan is then created to fund priority plant removal projects for each working group, moving from higher to lower ranking as funding allows.

The Uplands Program melds these regional priorities into a comprehensive integrated process that incorporates broad and consistent strategies, reduces agency inconsistencies, and takes into account differing agency mandates to achieve the goal of controlling invasive plant species. The program provides the needed support infrastructure (i.e., control methods, research, public education, oversight, and funding) to conduct an efficient and cost-effective statewide control program. The program is not only applicable to and coordinated with other state and federal efforts to manage invasive species, but it has also been used as a model by other states and countries. In 2007, its tenth-year anniversery, the Uplands Program was recognized by the U. S. Department of the Interior with its Cooperative Conservation Award.

The initial ten-year (2001-2010) plan succeeded on all counts, but also demonstrated that the same strategies would need to continue in perpetuity; or, at least until Florida no longer has an invasive plant problem. The long-term program goal is to reduce infestations of upland invasive exotic plants on public lands to 50% by 2025, based upon an estimated 1995 level of 1.5 million acres. In 2017, initial control operations reached a cumulative total of 47% of the affected area, putting the program goal well within reach.

Funding for the Uplands Program derives from the Land Acquisition Trust Fund, as set forth in Section 369.252(4), Florida Statutes, which reads: "A minimum of 20 percent of the amount appropriated by the Legislature for invasive plant control from the Land Acquisition Trust Fund shall be used for the purpose of controlling nonnative, upland, invasive plant species on public lands." During its first 20 years of operation, the Uplands Program spent $175 million on 2,791 invasive plant control operations and herbicide purchases targeting 3,116,595 acres of conservation land. The program has assisted land managers on nearly 700 federal, state, county, and city natural areas that comprise over 10 million acres. Cooperating agencies contributed $55 million in matching funds toward these projects. Another $12 million was spent on invasive plant surveys, research, outreach, and other program support activities. Invasive plants infested fifteen percent of public conservation land statewide as of 2017. Nearly fifty percent (705,175 acres) of the affected area is currently under maintenance control.

Although the Uplands Program is housed within the FWC, the program directs significant staff and monetary resources to controlling invasive plants on land managed by other public agencies. During the twenty years from 1997 to 2017, IPMS spent the following for management of terrestrial invasive exotic plants on public conservation land:

MANAGER	COST	ACRES[1]
Cities	$3,793,074	12,854
Counties	$31,051,599	206,589
Local Total	**$34,844,673**	**219,443**
DEP[2]	$1,568,523	12,726
FFS	$10,426,881	252,836
FPS	$31,478,115	309,340
FWC[3]	$20,636,691	621,408
Universities[4]	$498,408	1,115
WMD[5]	$34,181,841	864,271
State Total	**$98,790,459**	**2,061,696**
DOD[6]	$2,198,311	11,602
NPS	$10,460,297	238,109
USDA[7]	$43,915	28
USFS[8]	$1,241,804	10,527
USFWS[9]	$23,283,498	267,013
Federal Total	**$37,227,825**	**527,279**
Grand Total	**$170,862,957**	**2,808,418**

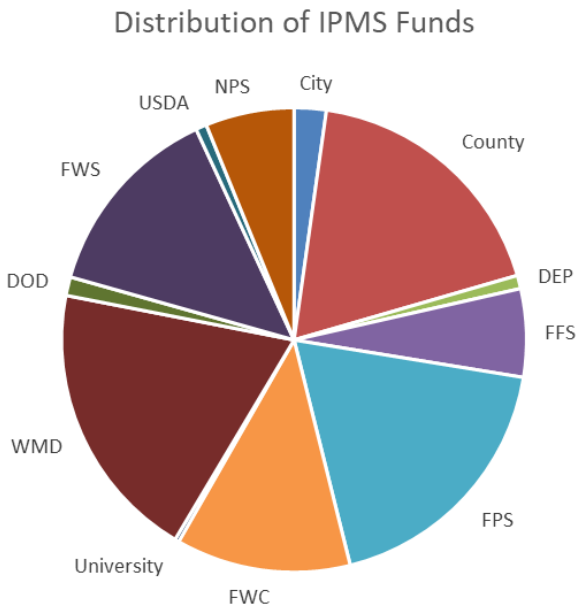


Figure 2. The distribution of funding across managing agencies. Costs are for control operations only, generally contracted at a price-per-acre. No salaries, administrative overhead, or other program support costs are included.

[1] Total cumulative acres for all projects on agency PCL, including initial and maintenance control. Initial control occurs once, but maintenance control is forever. Thus, cumulative project acres for any individual PCL may exceed acres of ownership.

[2] Department of Environmental Protection, other than the Division of Recreation and Parks (Florida Park Service). Includes Bureau of Mine Reclamation and Florida Coastal Office managed areas.

[3] Wildlife Management Areas, Wildlife Environmental Areas, and Public Small Game Hunting Areas; primarily assisting with herbicide for operations. The Wildlife Habitat Management Section has its own funding for invasive plant management on FWC managed land.

[4] Conservation lands managed by Florida's state universities.

[5] Florida's Water Management Districts (WMD), including the annual one-million-dollar Melaleuca Program.

[6] The US Department of Defense, conservation land managed on military installations.

[7] The US Department of Agriculture, other than the Forest Service; in this case, two of their research stations.

[8] The US Department of Agriculture, Forest Service; Apalachicola and Ocala National Forests.

[9] The US Department of the Interior, Fish and Wildlife Service; National Wildlife Refuges, including Loxahatchee NWR (aka WCA 1). This refuge is managed by the US Fish & Wildlife Service, except for invasive plant management. The South Florida WMD owns this property and manages invasive plants with cooperative funding from FWC and FWS.

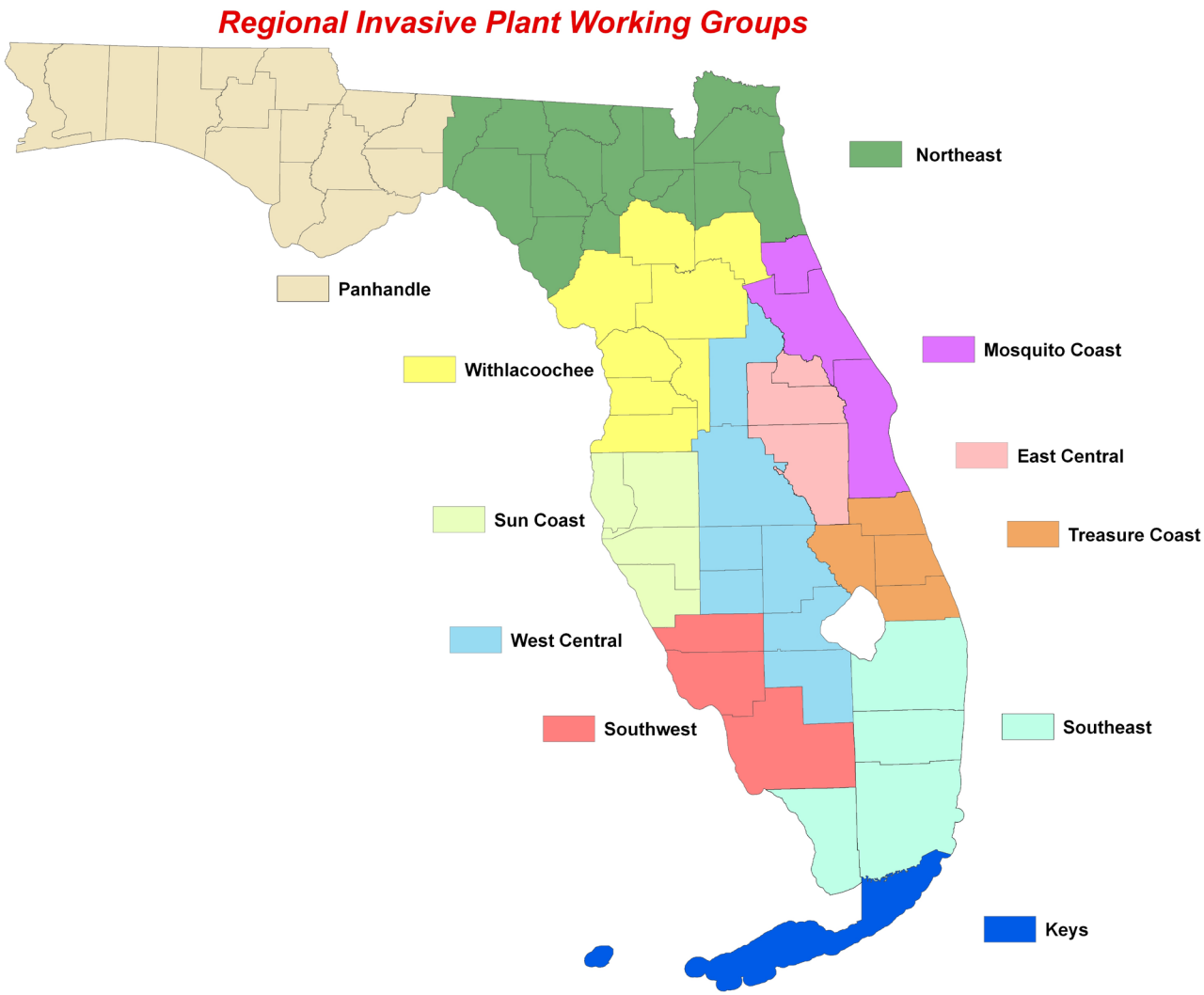


Figure 3. The Eleven Regional Invasive Plant Working Groups

Florida lies in three climatic zones, tropical, sub-tropical, and temperate, and thus possesses a wide array of natural communities. Unfortunately, invasive exotic plants have found their way into every natural habitat from coastal beach dunes to interior pine flatwoods (left pictures). Fortunately, the Uplands Program can control invaders wherever they are found (right pictures).

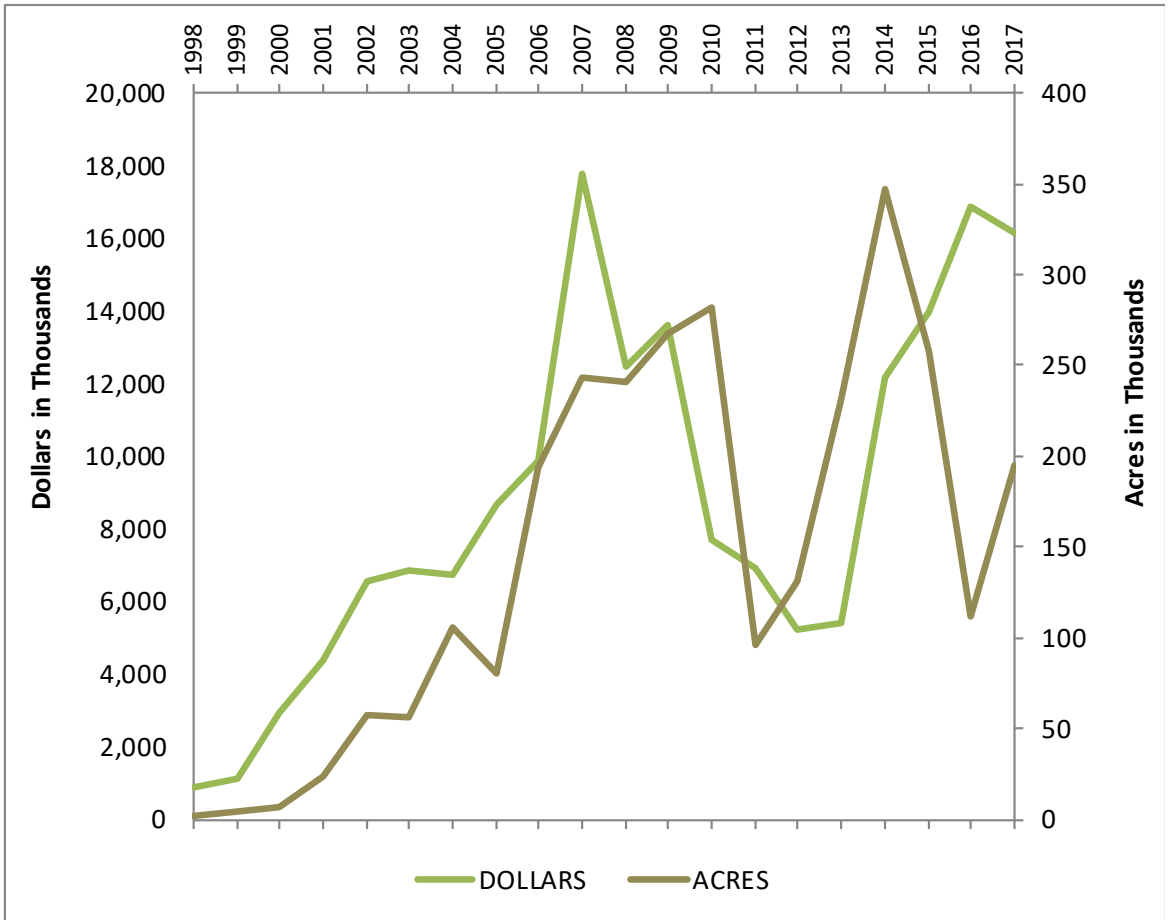


Figure 4. The relationship between dollars spent and acres of invasive plants treated—not quite 1:1, but the trend is obvious. The sharp drop in the 2010s reflects the effect of the Great Recession.

Invasive plant control methods include herbicides, biological controls, manual (hand-pulling), mechanical (heavy equipment), and physical (fire, water level manipulation) methods, used separately or in combination. Herbicides are pesticides designed to kill certain plants, without affecting fish and wildlife. They are a vital component of most control programs and are used for invasive plant management on waterbodies and natural areas, and extensively in agriculture. Herbicides are target-specific and are much safer to use than pesticides intended for insects or other animals. Herbicide application methods include:

Foliar. Herbicide is applied to the plant with aerial or ground based equipment. Foliar applications can be either directed or broadcast. Broadcast applications are used when damage to non-target vegetation is a minimal concern or when a selective herbicide is used.

Basal bark. Herbicide is applied directly to the bark around the circumference of the tree up to fifteen inches above the ground. The herbicide is absorbed by the plant through the bark.

Frill, girdle, or hack-and-squirt. Cuts are made into the cambium around the circumference of the tree. Herbicide is then applied to each cut.

Cut stump. After cutting and removing large trees or brush, herbicide is sprayed or painted onto the cut surface. The herbicide is usually applied only to the cambium layer on large stumps.

basal bark application

Mechanical control involves the use of a bulldozer, Brontosaurus mower, Hydroaxe, or other specialized logging equipment to remove woody plants, and mowing or discing of grasses. Followup with other control methods is essential after the use of heavy equipment because ground disturbance creates favorable conditions for regrowth from seeds and root fragments, and recolonization by other invasive nonnative plants. Mechanical removal may not be appropriate in natural areas because of disturbance to soils and non-target vegetation. However, it may be the most cost-effective way to remove dense monocultures of species such as Brazilian pepper and Australian pine.

girdle treatment

Many plants are prevented from becoming serious weeds in their native range by a complex assortment of diseases, insects, and other herbivorous organisms. When a plant is brought into a new environment with favorable growing conditions, the absence of these regulating species may allow non-native plants to become serious weeds. Classical biological control seeks to locate insects from a plant's native range and import host-specific species to attack and control the plant in regions where it has become a weed. This approach has a proven safety record and has been effective in controlling a number of weeds around the world.

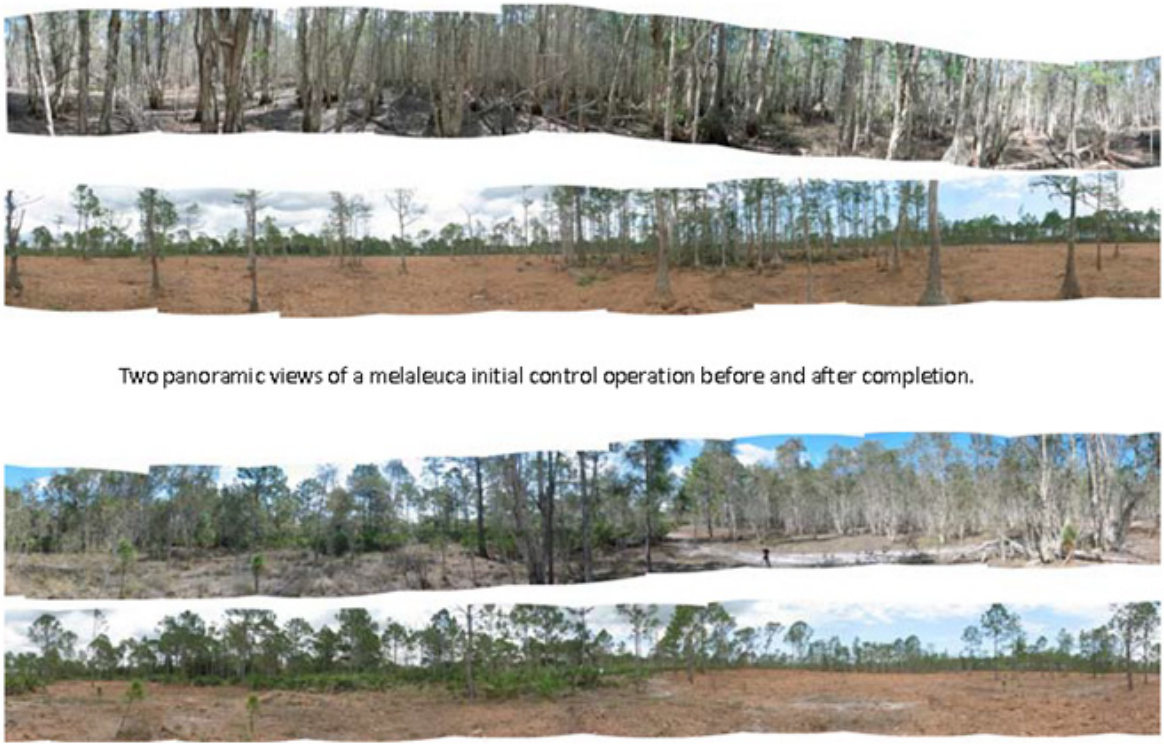
Brontosaurus mower

Prescribed burning and water level manipulation are cultural practices that are used in management of pastures, rangeland, and commercial forests, and, in some situations, may be appropriate for vegetation management on natural areas. Some species, such as melaleuca and cogon grass, respond positively to fire, so prescribed burning, if used, must be coupled with another control method.

melaleuca weevil

Left: The large mower head is able to quickly reduce monocultures of Brazilian pepper to mulch (background).

Right: A lone(?) melaleuca tree encroaches into an Everglades sawgrass marsh. Alligators are adapted to marshes and open water, but not to an impenetrable melaleuca forest.



Two panoramic views of a melaleuca initial control operation before and after completion.

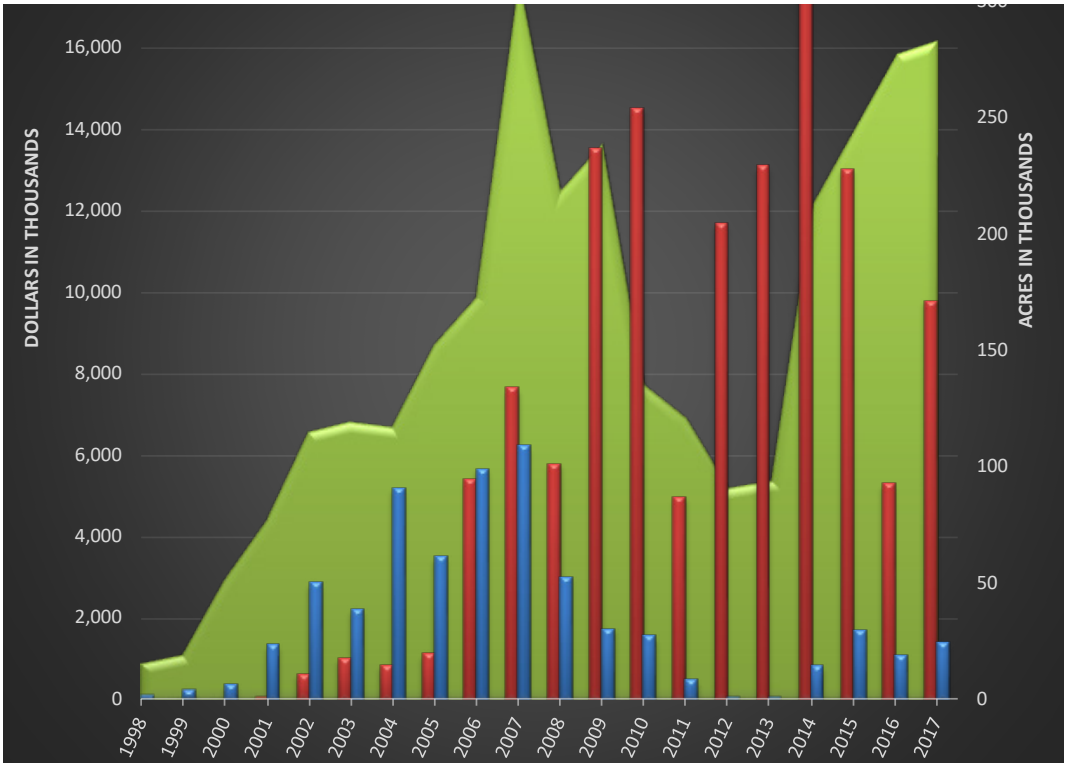


Figure 5. Acres treated for the first time (initial) versus subsequent retreatments (maintenance). The initial investment is high, but as more areas achieve a maintenance level, the per-acre costs drop significantly.

Old World climbing fern at Jonathan Dickinson State Park prior to (above) and after initial treatment (below). Subsequent retreatments were required to bring this area under maintenace control, but the dramatic difference shown here illustrates why future costs can decline so significantly. Credit: Florida Park Service

The Melaleuca Program

Introduction—*Melaleuca quinquenervia* is a tall (15-21 meters) evergreen tree that occurs naturally throughout eastern Australia, New Caledonia, Irian Jaya and southern New Guinea. In North America, it is classed as a Federal Noxious Weed in the United States and as a Prohibited Aquatic Plant and Noxious Weed in the state of Florida. Melaleuca was first offered for sale in Florida in 1887 by Royal Palm Nurseries in Manatee County, where it was sold from 1887 to1889 and 1913 to 1933. Over the next forty years, at least ten more introductions occurred in Florida from botanical gardens in France, Italy, and Australia. Because it was believed to suck up a great deal of water, it was planted in the early years of the century as part of a scheme to dry up the Everglades, in hopes they would become developable and mosquito-free. In 1912, twenty-five years after Royal Palm Nursery began selling melaleuca, A. H. Andrews with the Koreshan Unity introduced the plant in Lee County. The Koreshan introduction probably resulted in most of the infestations on the lower gulf coast of Florida. In 1936, to hasten its spread, H. Stirling collected melaleuca seeds and spread them by airplane in the eastern Everglades. The populations south of Lake Okeechobee were started in 1941 when trees were planted on levees and spoil islands for soil stabilization by the US Army Corps of Engineers. From these limited plantings, melaleuca spread into many thousands of acres of marsh within the lake. For years afterwards, melaleuca was commonly used as ornamental landscape trees, agricultural windbreaks and fencerows, and for erosion control along canals.

The South Florida Water Management District (SFWMD or District) has been actively engaged in controlling nuisance vegetation in the Everglades Protection Area since the canal and levees were constructed in the early 1950s. In 1972, the Florida Conservation Foundation published in its monthly newsletter several paragraph regarding the invasion of three exotic trees into Florida: melaleuca, Australian pine and Brazilian pepper. In 1975, two public interagency workshops, sponsored by the then Florida Game and Fresh Water Fish Commission, were held to determine ways to control melaleuca in South Florida. Continuation of these workshops led to the formation of the Exotic Pest Plant Council in 1984, and the Melaleuca Task force in 1990. The District first implemented melaleuca control strategies in the southeast corner of WCA-3B in 1990.

Program Expenditures—Funding for melaleuca control is derived from several sources. In the years between 1991 to 2001, $21,862,794 was budgeted to fight melaleuca infestations. Approximately $12,762,794 (58%) of this amount came from non-district sources. Early limited funding included the Florida Power and Light mitigation funds ($1.5 million), the Surface Water Improvement and Management fund ($1.5 million), and the US Army Corps of Engineers ($612,794). In 1993, the Florida Legislature (Section 206.606, Florida Statutes) authorized an annual appropriation of $1 million to the Department of Environmental Protection (DEP) for the specific purpose of melaleuca control. The then Bureau of Invasive Plant Management (BIPM) initiated a 50:50 cost-sharing program with the District.

Originally, the funding was administered by the BIPM Aquatic Plant Management Program. Control was switched to the Upland Exotic Invasive Plant Management ("Uplands") Program, after its creation in 1997, and the cost-share was then referred to as the "Melaleuca Program." In every fiscal year from 1998 to 2017, the Uplands Program funded Melaleuca Program projects—a

total of 32 projects over 20 years, totaling nearly 800,000 acres. Both initial and maintenance control operations were conducted on national, state, and county parks, state forests, wildlife management areas, and District property. In total, $28,223,709 was reimbursed to the SFWMD, which the District matched with $21,618,710 of its own funding.

Melaleuca Management—Melaleuca became a target of invasive plant control in the 1980s. The National Park Service treated 90,717 acres of melaleuca on Everglades National Park during 1986 to 1998 and 71,000 acres on Big Cypress National Preserve from 1984 to 1997. The US Fish and Wildlife Service treated 8,095 acres of melaleuca on Loxahatchee National Wildlife Refuge prior to 1987 and 6,755 acres from 1987 to 1998. The SFWMD pioneered the aerial treatment of melaleuca by helicopter in the 1990s. During 1994 to 1998, the District aerially treated 3,813 acres of Lake Okeechobee, 1,643 acres of WCAs (1995-1997), and 1,322 acres of the Pennsuco Mitigation Area. On areas that are aerially treated, ground crews are used for follow-up and maintenance control. With aerial treatment, large areas can be treated for relatively little cost. Ground control, on the other hand, can cost three to ten times more than aerial treatment, depending upon the size and density of the trees, ease of access to the site, and labor and machinery costs.

In the 1990s, the estimated coverage of melaleuca was 500,000 acres, with fifty percent on public conservation lands. In 2005, twenty-five percent of melaleuca was on these lands—a decrease of over 125,000 acres through Florida's dedicated funding for melaleuca control. Mature melaleuca trees have been completely cleared from Everglades Water Conservation Areas 2A, 3A, and 3B, north to south of Alligator Alley. These areas are now under long-term maintenance control. As of 2017, the melaleuca infestation is either under or is approaching maintenance control on most public land. On private land, melaleuca still runs rampant, which raises a concern for potential re-infestation.

Management Strategy—An effective, integrated management of melaleuca requires a combination of control techniques; chemical, mechanical, and biological. In 1990, the SFWMD and the Florida Exotic Pest Plant Council convened a Melaleuca Task Force, which later that year published the first edition of the Melaleuca Management Plan. The plan is periodically updated to reflect changes in management philosophy and operational advancements. The Areawide Management and Evaluation (TAME) Melaleuca project is a pest management program designed to promote long-term, biologically based management of melaleuca in south Florida. Through partnerships with public agencies and private land managers, the goal is to demonstrate the effectiveness of an Integrated Pest Management (IPM) approach for controlling melaleuca. The University of Florida's Institute of Food and Agricultural Sciences (IFAS) maintains the TAME Melaleuca website at https://tame.ifas.ufl.edu/tame_project/index.shtml.

Melaleuca management also requires knowledge of its reproductive biology. A mature tree may retain millions of seeds, all of which may be released from their protective capsules following a stressful event such as drought, fire, physical damage, or herbicide application. A single tree, when stressed, may release as many as 20 million seeds at one time. Once released, fifteen to twenty percent of the seeds will germinate. New trees take approximately three years to mature and produce viable seeds. Follow-up treatment within the third year after the initial treatment is essential to eliminate seedlings before they can produce viable seeds.

The District's control operations consist of three phases:

Phase I. Initial treatment of all mature trees and seedlings present in a defined management unit. The strategy for initial treatment is based upon the quarantine strategy, where isolated, mature, seed-bearing trees areas (outliers) are targeted first, in order to stop the expansion of the existing population, and then progressively eliminating trees towards the source of the infestation.

Phase II. Using GPS equipment, crews revisit previously treated units for follow-up treatment to control trees previously missed and remove seedlings that may have resulted from control activities of the preceding year. Several successive retreatments may be needed to achieve a maintenance control level for a unit.

Phase III. Long-term management of melaleuca requires aerial surveillance and ground inspection of previously treated sites to monitor the effectiveness of control. Once maintenance control has been established on a management unit, the unit is added to a treatment rotation schedule to keep re-infestation levels as low as feasible by preventing seed production.

The District's efforts in developing melaleuca control methods have concentrated on herbicidal control and the limited use of mechanical and physical control methodologies. The strategy for managing melaleuca is modified, as control methodologies improve, to increase efficacy and cost effectiveness. Herbicide (e.g., glyphosate, imazapyr, triclopyr) application by frill-and-girdle, cut stump, or foliar method is used by ground crews to control mature trees, saplings, and seedlings, as appropriate. Aerial application of herbicide (e.g., hexazinone, glyphosate, imazapyr) is useful for control operations on large areas of melaleuca monocultures, particularly where wildfires have caused a massive sprouting of "doghair" seedlings.

Mechanical removal using heavy equipment is not appropriate in most natural areas because of disturbances to soils and non-target vegetation. However, this method of control can be applied along canal and utility rights-of-way and other similar areas adjacent to infested wetlands. Stumps left after any mechanical operation require herbicide application to prevent root sprouts and re-growth from cut surfaces. Currently, felling trees in place and manual removal of melaleuca seedlings are the only forms of mechanical control being used. Physical controls, i.e., water level manipulation and prescribed fire, have limited utility, but are integrated with other control methods when feasible.

Biological control agents were introduced beginning with the melaleuca weevil (Oxyops vitiosa), which was released in WCA 3B in 1997. The insect is now established within melaleuca populations throughout south Florida. A second insect, a sap-sucking psyllid (Boreioglycaspis melaleucae), was released in 2002. In 2008, the melaleuca gall midge, (Lophodiplosis trifida) was released. These three biocontrol agents are well established and have been observed to severely curtail flowering and new growth of melaleuca.

Regardless of the control method used, a comprehensive data collection and evaluation plan is essential for the success of melaleuca management. Record-keeping is invaluable for making future management decisions. Data collected includes longitude and latitude coordinates, type of control method, type of herbicide and amount applied, herbicide application method, acres/hectares treated, and other operational information. The data are used to produce maps to keep track of progress on management units and entire PCLs.

Conclusion—Florida's 130 year-long melaleuca story illustrates the environmental and economic consequences of allowing aggressive invaders to proliferate for decades without taking management action. Hundreds of thousands of

acres of native habitat have been altered or lost, and the effort to reverse this course is costly. Florida's melaleuca effort (including biological, mechanical, chemical, and physical control) cost over $50 million as of 2017. To place this in perspective, however, DEP estimated in 1999 that failing to act against melaleuca would have cost the state $161 million annually in lost revenue. The high cost of managing this aggressive invader calls attention to two important points. First, aggressive action against newly detected invaders (Early Detection/Rapid Response or EDRR) could save significant public resources and substantially reduce impacts to natural resources. Second, eradication of many long-established, aggressive invaders is virtually impossible. A lasting commitment to maintenance control is the most cost-effective and environmentally responsible approach to managing these species.

The work accomplished to date demonstrates that melaleuca can be effectively and consistently controlled using an integrated management approach. The ultimate control of melaleuca, and other aggressive invaders like Old World climbing fern and Brazilian pepper, throughout the state will depend primarily upon sustained future funding. The magnitude of the threat from invasive species and the cost of control efforts are enormous. However, melaleuca is today under maintenance control in the Water Conservation Areas and in Lake Okeechobee, thus demonstrating that a long-term investment in invasive species management will yield positive returns.

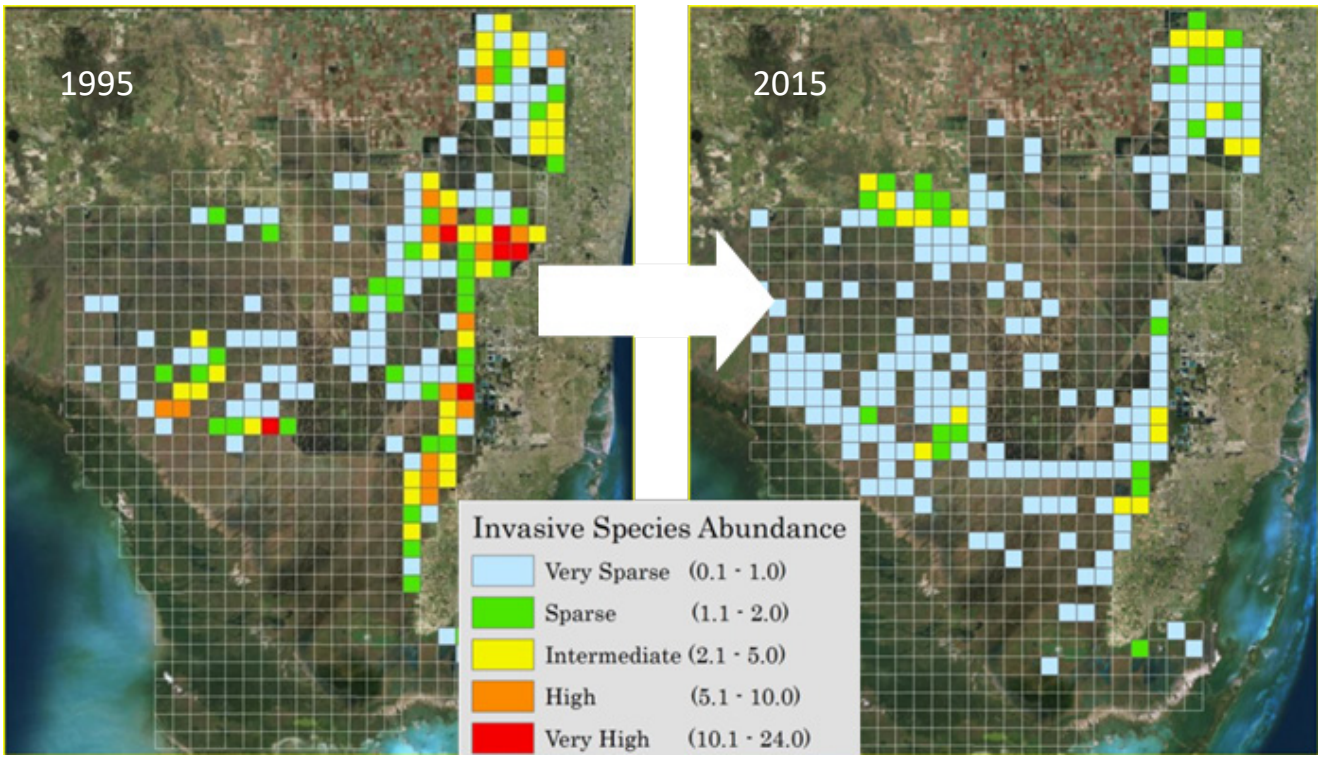


Figure 1. Change in melaleuca densities over twenty years. Source: LeRoy Rodgers, SFWMD

References

Department of Environmental Protection, Bureau of Invasive Plant Management. 2008. The Melaleuca Program, pp. 149-151. *In*: R.L. Cleary. Upland Invasive Exotic Plant Management Program Fiscal Year 2007-2008 Final Program Report. 156 pp.

Laroche, F. B. 1999. Melaleuca management plan: Ten years of successful Melaleuca management in Florida, 1988-98. Florida Exotic Pest Plant Council.

Serbesoff-King, K. 2003. Melaleuca in Florida: A literature review on the taxonomy, distribution, biology, ecology, economic importance and control measures. Journal of Aquatic Plant Management 41:98-112.

South Florida Water Management District. 2003. Long-term Management Case Study: Melaleuca. Invasive Exotic Species Strategic Action Framework. A report to the South Florida Ecosystem Restoration Task Force. 4 pp.

TAME. The Areawide Management and Evaluation of Melaleuca. 2007. A Century of Melaleuca in Florida. USDA-ARS Invasive Plant Research Laboratory, Ft. Lauderdale, Florida.

The Herbicide Bank

From the beginning of the "Herbicide Bank" in 2000, the program has provided chemicals at no charge to public land managers for conducting invasive plant management. Any agency staff responsible for vegetation management activities on public conservation land may use the Herbicide Bank, whether prior invasive plant control operations were funded by the Uplands Program or not. The availability of chemicals each year is affected by annual appropriations, but in any year is mostly restricted to priority herbicides and no adjuvants other than basal oil. Currently eligible chemicals include aquatic and terrestrial labels and amine or ester formulations.

Other agencies in Florida solicit quotes for chemicals; however, the FWC Invitation-To-Bid (ITB) includes language that allows other public agencies the ability to "piggyback" on the contract and access to the awarded pricing. The ITB is a one-year, non-renewable contract. Due to price volatility, vendors are generally not able to get price guarantees for any length of time from chemical manufacturers. A single-year contract is a compromise between vendors and the state fiscal year structure.

Other states and federal agencies would likely benefit from a similar program. While agency purchasing departments vary across regulations and requirements, an ITB should follow a standardized process, regardless of the agency. The most important document prepared for an ITB is the Scope of Work (SOW), which includes a Price Sheet, and states the bid conditions specific to an herbicide solicitation. In FWC, the scope is written by program staff that have knowledge of herbicide chemistry, branded and generic products, treatment methodology, and invasive plant management. The FWC purchasing department creates the ITB package that will be posted to the Florida Vendor Bid System (VBS).

The purchasing department reviews submissions to determine which are "responsive" (whether the vendor actually read and followed the bid requirements). Responsive vendor bid packages and a draft award list are then provided to the Contract Manager for review. Each award is based upon a product and a container size. It is possible that one product could be awarded to three different vendors for three different container sizes (e.g., 2.5, 30, and 250 gallons). This might seem cumbersome, but the smaller the container size, the higher the price. A single per-product

award would be decided by the lowest combined price. This means a vendor could 'low-ball' the largest (and least purchased) size and 'jack up' the smallest (most often purchased) size, to win the award—and experience has demonstrated this occurs. Once review is complete, the "Decision to Award" is posted on the VBS. If the award passes without protest, Purchase Orders can then be written.

For additional cost saving, the Herbicide Bank does not supply a brand name product when an equivalent generic product exists. For some products there are no available generics; however, there may be a suitable alternative chemical (same family or mode of action) that can be used instead. Generic products must be equivalent to an industry standard product; e.g., Garlon® 4, which is a terrestrial triclopyr with 61.6% active ingredient (a.i.). The price sheet lists "triclopyr ester 61.6%" as a generic product. There are several different generic "garlons," any of which a vendor could offer, provided the label reads 61.6% a.i. Vendors must supply labels for every offered generic product with their bid response.

Adjuvants include hundreds of products from antifoamers to water conditioners (not quite A-Z). However, only a few, common, types are bid out and even fewer are provided by the Herbicide Bank. The most used adjuvant is a carrier oil for basal bark treatment of Brazilian pepper and other invasive hardwoods. Basal oil is usually ordered in the 11.25-gallon size, which is simply a partially filled 15-gallon barrel. The reason for this is that a 2.5-gallon jug of triclopyr ester can be poured into the barrel to create an 18% basal treatment mix, which is the current control technology (CCT) for most woody species.

Herbicide Bank recipients use an online Request Form to ask for chemicals. Land managers are encouraged to request a one-year supply to allow for uninterrupted fall and summer treatments. All agency requests for chemicals must be coordinated internally at the highest practical operational level. For example, the Florida Park Service would submit one request for all the parks within District 1. The chemicals are shipped to a single central facility. Vendors deliver orders at their cost (factored into their bid price), so a coordinated delivery system is more cost-efficient for them, which leads to better pricing for the state.

Upon receipt of a delivery, ownership is transferred to the requesting agency, as are inventory and auditing requirements. To ensure that chemicals were used appropriately, a Summary Report must be submitted with or prior to the next Request Form. This report summarizes the use of chemicals for each management unit (park, forest, etc.), including total gallons used, plants treated, and acres treated. The reporting period can cover one to a few years, depending upon staff availability and sufficient equipment, or due to delays caused by wildfires or hurricanes. When properly stored, most products have a shelf-life of several years.

Funding for the Herbicide Bank has varied over the years, but as of 2017 this program provided $13,232,303 of chemicals that were used for initial and maintenance treatment on 775,368 acres. For private contractors, chemicals typically comprise no more than 10% of the total project cost—their major cost is labor. Thus, in comparison, that $13 million of "free" chemicals has saved the Uplands Program ten times that amount in "free" labor. Now that's a bargain!

Research & Outreach

Introduction—The science of invasive plant management is complex. Integrated pest management programs are utilized to control typically one species while causing minimal damage to other native non-target species, in contrast to cropping systems where control of all plants except for crops is the goal. Since beginning in 1970, state funding of invasive aquatic and upland plant research has resulted in a large pool of expertise within Florida's university system and various state and federal agencies. Often this scientific expertise has attracted other sources of research funding that have improved Florida's invasive plant management programs. For example, the management of invasive plants in Florida has been greatly aided by research funded and conducted by the U.S. Army Corps of Engineers and the U.S. Department of Agriculture's Agricultural Research Service (USDA-ARS). However, these research efforts and outside funds have never sufficed to replace state funding. Because of this, the Florida Fish and Wildlife Conservation and Commission (FWC) has continued to make available research funding to universities, and federal and state agencies. During its 50 years as the lead agency for invasive plant research in Florida, IPMS has contracted for 272 completed research projects at a total cost of $32,989,549.

Research at the USDA-ARS lab in Fort Pierce, Florida

History—The original intent of Florida's invasive plant management research program in the 1970s and 1980s was to reduce dependence on aquatic herbicides because of public concern about pesticide use, especially in water. Early research funding targeted biological control methods using insects and plant pathogens on water hyacinths (*Eichhornia crassipes*) and developing sterile grass carp for use on submerged species, such as hydrilla (*Hydrilla verticillata*). Mechanical control and physical control methods, such as fire and water level fluctuation, were also investigated. From 1970 to 1995, the program spent nearly $8.5 million in total for research to support science-based invasive plant management in Florida's aquatic ecosystems, with a strong emphasis on finding effective biological control agents. From 1988 through 1995, the annual legislative allocation for invasive plant management research was approximately $200,000. In 1996-97, an additional $150,000 was allocated for biological control research. Today, approximately $350,000 of the annual research allocation is spent on biological control. An additional $1 million annually was spent on basic research on plant growth requirements, water chemistry, seasonal population dynamics, the environmental impact of invasive plants, and exploration of other control methods. Knowledge gained from this research will continuously improve effective and efficient invasive plant control programs.

The Center for Aquatic and Invasive Plants was established at the University of Florida in 1979 to help lead research efforts in invasive plant management. Besides basic and applied research, the Center developed cooperative programs with state agencies, local governments, and private companies for herbicide applicator training and certification (partnered with the Florida Department of Agriculture and Consumer

Services), as well as producing public outreach materials regarding the benefits of invasive plant management. As partners, FWC and the Center, along with cooperative funding from several sources, have expanded this public awareness program on invasive plants by developing posters, coloring books, identification cards, and lesson plans for public school teachers. An expanded, comprehensive website addressing all phases of invasive plant control in Florida was produced and continues today.

In 1993, the state's invasive plant management program, including research and outreach, was moved from the Department of Natural Resources to the Department of Environmental Protection (DEP). In 1998, with the addition of the state's invasive upland plant management program, research priorities shifted from aquatic species only, to including wetland and terrestrial species. Work began with the search for melaleuca (*Melaleuca quinquenervia;* Figure 2) and Brazilian pepper (*Schinus terebinthifolia*) biological control agents and herbicidal management techniques.

Biological control research on melaleuca has been funded since 1994, on Brazilian pepper since 1999, and on Old World climbing fern (*Lygodium microphyllum*) since 2000. Researchers in 2005 believed that, left unchecked, Old World Climbing fern could become widely established in the Everglades by 2014, exceeding the then current combined coverage of the top five invasive nonindigenous plant species found in South Florida. This prediction proved to be accurate, if not a bit underestimated. In 2008, the program was moved from the DEP to the FWC, where it resides today as the Invasive Plant Management Section (IPMS).

Costs and Benefits—Invasive non-native species are the second (or third) most critical threat to conservation of biodiversity worldwide, in addition to habitat loss and climate change.

Melaleuca capsules and seeds.

Impacts from and control of invasive species also have substantial costs. Over $240 million was spent by public agencies in Florida between 1980 and 2000 to control invasive plants in natural areas and waterways. Agricultural production in Florida is affected by invasive pests (all taxa), with an economic impact of $179 million annually. However, non-native agricultural species also support substantial elements of Florida's economy. Florida agriculture, valued at over $282 billion annually in 2014, relies almost entirely on non-native (but not invasive) species. The horticulture industry is the sixth largest agricultural commodity group in the United States and is the fastest growing sector of agriculture. Florida's horticultural industry was valued at $22.5 billion in 2014; although, while most ornamental plants have not become invasive, the majority of non-native plant species invading the state's natural areas were initially introduced for horticultural purposes.

The substantial benefits and costs associated with non-native species have resulted in conflicts concerning the mechanisms by which plants are categorized and labeled as invasive. One method used for resolving such conflicts was to advance the field of plant risk assessment. The UF Institute of Food and Agricultural Sciences (IFAS) developed the "Assessment of Non-native Plants in Florida's Natural Areas" with support from the IPMS Research and Outreach Program. The

assessment originally focused on species already present in Florida, identifying their current distribution and ecological impact, potential for spread, difficulty of management, and economic value. This tool had broad support from the horticulture industry and the Department of Agriculture and Consumer Services. It has been used to address politically sensitive invasive plant issues in production agriculture, as well as for natural areas management. Further building on this concept through horizon scanning, invasive species in similar climates are assessed to predict which species may become invasive in Florida.

Screening plant species for their potential invasiveness.

An overview of selected research from the 2000s—

1. Seed bank and regeneration ecology for predicting *Scleria lacustris* in Florida wetlands. University of Florida (UF), United States Geological Survey (USGS).

Scleria lacustris (Wright's nutrush) is an introduced sedge of increasing ecological concern to natural resource managers in Florida. Collected first in Brevard County in 1988 and soon after in Lee County, its distribution now extends to more than twenty natural areas and seven counties within four major drainage regions of the central and southern peninsula. Nearly all affected locales are large wetlands either within or hydrologically linked to expansive conservation ecosystems. The seeds of most native wetland sedges do not tolerant desiccation and require moist or inundated conditions for maintained viability. Similarly, for many wetland species, inundation provides release from the dormant state allowing for germination to proceed when water levels become suitable.

S. lacustris has a sprawling growth habit that alters the density and structure of native vegetation, while also obscuring open water habitat. *S. lacustris* appears to recur in seasonally inundated rather than permanently wet natural habitats. Especially prevalent populations seem to follow periods of springtime drought or managed drawdowns; however, consecutive years of drought are linked to much reduced populations. These factors lend to prediction that the incidence of *S. lacustris* might be restricted at both ends of its life cycle, entailing dry down for regeneration and high moisture or inundation following seed shed, conditions that are inherent to seasonal wetlands.

2. Seed ecology, dormancy, and germination of *Colubrina asiatica* (Ramnaceae) in coastal hammocks of south Florida public lands. UF.

Colubrina species endemic to Hawaii have physical dormancy and this trait is associated with many species within the Rhamnaceae family. Natural openings in the seed coat permit entry of water into seeds, and the "unplugging" of these tissues is not a random or haphazard event. The timing of germination in seeds with physical dormancy is environmentally controlled in nature, and consequently, the timing of germination is predictable. Management techniques associated with the removal of *C. asiatica* may inadvertently create those conditions which break physical dormancy and therefore stimulate vigorous germination.

3. Improving herbicide effectiveness for *Lygodium microphyllum* and *L. japonicum* control. UF.

Lygodium microphyllum infesting an Everglades tree island.

Herbicide studies in small containers (mesocosms).

Old World climbing fern (*Lygodium microphyllum*) is one of the worst threats to forested wetlands and coastal prairies in south Florida. In north Florida, Japanese climbing fern (*L. japonicum*) threatens natural areas and lowers productivity in pine plantations. Both species are true ferns and spread by windblown spores that can result in infestations miles from the parent population. Management of both ferns is difficult, given their prolific reproductive capacity (one plant can produce millions of spores), regenerative ability after fire or frond removal, and possible tolerance to some herbicides.

Several herbicides and herbicide combinations have been evaluated for control of both ferns. Currently, glyphosate and triclopyr herbicides have been shown to be the most effective for both species. However, little is known about herbicide movement and uptake in either species. Herbicide translocation research with *L. microphyllum* is presently underway at the UF Center for Aquatic and Invasive Plants.

4. Host range testing of candidate biological control agents of *Lygodium microphyllum* in Australia and host range testing of potential insect agents in the Gainesville Quarantine. USDA-ARS.

Old World climbing fern (*Lygodium microphyllum*) is spreading very rapidly across Florida. Aerial surveys sponsored by the South Florida Water Management District estimated infestations at 39,000 acres in 1997 and then 109,000 acres in same surveyed areas in 1999. There is unquestionably more *L. microphyllum* than these figures indicate because aerial surveys cannot detect small infestations or infestations that are below forest canopies. In 2000, 800 acres of the fern were found in Everglades National Park where none were previously known.

The biological control effort against the fern began in 1998. The focus of the overseas research is at the USDA-ARS Australian Biological Control Lab in Brisbane, Australia. This lab has and is also handling the overseas component of the melaleuca biological control program. FWC funding supported the preliminary screening, quarantine testing, and 2005 release of *Cataclysta camptonozale*, a defoliating pyralid moth, followed by the 2008 release of *Floracarus perrepae*, a gall mite.

5. Classical biological control of Brazilian pepper tree (*Schinus terebinthifolius*) in Florida, Quarantine risk assessment studies for classical biological control of Brazilian pepper, and Overseas surveys for classical biological control of Brazilian pepper, Argentina. UF, USDA-ARS.

Brazilian pepper infests more area in Florida than any other invasive species. This research

seeks to decrease the competitive ability of this species by introducing safe biological control agents. An overseas survey will also be conducted in Argentina and a risk assessment will be conducted in quarantine at the USDA/ARS facility in Ft Lauderdale. These efforts will be coordinated in parallel and resources will be shared with the UF/IFAS research being conducted from Gainesville and Ft Pierce.

Biocontrol research at the University of Florida.

6. Biological control of air-potato (*Dioscorea bulbifera*): genetic characterization of Florida's populations and foreign exploration for natural enemies in Africa. UF.

Air-potato is a serious invasive plant that rapidly climbs into tree canopies and forms a 'vine mat' that smothers native vegetation. It invades a variety of natural habitats in 23 counties, extending from the panhandle to the southern peninsula. The center of origin of the genus *Dioscorea* is thought to be Asia, although a secondary center of diversity exists in West Africa. *Dioscorea bulbifera* is the only member of the genus that occurs in the wild in both Asia and Africa.

Earlier genetic characterization provided strong evidence that the Florida population is of African origin. Additionally, very little genetic variability was found in Florida, suggesting that the population resulted from a single introduction, and reproduction since arrival has been clonal. Foreign exploration for natural enemies was initiated in Uganda and Ghana in collaboration with local institutions. Several insect herbivores were collected, including defoliators, bulbils feeders, and subterranean tuber feeders. Recent efforts to establish a colony of one of the insects in Ghana have so far not been successful. A 'test plant list' was compiled and submitted to the USDA-APHIS Technical Advisory Committee (TAG) and for review.

An overview of education and outreach activity—

In addition to research, IPMS funds education and outreach efforts. The section maintains a web page that contains information and links for both the Aquatic and Upland Invasive Plant Management Programs. The section occasionally publishes educational materials, such as its "Weed Alert" flyers, which are available online or by request. Other outreach materials, produced by agreement with the UF/IFAS Center for Aquatic and Invasive Plants (CAIP) include: an aquatic plant management website with plant photos, topic pages, and plant line-drawings; posters and photomurals, which are available to teachers nationwide; and a series of fold-out plant ID guides aimed at the general public.

CAIP is a multidisciplinary research, teaching and extension unit directed to develop environmentally sound techniques for the management of aquatic and natural area weed species. The Center utilizes expertise from many departments within the university and its Agricultural Research and Education Centers throughout the state. CAIP also hosts the Aquatic, Wetland, and Invasive Plant Information Retrieval System (APIRS). APIRS (http://plants.ifas.ufl.edu) contains more than 90,000 citations covering plant management.

The CAIP and IPMS collaboratively developed a comprehensive, 500-page website about plant management in Florida: http://plants.ifas.ufl.edu/

guide. This guide was developed to be a reliable source of citizen-accessible information that addresses and answers questions and concerns about Florida's natural resources, especially on issues related to invasive plants and their management. More than 400 major and minor topics are addressed and indexed on the web site.

Table 1. Current research and education projects by category, number, and funding.

Category (#)	Funded Amount
Biocontrol (8)	$622,334
Ecological (2)	$126,686
Education (6)	$397,584.49
Herbicide (13)	$488,252.14
Prevention (1)	$35,995
Total = 30	$1,381,530.53

Current biological control projects include:

Water-hyacinth
Air-potato (2)
Earleaf acacia
Old World climbing fern (3)
Downy rose myrtle
Chinese tallow
Brazilian peppertree

Current herbicidal control projects include:

Hydrilla
Small-leaf spiderwort
Brazilian pepper
Coral ardisia
Old World climbing fern
Skunk vine
African grasses (forage)

Case Study 1

Cooperative Invasive Species Management

Merritt Island National Wildlife Refuge (FWS), Canaveral National Seashore (NPS),

and the Florida Upland Invasive Exotic Plant Management Program

Project Coordinators: Ralph Lloyd, Mike Legare, Layne Hamilton, Ron Hight, Marc Epstein, Wayne Boykin, Stanley Howarter, Department of the Interior, Fish and Wildlife Service; John Stiner, Kristen Kneifl, Department of the Interior, National Park Service; Greg Jubinsky, Drew Leslie, Ruark Cleary, Linda King, Jackie Smith, Florida Fish and Wildlife Conservation Commission, Invasive Plant Management Section, Upland Invasive Exotic Plant Management Program; Sharon Tyson, Department of Environmental Protection, Mosquito Lagoon Aquatic Preserve; David Farr, Volusia County Mosquito Control District

Introduction

In the early 1960s, NASA began to acquire land east of Titusville, Florida that is now the John F. Kennedy Space Center. Acquisition was completed in 1963 and NASA turned those lands not vital to the space program over to the Department of the Interior. Today, the 43-mile long barrier island is managed by the U.S. Fish and Wildlife Service (FWS) as the Merritt Island National Wildlife Refuge (MINWR) and by the National Park Service (NPS) as the Canaveral National Seashore (CNS). CNS manages the eastern half of the barrier island while MINWR manages the western half. The property is adjacent to the Indian and Banana Rivers, and Mosquito Lagoon. MINWR and CNS work closely with NASA and the State of Florida to supplement each other's control efforts.

In Florida, almost one-third of the plants occurring in the wild are not native to the state. Of the estimated 1,200 non-native species, approximately eleven percent are invasive in natural areas. A 2002 report noted over 50 invasive plants in and around the Merritt Island area. Control efforts were historically and typically focused on controlling invasive plants with chemical and mechanical treatment, methods that can require extensive retreatments. CNS received no direct funding for invasive plant control prior to 2000; all control efforts were funded out of limited operations monies from MINWR. In 2000, CNS began participating in a state (formerly Department of Environmental Protection, now Fish and Wildlife Conservation Commission) program where public land management agencies could submit proposals for invasive plant control project funding. This new program began in 1997 and focused on protecting native plant diversity and wildlife habitat on all public conservation land (PCL) in the state. Proposals to the program were consistent with state and federal (e.g., NPS) goals and objectives.

2000 was also the first year of a 50:50 cost-share agreement between the Florida Fish and Wildlife Conservation Commission (FWC) and the National Park Service. The initial CNS project consisted of treating Brazilian pepper and Australian pine on 150 acres (see Figure 1) at a cost of $140,558, or $70,279 from each agency. CNS is one of few PCL to receive state funding assistance every year from 2000 to 2017. During this period, CNS received $3,206,025 from the state and contributed $996,279 of federal funds. A total of 20,166 acres received initial treatment and maintenance control was conducted on 33,162 acres. Although there was not a similar cost-share agreement with FWS, MINWR received $2,894,765 between 2002 to 2017 (except for 2007) and contributed $288,466 for initial control of 35,468 acres and maintenance control of 19,281 acres.

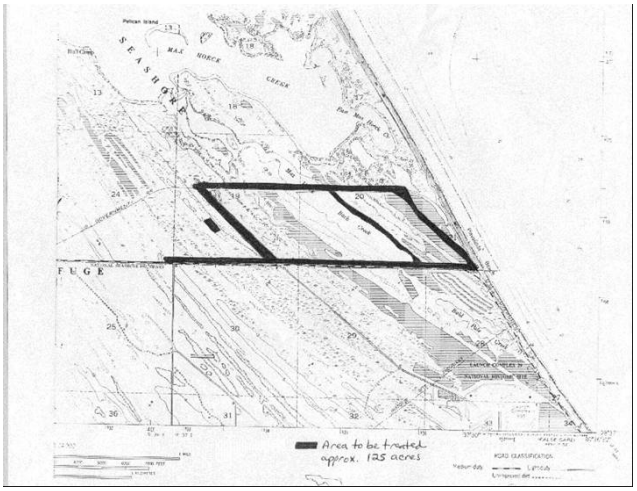


Figure 1. Map from the first joint FWC (then DEP) and CNS project NP-004 (EPMT-2000-04).

Site Management Plans

Ecosystem restoration through removal of invasive exotic plants is one of the highest priorities listed in the Canaveral National Seashore and the Merritt Island National Wildlife Refuge Resource Management Plans. This includes protection of habitat for several federally listed species and a species of special concern that occur in the project area. The long-term goal of MINWR and CNS is to reduce Brazilian pepper, Old World climbing fern, Australian pine, cogon grass, and other invasive plants to a controllable maintenance level.

Approximately one-half of the 200,000 acres of MINWR and CNS consists of brackish estuaries and salt marsh. The remaining land consists of sandy beach, coastal strand and dunes, oak scrub, pine flatwoods, and mesic and hardwood hammocks. An earthen dike was constructed along the edge of Mosquito Lagoon in the 1960s for mosquito control. Portions of the dike are being removed in partnership with FWS, the St. Johns River Water Management District, and Volusia County Mosquito Control District as part of a marsh restoration initiative. Mosquito Lagoon is designated an Outstanding Florida Water, Estuary of National Concern, and Essential Fish Habitat.

MINWR, CNS, and Kennedy Space Center have the largest contiguous population of the federally protected Florida scrub jay (*Aphelocoma coerulescens coerulescens*). This area also provides habitat for the federally listed bald eagle (*Haliaeetus leucocephalus*), eastern indigo snake (*Drymarchon coraisis couperi*), and fragrant prickly apple (*Harrisia fragrans)*, as well as the gopher tortoise (*Gopherus polyphemus*), a state listed species of special concern.

Invasive species occur in a variety of habitat types and are altering native plant communities by displacing native species, changing community structure, and disrupting ecological functions. Invasive plants can present a danger during wildfires due to the vegetation leading into the crown of a tree. Prescribed fire is one technique used to control re-growth of invasive species. In addition to prescribed burning, treated sites are checked for new growth and retreated by Refuge and Park staff.

Project Description

The Invasive Plant Management Section, Upland Invasive Exotic Plant Management ("Uplands") Program has funded fifty projects on MINWR and CNS, either separately or as a single project combining the two. Targeted areas have consisted of numerous sites varying from less than one acre to several thousand acres. By 2010, all mainland portions of MINWR and CNS had been treated for invasive plants at least once.

In 2011, the project area was the 3,200-island portion of Mosquito Lagoon, located in the northern and western section of CNS. After the islands were treated, management units were put under a three-year maintenance rotation schedule, similar to prescribed burning rotations. Maintenance treatments on both PCL continue to this day. Treated areas are mapped using GPS and entered into a GIS database for future reference

and long-term vegetation management. Follow-up inspections are conducted by helicopter and ground observations to ensure contractors meet contractual objectives.

Funding proposals submitted to the Uplands Program follow a standardized format that includes a description of the proposed project, treatment history, and target plants. A few (excerpted) examples from MINWR and CNS during the earlier years of the program illustrate multi-year cross-boundary cooperative planning, integrated management techniques and coordinated timing, and shared successes that will continue into the future.

Burn Unit 3.1 was roller-chopped in August of 2005 and burned in January of 2006. The unit was ideal for controlling Brazilian pepper,

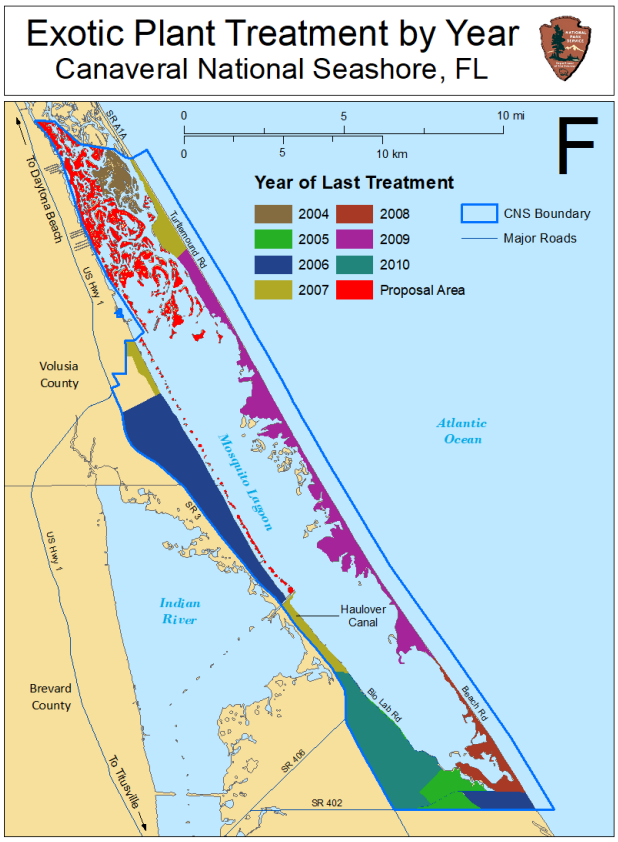


Figure 2: Areas treated for exotic plants at Canaveral National Seashore, 2004-2011. Since 2012, units have been managed on a three-year rotation schedule.

Australian pine, and Guinea grass due to easy access and an ideal timing for follow-up after the prescribed burn. Brazilian pepper cover was 20% and Australian pine was on a few sites that were treated 5 years before and needed follow-up. Burn Unit 2.1 was burned in March of 2006. This site consists of native upland and wetland habitat and an abandoned orange grove. Brazilian pepper cover was 25% and Australian pine was the same as in Burn Unit 3.1.

The 2,702-acre backcountry portion of CNS comprises the middle twelve miles of the barrier island, which is accessible only by foot, and includes one of the last undeveloped sections of beach on the east coast of Florida. The section west of the dune is jointly managed with MINWR. The six-mile sections of barrier island just to the north and south of the treatment area were retreated in 2007 and 2008. The backcountry portion was one of the first to be treated at CNS (2002) and required follow-up treatment of re-sprouts and new seedlings. Brazilian pepper coverage was approximately three percent.

The southwest corner of CNS is jointly managed with MINWR. The 2,000-acre project area is bounded by the park entrance road on the south, Kennedy Parkway on the west, Bio-Lab Road on the north, and Mosquito Lagoon on the east. The western half of this tract was treated in 2003-04 and the fringe along Mosquito Lagoon in 2002-03. Other mainland areas to the north received treatment in 2006 and 2007 and are in good condition. Targeted areas need continuing re-treatment to eliminate re-sprouts and new seedlings.

Target Plants

Brazilian pepper (*Schinus terebinthifolia*) invaded almost all habitat types throughout the entire barrier island. Infestations were most severe on disturbed sites, along roads and dikes, on marsh and wetland fringes, and on the edges of

elevated sites in the marsh. Brazilian pepper has been treated by staff and private contractors. Plants have been treated annually utilizing a full range of resources including mechanical cutting and removal, prescribed burning, and aerial and ground application of herbicides.

In select locations, Brazilian pepper has been cut with a Brontosaurus mower or uprooted and piled using an excavator equipped with a thumb device. Brazilian pepper has been chemically treated by either foliar, basal bark, or cut stump application of herbicides. Basal bark treatments apply a solution of triclopyr ester mixed in carrier oil to the base of the tree. When trees are cut down, the stump is treated with triclopyr amine. Foliar application is used most commonly on seedlings and saplings.

In early 2008, numerous Old World climbing fern (*Lygodium microphyllum*) sites were discovered. These sites were treated in early 2008 with an aerial application, followed up by ground and aerial application in late 2008. The location and invasive nature of this plant make follow-up ground treatments a priority. Infested sites include grassy swale marshes, mesic hammocks, and palmetto scrub. Staff assisted in transporting contractors to remote work sites by using a Marsh Master, an amphibious track vehicle. Staff also support treatment with flight time for detection and treatment.

Air-potato was probably introduced to MINWR and CNS by early residents who lived on the land prior to acquisition by NASA in 1963. Air-potato has been targeted by the Brevard County Agricultural Extension Service as their number one exotic pest plant. Contractors hand collected the tubers and disposed of them at a county landfill. The vines were hand sprayed with glyphosate.

In addition to air-potato, rosary-pea, cogon grass, and guinea grass were treated throughout the north end of the barrier island. Sites were initially treated in 2006, 2007, and 2009, and required maintenance re-treatments. Air-potato and rosary pea infestations are at low levels, cogon grass occurs in dense isolated patches, and guinea grass sites are at high density. Rosary pea and Guinea grass were also hand sprayed with glyphosate. Cogon grass was treated with glyphosate and imazapyr. Additional treatment was completed through an FWS ISST funded contract in the summer of 2010.

Public Education

Public education and outreach are another component of a funding proposal and one of the criteria used for priority ranking. Over a million people visit Merritt Island National Wildlife Refuge and the Canaveral National Seashore each year. General visitation to MINWR and CNS includes fishing, hunting, bird watching, and wildlife festivals. Kiosks, interpretive signs on trails, outdoor event displays, brochures, posters, and other educational material are used to describe the habitats and wildlife on these PCL.

At several kiosks throughout MINWR, visitors can read information on invasive exotic species. Wildlife festivals include presentations and booths on control of exotic plants, and the importance of not introducing such species. Native plants are also available for purchase through the Florida Native Plant Society. Throughout the year, invited guest speakers offer presentations regarding invasive exotic species and encouraging use of native plants.

The southern entrance road to CNS is used to inform the public about the threat of invasive plant species to Florida's native plant communities and about the multi-agency effort that is underway to address the problem. Invasive plant removal project signs are placed along the roadway and a brochure is given to each car stopping at the fee booth when work is being done. Mosquito

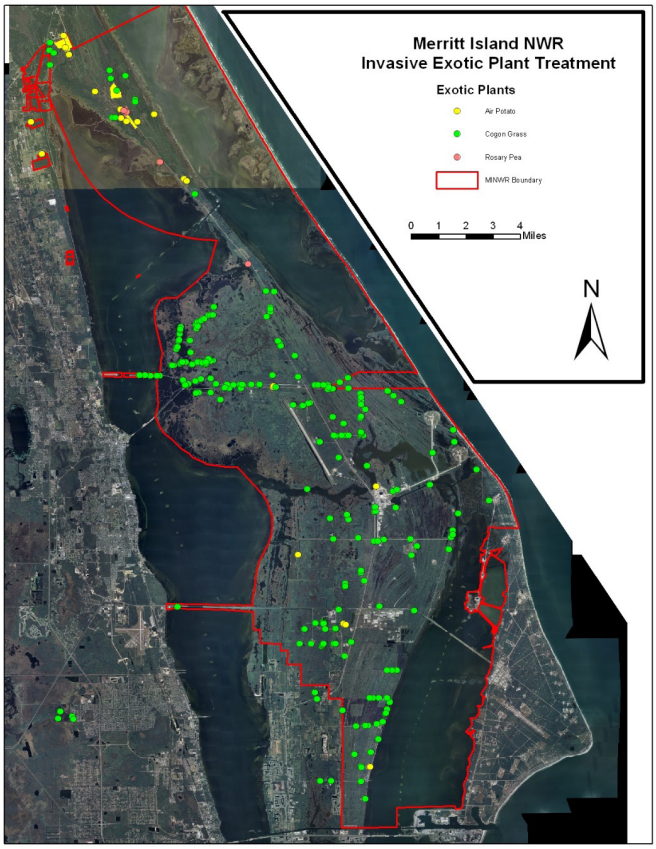


Figure 3: Invasive plant treatment locations on Merritt Island National Wildlife Refuge, 2006-2010.

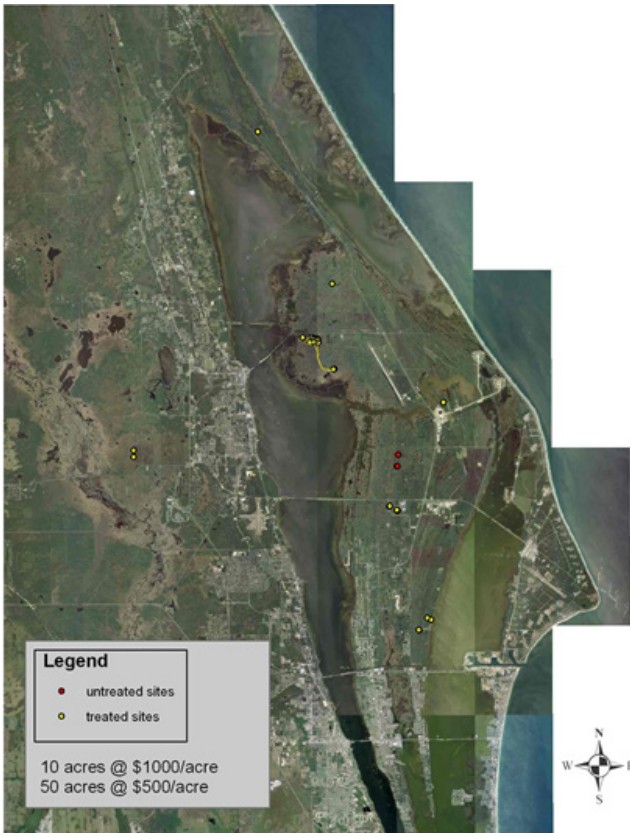


Figure 4: *Lygodium microphyllum* treatment locations on the Refuge, 2010. Total treatment area was 4,100 acres and the cost of treatment was split between NPS and FWC. The final cost-per-acre was $68.

Lagoon, on the north of CNS, is a nationally known fishing destination, with an estimated 45,000 boats visiting each year. Interpretive signs are posted at each boat ramp near an ongoing project and a press release is issued to local newspapers. Projects are also featured on the park website.

Scenes of Klondike Beach Area

Case Study 2

Long-Term Invasive Species Management at Loxahatchee National Wildlife Refuge: Interrupted Maintenance Yields Negative Results

A 50-year license agreement between the Central and Southern Florida Flood Control District (precursor to the South Florida Water Management District) and the U.S. Fish and Wildlife Service in 1951, coupled with the Fish and Wildlife Coordination Act of 1958 and the Migratory Bird Conservation Act of 1929, authorized the establishment of the Arthur R. Marshall Loxahatchee National Wildlife Refuge. The Refuge is the only remnant of the northern Everglades in Palm Beach County.

The 143,238 acres known as the "refuge interior" encompasses Water Conservation Area 1 (WCA 1), which is owned by the state and managed by the Service under the District license agreement. The Service also holds in fee title 2,550 acres to the east and west of WCA 1. The interior is characterized by interspersed natural communities of slough, wet prairie, sawgrass marsh and sawgrass-brush, and tree island or bayhead. The Refuge provides critical habitat for nesting wading birds, the endangered snail kite and wood stork, and the endangered spike ray fern (*Schizaea pennula*), which is found only on the Refuge.

The Service treated 8,095 acres of melaleuca on the Refuge prior to 1987 and 6,755 acres from 1987 to 1998. In 1998, the Refuge began participating in a state (formerly Department of Environmental Protection, now Fish and Wildlife Conservation Commission (FWC)) program where public land management agencies could submit proposals for invasive plant control project funding. This new program began in 1997 and focused on protecting native plant diversity and wildlife habitat on all public conservation land (PCL) in the state. The Upland Invasive Exotic Plant Management ("Uplands") Program conducted control operations for melaleuca (Melaleuca quinquenervia) and Old World climbing fern (Lygodium microphyllum) during state fiscal years 1999, 2001, and 2003. A total of 938.5 acres were treated at a cost of $325,575.

In 2002, the license agreement with the District was renewed, with the addition of performance measures that included public outreach on the importance of ecosystem health and invasive species

Figure 1. A tree island overrun by Old World climbing fern (Lygodium microphyllum). Source: SFWMD.

control, and control operations to remove non-native vegetation. The Refuge established a goal to achieve maintenance control of melaleuca, lygodium, Brazilian pepper (Schinus terebinthifolia), and Australian pine (Casuarina equisetifolia) by 2017. Brazilian pepper and Australian pine are currently under maintenance control (less than 1% cover for individual species). Melaleuca and lygodium were in the early stages of treatment and were awaiting development of a detailed, phased management plan that would incorporate aerial treatment of dense infestations followed by ground treatment. Climbing fern treatment was to follow behind in areas recently treated for melaleuca, thus allowing for initial lygodium treatments and maintenance melaleuca treatments to be coordinated within management units.

Old World climbing fern affected approximately 63,000 acres of the Refuge in 2006. The heaviest infestations were in the northern interior where the plant had overrun tree islands. Approximately 90% of the tree islands had lygodium present, with coverage ranging from 5% to nearly 100%. Sawgrass marshes, which comprised roughly half of treatment areas, are typically free of lygodium. The goal of projects beginning in fiscal year 2006 was to control lygodium on active nesting islands and within a one square kilometer area surrounding the islands to prevent immediate re-infestation, as well as providing maintenance control of melaleuca.

The first of two projects in fiscal year 2006 was for re-treatment of melaleuca on 15,000 acres in the southern Refuge interior. The area was initially treated for all invasive plants by contractors for FWS in 2002. This project fell under the Melaleuca Program (described in the body of this report) and included aerial spraying and ground treatment of melaleuca. The second project targeted Old World climbing fern on approximately 10,000 acres in the central portion of the Refuge. This area had been treated in 2006 for melaleuca through Uplands Program funding. Infestation levels in the treatment area ranged from scattered small patches to very dense areas of lygodium, including some heavily infested tree islands.

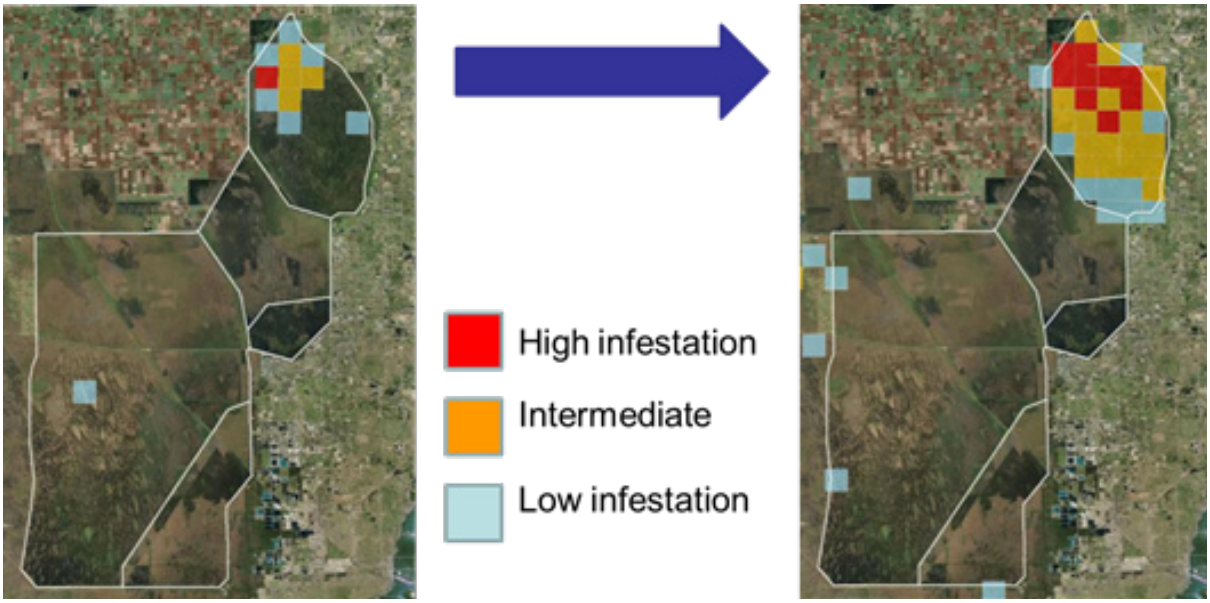


Figure 2. Twenty-year change in infestation levels from 1995 (left) to 2015 (right). Source: SFWMD

Two projects followed in fiscal year 2007, one for initial control of lygodium on 10,000 acres and one for initial control of melaleuca on 21,568 acres. The Uplands Program provided an additional $2,207,256 of herbicide for the aerial treatments. Total cost for the 2007 treatments was $3,875,948, which represented the largest expenditure on a single PCL in the program's history. The first of two projects in fiscal year 2008 was included in the Melaleuca Program funding and the work was performed by District contractors. Total expenditures equaled $4,248,805 for initial treatment of 14,104 acres of lygodium and 19,142 acres of melaleuca. The second project was an initial lygodium treatment on 3,450 acres in the central portion of the refuge, which had been treated for melaleuca through the Uplands Program in 2006.

Total expenditures on the Refuge between 1999 to 2008 were $6,876,100 from the FWC Uplands Program, not including the $3-4 million in matching funds from the District. A total of 60,611 acres of melaleuca and lygodium were initially treated and 15,018 acres received maintenance treatment through FWC funding. A minimum of 20,000 additional acres of initial treatment was done by the District with their matching funds. In 2008, responsibility for maintaining areas that were treated with state funds was passed to the Service.

Unfortunately, the Service was unable to conduct the necessary maintenance control on areas the state initially treated, so by 2013 the Refuge was in worse condition than prior to any plant treatment having been done. Systematic reconnaissance flight data collected by the District between 1995 to 2015 (see Figure 2) revealed that melaleuca and lygodium infestation levels and extent had increased on the Refuge over this time (see Figure 3), while decreasing on all other PCL in the region. Nearly every unit of the Refuge had low to high infestations, with approximately 25% of acres severely impacted by both species. In January 2012, digital aerial sketch mapping (DASM) of Refuge Unit A (1,975 acres) recorded approximately 411 acres of lygodium coverage, 302 acres of which was classified at less than or equal to 50% density. DASM technology is not able to detect all lygodium and ground-truthing surveys indicated that density was higher and more extensive in certain portions of the unit.

In February 2013, approximately 150 acres of lygodium at 50 percent or greater density was aerially treated. This aerial treatment was followed by a Service funded contract for ground treatment of any lygodium that was missed on the tree islands that were aerially treated. Islands that were not the target of aerial treatment were not treated under this contract. During the same

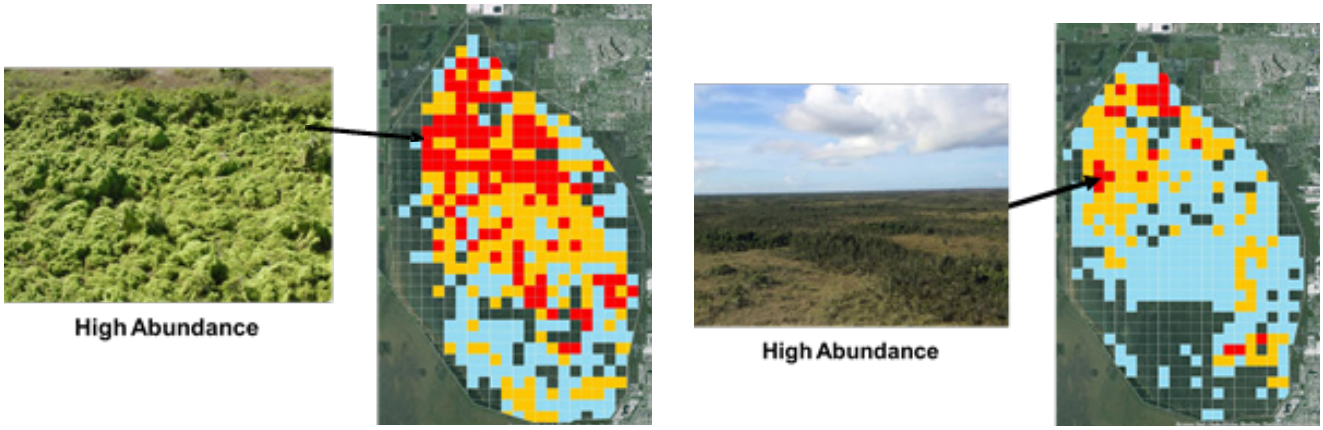


Figure 3. Extent of coverage in 2015 for lygodium (left) and melaleuca (right). Source: SFWMD

time, DASM recorded approximately 505 acres of lygodium coverage in Unit B (1,975 acres), 463 acres of which was classified at less than or equal to 50% density. In February 2013, approximately 90 acres of lygodium at 50 percent or greater density was aerially treated.

The Service submitted proposals to the Uplands Program in fiscal years 2012 and 2013, but these were rejected as inadequate. After several coordination meetings, the state, District, and Service worked together to produce a management plan for attaining maintenance control levels on the Refuge and to formalize the plan in a Memorandum of Understanding (MOU) between FWC, the District, and the Service. The MOU prescribed that FWC and the District would work from the south toward the north of the Refuge, while the Service would conduct initial and maintenance treatments in the north and eastern areas. In fiscal year 2014, with a five-year management plan in place, a maintenance control project was conducted on 15,403 acres of the Refuge at a cost of $2,897,575 shared among the three agencies. In the following three years, 18,311 acres of initial control and 22,416 acres of maintenance control were conducted at a cost of $11,542,316.

The five-year agreement was renewed in 2019. Under the current agreement, District staff will implement all control efforts in the Refuge with funding support from USFWS and FWC. An annual budget of $5,000,000 is allocated to this project. Funding for this plan comes from both USFWS and FWC, with the District guaranteeing the remainder. The new license agreement requires USFWS to commit at least $1,250,000 each fiscal year and provides incentive for USFWS to provide more funding in the form of a license agreement extension. Expected contributions from USFWS and FWC are approximately $2,000,000 and $1,000,000, annually. Aerial reconnaissance and mapping will be provided by the District.

There is not an anticipated date for when the Refuge may be brought under maintenance control. Anticipated expenditures for the current five-year plan are over $25,000,000 (see Table 1). This includes both initial and maintenance operations, to ensure that previously treated areas are kept under control at the same time as new areas are added. The highly invasive nature of lygodium, which has the ability to produce millions of windblown spores that can travel for miles (or further, in a hurricane) and the presence of offsite infestations make it likely that another five years will be required to complete initial treatment of this species. Initial treatment of melaleuca may be completed sooner. Once all initial treatments are completed, maintenance control will be required for the foreseeable future.

Had a maintenance plan been put into place in 2008 that included sustained reoccurring funds, the Refuge would likely today be under maintenance control, with units being treated on a maintenance control rotation schedule. The Uplands Program's emphasis has shifted toward achieving a rotation schedule on all PCL that

Table 1. Anticipated expenditures for invasive plant management at Loxahatchee NWR. Source: SFWMD, 2019, Loxahatchee National Wildlife Refuge Invasive Plant Management Plan, 2019 – 2024.

Budget Item	FY19	FY20	FY21	FY22	FY23	Total
USFWS	$2,295,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$10,295,000
FWC	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$5,000,000
SFWMD	2,200,000	$2,000,000	2,000,000	$2,000,000	2,000,000	$10,000,000

are funded by the program. While initial control is still conducted where necessary, such work is not approved unless there is a commitment from the land managing agency to maintain those sites in perpetuity. However, the program has learned that many PCLs do not have the funding to conduct maintenance control without continued funding assistance. Thus, it is incumbent on those applying for money to show an achievable management plan for maintenance treatment.

Past program efforts relied on land managers requesting funds for invasive plant management on individual sites, with the amount of money received determining what could be accomplished in a given year. This minimal, often non-recurring funding model did not result in cost-effective or sustainable success. In the recent past, federal management funding continually decreased. State funding fluctuated, but to a lesser degree. Sustained funding, even when insufficient, allows development of a long-term treatment strategy. For large PCL where infestations are significant, landscape level planning and continuous funding are paramount.

One method to overcome the lack of sufficient recurring funds is to form cost- and resource-sharing cooperative agreements between land managing agencies. Such agreements can include the sharing of personnel, equipment, chemicals, biocontrol agents, computer technology, inventory and monitoring data, and educational materials. Cooperators also share the knowledge and skills of available experts and technicians, sponsor joint training, and convene technical workshops and informational meetings. Successful cooperative agreements also help to reduce parochial conflicts and institutional barriers that limit the most efficient use of public management resources.

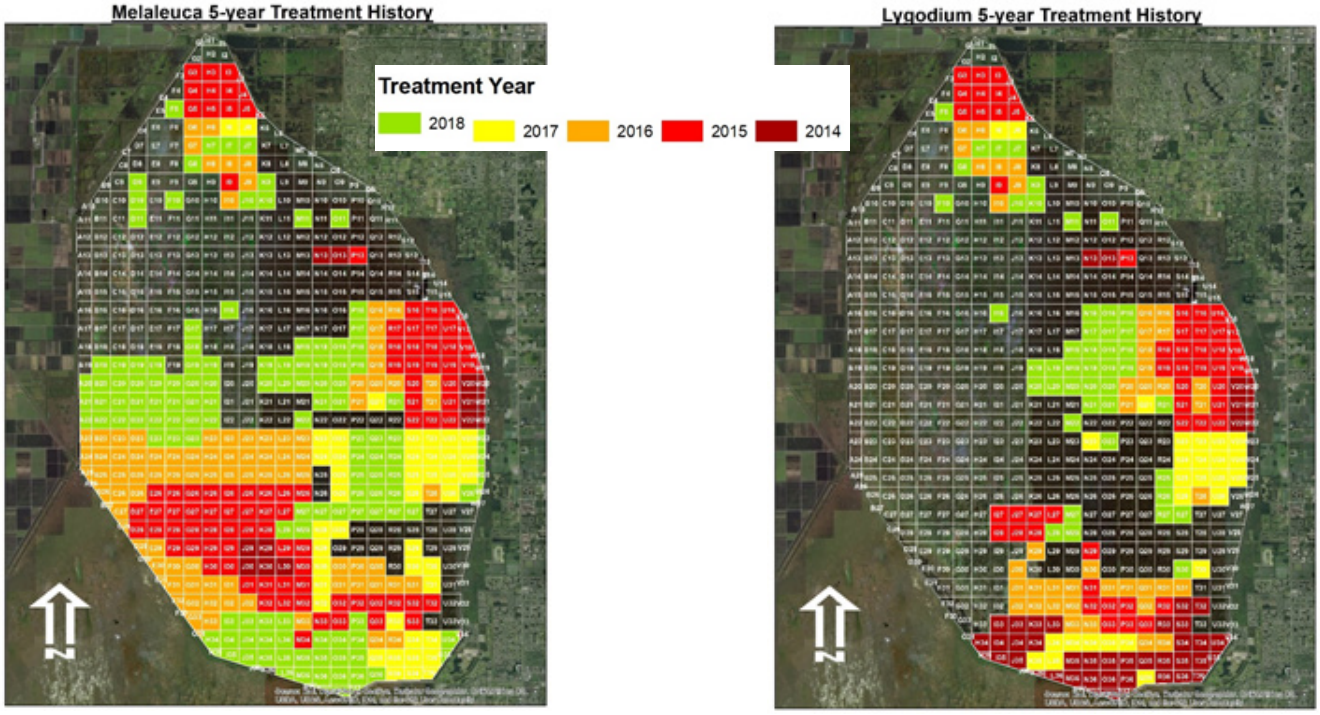


Figure 4. Areas treated by groundcrews over 5 years (2014-2018) within the Refuge. Source: SFWMD, 2019, Loxahatchee National Wildlife Refuge Invasive Plant Management Plan, October 2019 – September 2024.