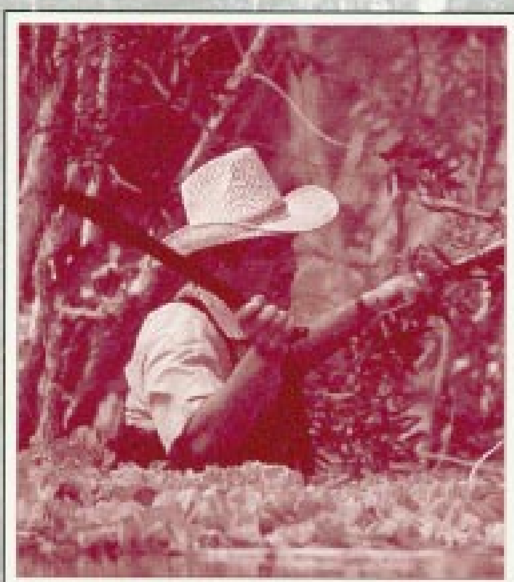
Melaleuca Management Plan

Ten Years of Successful Melaleuca Management in Florida 1988-98



Florida Exotic Pest Plant Council

May 1999
Third Edition

Francois B. Laroche, Editor

MELALEUCA MANAGEMENT PLAN

TEN YEARS OF SUCCESSFUL MELALEUCA

MANAGEMENT IN FLORIDA
1988 - 1998

RECOMMENDATIONS FROM THE
MELALEUCA TASK FORCE

FLORIDA EXOTIC PEST PLANT COUNCIL

APRIL 1990
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MAY 1999
Third Edition

François B. Laroche, Editor

MELALEUCA: ***A THREAT TO THE RESTORATION OF THE GREATER EVERGLADES ECOSYSTEM, AN EXPLOSION IN SLOW MOTION.***

This Manuscript is dedicated to **JAVIER CARDENAS, FRANCISCO VILLA FUERTE, JUAN ESPINOZA AND JOHN RAY HILL** who died, in a helicopter crash, while eradicating melaleuca in the Everglades Water Conservation areas on January 22,1997.

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The Melaleuca Management Plan was developed to provide criteria to make recommendations for the integrated management of melaleuca in Florida. The original plan was published in April of 1990. A second edition was published in 1994. This is the Third edition and it should be periodically updated to reflect changes in management philosophy and operational advancements.

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EXECUTIVE SUMMARY

F. Allen Dray, Jr.

Early in 1990 the Florida Exotic Pest Plant Council and the South Florida Water Management District jointly convened a task force of federal, state, and local land managers, scientists, and others. Their charge was to develop a comprehensive plan for managing one of the Everglades most notorious plant invaders, *Melaleuca quinquenervia*. The result was the first edition of this Melaleuca Management Plan. The task force reconvened in 1994 to assess progress and revise the plan as needed. In the ten years since its original publication, this Plan has served as a framework for agencies managing or seeking to protect natural areas infested by melaleuca. It has facilitated interagency cooperation and coordination of control efforts, improved resource utilization efficiency, enhanced public awareness of the problem, and inspired legislative support.

The past decade has seen strong progress toward the goal of eliminating the threat to Florida's Everglades posed by melaleuca, though the task is far from complete. Ecological studies have given us a better understanding of melaleuca's biology and, thus, how to more efficiently manage this invasive weed tree. Such studies have shown that melaleuca coverage of a 1 square mile plot can increase from 5% to 95% in a mere 25 years. We've found that although melaleuca trees hold millions of seeds in capsules on their branches, only 15 to 20% of these are viable. This deficiency has not slowed the spread of melaleuca, however. Scientists have measured biomass, leaf production, and other population parameters to help gauge the success of biological control agents. Overseas explorers discovered more than 400 insects that damage melaleuca in its native Australia, and identified the most promising for use as biological controls. The first melaleuca biocontrol insect (the snout beetle *Oxyops vitiosa*) was released into Florida during 1997. Host screening has been completed for two other species, and is nearly completed on a third. Field populations of *Oxyops* are increasing, and melaleuca saplings are already being highly stressed at some release sites.

Ongoing mechanical, chemical, and physical control efforts have pursued a strategy which emphasizes finding and removing outliers (isolated mature, seed-bearing trees) to halt the advance of existing populations, and then progressively eliminating trees towards the source of the infestation. This strategy has been highly successful, with melaleuca acreage declining by nearly a third in the past decade. The largest reductions have occurred at Big Cypress Preserve, The Everglades Water Conservation Areas and Everglades National Park. Overall, more than 78 million stems (mature trees and saplings) have been treated and/or removed since control efforts began against melaleuca.

Achieving this level of success has not been inexpensive. The melaleuca project (including biological, mechanical, chemical, and physical control efforts) has cost about $25 million thus far. To place this in perspective, however, the Florida Department of Environmental Protection estimated that failing to act against melaleuca would ultimately cost the region $161 million annually in lost revenues, etc. It should also be noted that herbicide application techniques have been refined to enhance efficacy and efficiency, thereby reducing the amount of chemicals used and the cost to use them. Further, benefits from biological controls will begin accruing in a few more years, and should then help further reduce annual control expenditures.

I. INTRODUCTION

Robert F. Doren

For most of this century ecologists have recognized the serious threat that non-native invasive species pose to our natural areas and resources. The threat weeds and insect pests pose to agricultural and forest production has been understood for even longer. However, only recently has the impact these invasive species have on natural lands been clearly understood or appreciated.

Exotic species arrive by many means, some are intentional and some are not. Through our actions, which move exotic species around the globe, we become the perpetrators and witnesses to the homogenization of the world's flora and fauna and the concomitant losses of billions of dollars of agricultural production, millions of acres of natural lands, and much of the world's biological diversity. What we are doing to disrupt millions of years of evolutionary patterns is happening at jet speeds and may well be the single least-reversible human impact to global biological diversity.

It is estimated that more than 50,000 exotic plant species have been introduced into Florida (D. Hall pers. comm.) Florida has more exotic invasive plants than any other state except Hawaii. There are 66 species listed as occurring in Florida described as the most invasive weeds, and another 60 listed as species shown to have potential to disrupt native plant communities (FLEPPC 1999). Of these 126 proven and potentially invasive weeds melaleuca is clearly one of the biggest threats to the ecological integrity of the south Florida ecosystem.

To date Florida's efforts to manage invasive exotic species has been oriented around site-based or species-based projects. In addition these projects have generally been conducted independently by agencies and with a minimum of integrated action or planning. There is still no statewide strategy for dealing with invasive species, although such a plan is being developed. Without an integrated organization and strategy to address the expanding invasion of exotics into the state's wetlands and other natural areas, early control efforts will continue to be only site- or species-based projects, which are spotty at best.

However, with a clear understanding of the need for integration and long-term thinking, concerned resource managers organized the Exotic Pest Plant Council (EPPC) in 1984. The EPPC was established to unify the exchange of information between land management agencies, research scientists, industry and other interested groups that were concerned with the impacts of exotic plants in natural areas, and to serve as an advisory body to other groups or agencies. EPPC brought together those agencies and organizations concerned with invasive species and prioritized the worst four species in order to begin developing species-based management plans that incorporated tactical elements, priorities for funding and control, and strategies for tackling the broader issues of controlling these species. The original four included (in order of priority) melaleuca (*Melaleuca quinquenervia*), Brazilian pepper (*Schinus terebinthifolius*), Australian pine (*Casuarina equisetifolia*) and giant sensitive catsclaw (*Mimosa pilleta*). Old World climbing fern (*Lygodium microphyllum)* was recently added to this list. By bringing agencies and organizations together, EPPC provided the integration for the development species-based management plans. Two have been completed (melaleuca and Brazilian pepper) and one is being developed (Old World climbing fern).

The Melaleuca Management Plan provides recommendations from the Melaleuca Task Force (MTF) - a working committee of the Exotic Pest Plant Council - for the integrated control of melaleuca in Florida. The MTF is an interagency group of professionals who either have direct experience in managing melaleuca or have the technical knowledge required for an integrated management approach. The Melaleuca Management Plan for Florida was first published in April 1990. This first edition was intended to guide the integrated management of melaleuca within Florida. It identified program goals and objectives, along with management options and recommendations produced by the MTF. This current plan is an update and includes technological advances, as well as operational progress, which has occurred since the first edition.

It is the consensus opinion of the MTF that the uncontrolled expansion of melaleuca constitutes one of the most serious ecological threats to the biological integrity of south Florida's natural systems. However, through the development and implementation of this plan it became clear that it is possible to mitigate this threat based on the current knowledge of the infestation and available management techniques. As a result of the implementation of the melaleuca management plan over the past decade, a decrease of approximately 100,000 acres of melaleuca in "managed" areas has been documented.

II. PROBLEM STATEMENT

Robert F. Doren

Melaleuca quinquenervia (Cav.) Blake is native to Australia and was through several introductions brought into Florida in the early 1900's as an ornamental tree and as a putative commercial source of wood. As a result of removing melaleuca from its evolutionary origins, and factors such as abundant seed production, asexual growth habits, fire adaptation, lack of evolutionary-based competition and predation have facilitated its spread throughout Florida's natural areas. Consequently, in Florida melaleuca dominates and replaces many natural area plant communities.

Given the rapid expansion of this species (Laroche et al. 1992), melaleuca altered thousands of areas of the Everglades by replacing native tree islands, sawgrass marshes, mesic prairies and aquatic sloughs. Mature melaleuca trees commonly form dense monocultures that virtually eliminate all other species. These stands have limited wildlife value and are characterized by reduced species diversity (Austin, 1978; Schortemeyer, et al., 1981; Mazzotti et al., 1981; Sowder and Woodall, 1985). As melaleuca invades wet prairie/marsh systems diversity is decreased over 60 - 80% (Woodall, 1988; Austin, 1978).

Magnitude of the Problem - Melaleuca was planted as seed from Australia in the early 1900's at two coastal locations: Broward County, near Davie and in Lee County, near Estero. In the late 1930's trees were planted along the rim canal around the southern levees of Lake Okeechobee and at Monroe Station in the Big Cypress National Preserve. The present distribution of melaleuca is predominately centered in and around the areas of original introduction. Its spread was enhanced through its use as wind breaks and fence rows, and its popularity as a fast growing ornamental. Wind and water—via canals— have been the most likely factors that have facilitated its spread into the interior of the Everglades where the relatively undisturbed inland wetlands have been invaded. Melaleuca has been slowest to invaded the Holey Land, Everglades National Park and Water Conservation Area (WCA) 2-A. This is probably due to the fact that these areas have been less disturbed than other areas, and are farther from large populations. Infestations that include widely scattered outliers, and small forests or heads occur in the eastern part of Everglades National Park along the western side of L-67 extension. Very large and dense infestations (many outliers and extensive monospecific forested areas) occur in the Loxahatchee National Wildlife Refuge, and the most easterly portion of Everglades National Park along the L-31N canal. Extremely heavy infestations (very large heads and extensive dense forests) now occur predominantly only in privately held lands in Broward, Dade, Palm Beach, Lee, Martin and Collier Counties. In Lee County the areal extent and density appear to have expanded considerably within the last ten years, particularly south of the Caloosahatchee River. These invasions are often associated with forested transitional wetlands with open canopy.

However, on the public lands where resources have been focused as directed in the management plan, melaleuca has been very effectively controlled. Virtually all of Big Cypress National Preserve, Water Conservation Areas 3A, 3B and 2A. These areas are now under a maintenance control program. Much of the melaleuca in the eastern portions of Everglades National Park along L-67 have been removed but the eastern most forests of melaleuca are still present. Conservation area 2B and Loxahatchee National Wildlife Refuge still have large and extensive forests of melaleuca.

As a result of the implementation of the Melaleuca Plan almost 100,000 acres of natural area have been cleared of melaleuca. Unfortunately, an almost equal expansion of melaleuca on privately held lands where no control activities have occurred has resulted in no net loss of acreage of melaleuca.

In addition to the large area of melaleuca removed and those areas now under maintenance control, the biological control program has been successful in releasing a weevil to feed on melaleuca, and has another insect that will soon be released. The weevil population is surviving and reproducing. Probably due to its recent release it has not yet begun to have any significant effect on melaleuca populations.

III. GOAL

The goal of the Melaleuca Task Force is to protect the integrity of Florida's natural ecosystems from the biological degradation caused by the invasion of melaleuca.

IV. OBJECTIVES

The Goal of the Melaleuca Task Force can be achieved through the following objectives:

1- **Eliminate melaleuca from Florida's natural ecosystems that still contain large populations**

2- **Achieve an overall reduction of melaleuca throughout Florida such that maintaining Florida's natural areas melaleuca-free is economically feasible**

3- **Implement an effective public information awareness and participation program that will encourage support for melaleuca management issues**

4- **Coordinate with, and support the goals of the Everglades Restoration task Force**

5- **Ensure sufficient resources are focused on maintaining the areas where melaleuca has been removed free from new infestations**

6- **Continue to support an active biological control program that includes the development of a quarantine facility**

V. RECOMMENDATIONS

François B. Laroche and Robert F. Doren

The following recommendations reflect changes, which have occurred since the previous Melaleuca Management Plan was drafted in 1990 and 1994. All previous recommendations were fully implemented. For example, the South Florida Water Management District provided $75,000 during 1990 - 92 to the USDA melaleuca bio-project. In 1993 the District increased its funding to $150,000 annually. The South Florida Water Management District initiated a melaleuca control program in WCA-3B in November of 1990. The District also provided financial support to the melaleuca control program at the Everglades National Park and the Loxahatchee Wildlife Refuge.

The current recommendations are in the order of priority recommended by the members of the 1999 MTF.

1. **Augment the funding requirements necessary for continued evaluation and subsequent release of melaleuca biocontrol agents into Florida**. Paramount to an effective and integrated melaleuca management program is the continued support for the testing and evaluation of biological controls. Woody plant species such as melaleuca require a diversity of bioagents (at least 5 species) to achieve control (Balciunas and Center, 1991).

2. **Continue to seek full funding for the construction, staffing, and operation of a quarantine facility in south Florida**. The total cost of building this facility has been estimated at $5,000,000. The construction of this facility coupled with the addition of personnel would at least double the number of insects that could be evaluated and released relative to the current program.

3. **Continue melaleuca elimination programs in all publicly owned natural areas in Florida and refocus some resources from controlled areas to areas needing control**. At present, the melaleuca management program in Florida is not functioning as a fully truly integrated program as was envisioned in the Melaleuca Management Plan. This is due predominantly to the lack of sufficient resources to implement the entire plan. If existing populations in the Florida natural areas can be eliminated, then control efforts using herbicides can be greatly reduced in favor of the more ecologically compatible biological controls.

4. **Enhance existing control programs through coordinated efforts to seek additional funding sources**. Where active elimination programs currently exist they must either be funded sufficiently to remove the remaining melaleuca, and where removal has been successful resources must remain available to prevent re-

invasion. Currently, there are several active melaleuca management programs in the priority areas identified by the Melaleuca Task Force, including the eastern most portion of Everglades National Park along L-31N, Loxahatchee National Wildlife Refuge, Water Conservation Area 2B, and Lee County (see Section VIII for detailed summaries). Maintenance programs are in place for Big Cypress National Preserve, Water Conservation Areas 3A, 3B and 2A, and for the area of Everglades National Park west of the L-67 area.

5. **Continue investigations into alternative methods of control (i.e., aerial application, for mature and seedling trees, Wood chip for commercial mulch and boiler fuel, pathogen research etc.)**. Management strategies should be revised as control methodologies are developed which improve efficacy and cost effectiveness.

6. **Utilize the support and resources of organizations such as the Exotic Pest Plant Council to organize a network of professionals to lobby the State Legislature and the U.S. Congress to provide financial support and enact laws for melaleuca and other exotic pest plant management issues**.

7. **Establish a melaleuca-free buffer zone along the boundaries of the publicly owned natural areas in Florida, and encourage public and private landowners to remove melaleuca infestations from within the buffer zone**.

8. **Utilize the support and resources of organizations such as, the South Florida Water Management District, The Florida Department of Environmental Protection, and the University of Florida Institute of Food And Agricultural Sciences, in the production and dissemination of information intended to educate the public about the problems associated with the introduction of nuisance exotic plants such as melaleuca**. Assist the county extension service in public education through special publications, brochures and reports, and sponsoring workshops, seminars and public meetings concerning melaleuca management issues. Provide technical support to other Agencies.

VI. TECHNICAL BACKGROUND

South Florida is characterized as a humid, subtropical region with relatively high annual rainfall (53 inches) and warm annual mean temperatures (74^{o} F). Because of the mild climate, a large nursery industry has developed in the state producing ornamental and aquarium plants. The abundance of aquatic and associated wetland habitat, coupled with extensive urbanization, have facilitated the introduction and subsequent escape of many foreign aquatic and wetland plant species. Presently, there are at least twenty-five exotic plant species that inhabit the state's waterbodies and wetlands (Schmitz et al., 1991). These introduced plant species are invasive and can outcompete native vegetation. The competitive edge that these exotic plants have over native plant communities comes from a lack of natural controls, which are typically screened out prior to the plant’s introduction into this country.

In south Florida, exotic invaders characteristically establish in "disturbed" areas--construction sites, abandoned farm land, wetlands that have been cleared or have been stressed due to hydroperiod changes, along roadways, and along canals and drainage ditches. Once populations are well established in "disturbed" sites, pressures are exerted through the constant barrage of seed dispersal to invade surrounding areas. Undisturbed areas are difficult to colonize largely due to stiff competition from native plant communities. However, the natural ecosystems of south Florida, which appear to be undisturbed, have been altered by drainage and water storage projects that, in essence, have "disturbed" these natural areas, thus permitting the establishment of many species that are characteristic colonizers of disturbed sites.

Although many exotic species more readily invade disturbed sites, several species such as melaleuca, are not restricted only to areas of disturbance. Melaleuca is a pioneering species and has been spreading since its introduction. In its native range it grows in low-lying flooded areas and is especially well adapted to ecosystems that are periodically swept by fire. These are the conditions that are common to most of south Florida, making it ideal habitat for melaleuca.

A. BIOLOGY OF MELALEUCA

Mike J. Bodle and Thai K. Van

Melaleuca is a hardy, fast-growing tree imported from Australia and has papery white bark resembling the white birch. These characteristics spurred its use as an ornamental landscape tree, as agricultural windrows, and as protective living "guard rails" and soil stabilizers along canals. Melaleuca readily invades canal banks, buffer zones between pinelands and cypress areas, and uninterrupted sawgrass prairies (Myers, 1975; Austin, 1978; Duever et al., 1986; Wade et al., 1981; Woodall, 1981b, 1983). Melaleuca's potential spread in south Florida is variously held to be unlimited, ultimately encroaching upon all open land (Hofstetter, 1991a), or limited to underutilized niches in the relatively young Florida landscape (Myers, 1975). Yet, acknowledgement of such alternative views embraces their common thread -- that we need to control melaleuca -- whether or not it could ultimately cover the peninsula.

Soil types fail to limit the ability of melaleuca to take hold. The tree grows equally well in the deep peat soil of Arthur R. Marshall Loxahatchee National Wildlife Refuge in the northern portion of the remnant Everglades and in the inorganic, calcareous soil of western Dade County (Wade et al., 1981). Melaleuca's incredible resilience and capacity to invade all of South Florida's natural areas underscore the ecological imperative to control its spread.

Habitat - The characteristics and habitat requirements of melaleuca are not adequately known to explain the observed differences in the pattern of spread of melaleuca in South Florida (Hofstetter 1991a). In Southwest Florida, melaleuca has been described as a species, which appears early on disturbed sites, those in which existing vegetation has been removed, and mechanical disturbance of the sediment has occurred. (Myers 1975, Austin 1978). Myers in Ewel et al., (1976) states that "massive invasion by melaleuca is largely restricted to disturbed areas. It seems clear that most undisturbed ecosystems are to a large degree resistant to, but not necessarily immune to, colonization".

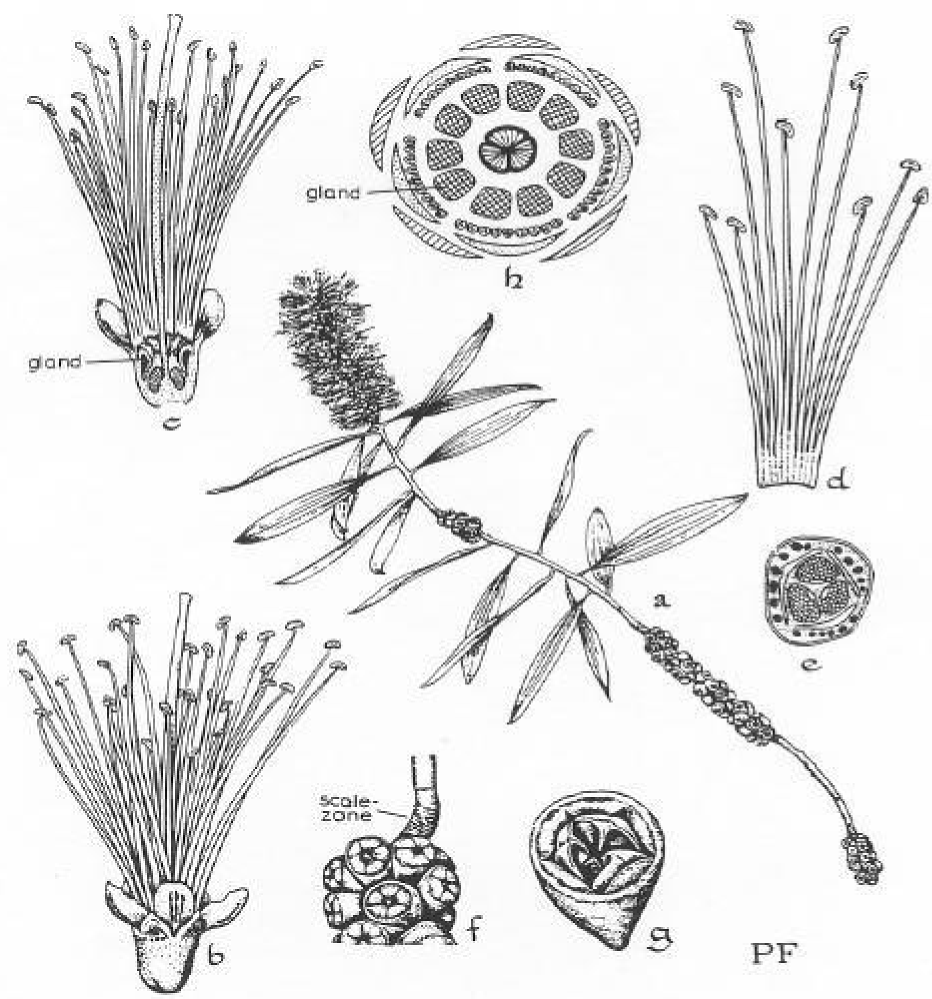
In southeastern Florida however, melaleuca has not shown a preference for areas where sediments have been disturbed mechanically (Hofstetter 1991a). Here, melaleuca has invaded essentially every existing community, including those in which native vegetation is seemingly healthy and vigorous. Hydrologic patterns have been greatly altered in southeast Florida, however, and no fresh-water wetlands remain in their natural (historical) state. Invasion potential differs from community to community with wetter communities typically more susceptible than drier communities. However, drier communities, which are wetter than normal also, become increasingly susceptible to invasion. Frequent wildfires also aid in the establishment of melaleuca. These fires cause melaleuca to release its seeds, destroy the competing seed and litter layer as well as prepare the site for melaleuca seedling germination.

Description and Growth - *Melaleuca quinquenervia* (Cav.) Blake, melaleuca, is a member of the Australian Myrtaceae (myrtle family) which also includes the *Eucalyptus* (gum) and *Callistemon*, (bottlebrush) genera. Worldwide, many of the 3,000-plus Myrtaceae species are cultivated as sources of fruits, spices, aromatic oils or timber. The flowers of *M. quinquenervia*, like most Myrtaceae, have numerous stamens on a cup-shaped receptacle with the ovary below. Myrtaceae leaves are simple and entire and the plants are usually aromatic. The genus *Melaleuca* is native to Australia and includes more than 200 species. *Melaleuca quinquenervia* is the only representative of the genus in Florida where it is commonly called the melaleuca tree. Australian common names include cajeput tree, punk tree, and broadleaf paperbark tree, its official common name. It is easily recognized by its white, spongy flaking bark, lanceolate, longitudinally, parallel-veined leaves, and clusters of woody seed capsules along the stems.

Usually saplings grow with a single main stem, although a damaged terminal bud is readily substituted by an axillary bud resulting in new shoot growth along a new axis. Damage may also induce new shoot growth from the roots, resulting in multi-trunked trees or coppices. Because of these damage responses, older trees are often multi-stemmed. Multiple branching can also be caused by extended inundation and drought stresses (Lockhart, et al., 1999). Physical characters of *Melaleuca quinquenervia* are illustrated in Figure 1. Branching occurs at irregular intervals along the trunk. Vegetative and reproductive sections along each branch are distinct and alternate. Leaves are spirally arranged along the vegetative branch segments. Reproductive and vegetative segments are separated by overlapping scars of resting terminal bud scales or "scale-zones" (Tomlinson, 1980). New elongating branch growth occurs sporadically and varies from branch to branch. Periods of branch growth are separated by brief or lengthy periods of "rest" (Tomlinson, 1980). The relative length of the scale-zone increases with increased "resting" time between periods of shoot elongation. Reproduction occurs along flower bearing branch segments. Previous inflorescence are apparent because of the persistent woody seed capsules. Different trees and different shoots on the same tree are non-synchronous in their flowering.

Flowering and Fruiting - An individual melaleuca tree may flower within three years of germination and as many as five times per year (Meskimen, 1962). Flowering occurs as vegetative branch segments convert directly into flowering spikes. This conversion is preceded and succeeded by a "resting" phase indicated by the scale-zone. In Florida, main flowering periods are fall and winter. Melaleuca could be considered as a 'winter' tree. While some flowering and growth do occur year-round, the main flowering season in South Florida is limited to Nov/Dec/Jan, with bursts of vegetative growth generally occurring after flowering and peaking in Jan/Feb. However, in wet years, both flowering and new growth can be extended in response to greater water availability. In a heavy blooming year, flowering season may start earlier in Jul/Aug and extend longer into Mar/Apr with several flowering cycles. Flowers are clustered in trios and each ovary is tripartite and surrounded by the calyx tube and ten hairy glandular outgrowths of the tube. These glands secrete nectar, which collects within the basal floral cavity. Six to ten stamens are opposite each of five sepals and five white petals. Insects pollinate flowers however, seed fertility is low. Rayachhetry et al., 1998 indicated a rather low seed fertility and suggested that low germination in melaleuca may simply be related to low seed fertility. Other studies are currently underway to determine soil seed banks and seed viability/longevity in the field. To date results from seed burial tests indicate that seed viability was reduced by about 50% after 8 months in the soil. After ripening, the persistent woody capsules hold the mature seeds until desiccation induces dehiscence and the release of two to three hundred very small seeds from each capsule. Capsules may remain on a branch for at least ten years (Meskimen, 1962). A tree, or branches of a tree, will desiccate when stressed by freezing, drought, fire, herbicide treatment or breakage. At such times, a single tree may release as many as 20 million seeds (Woodall, 1981b).

Figure 1. Melaleuca, *Melaleuca quinquenervia*: (a) Habit (x1/2); (b) flower (x4); (c) flower in longitudinal section (x4); (d) stamen group (x6); (e) ovary in transverse section (x8); (f) unripe fruits (x2); (g) dehisced fruit (x4); (h) floral diagram. (Reprinted with permission from P.B. Tomlinson. 1980. *The Biology of Trees Native to Tropical Florida,* Harvard University Printing Office, Allston, Mass., p. 285. Illustration by Priscilla Fawcett.)



Reproduction - A large, mature melaleuca tree has a high reproductive potential as the branches contain millions of seeds stored in the capsules. A single branch may retain seed capsules of different ages and the seed may remain viable for several years within the seed capsule. The seed capsule must be dry before the seed will release. Desiccation can be caused by such things as growth of the stem, cutting or breaking of the stem, fire damage, frost damage, self pruning due to shade and by natural death of the tree. If the branch of a tree is broken or cut from the tree, this will trigger a rapid release of most of the seeds contained in the capsules on the branch. A hot crown fire will cause complete capsule dehiscence in a matter of days (Woodall, 1983). Fire burning under and up into a melaleuca tree will cause a massive seed release as the branches dry and their capsules open. Likewise, if an entire tree is felled, it will, in turn, release its seed.

Additionally, if a melaleuca tree is cut or damaged by fire or frost, there may be prolific sprouting from the base. In the case of fire and frost, the point at which the regrowth occurs depends upon the severity of the fire or cold relative to the size of the tree. Extensive rooting and sprouting can also occur from a fallen or cut tree. Likewise, melaleuca logs used as fencepost frequently sprout new growth

Woodall (1983) reports that melaleuca has two reproduction possibilities due to the fact that seed retention extends beyond seed ripening. First, a low-level, virtually continuous seed release ensures that at least some of the seeds on the ground near the tree will be fresh, thus allowing the species to exploit all reproduction opportunities no matter how short they are in duration. Second, retention of seeds allows for a potential mass seed release if some natural catastrophe kills the seed tree.

Seedling Establishment - Melaleuca seeds germinate upon moist soils, usually within a few days of wetting, and may remain viable up to six months under water or in wet soils (Meskimen, 1962; Myers 1975). Also, seeds may germinate while completely inundated (Lockhart, 1995). Further, seeds survive only briefly outside the capsule. Williges and Harris (1995) reported no melaleuca seed germination from germination trials of seeds of all species collected in melaleuca-infested areas of Lake Okeechobee. Apparently, no viable seeds persisted for collection. Meskimen (1962) found a trend for germination to occur more in sun than in shade. Rarity of seedlings within dense stands of melaleuca may be from either shading or allelopathic effects of melaleuca litter (DiStefano & Fisher, 1983). Melaleuca leaf leachates have slowed germination of slash pine (*Pinus elliottii*) and cypress (*Taxodium* sp.) seedlings, perhaps lending another competitive factor to melaleuca's invasive abilities in Florida (DiStefano, 1981). Seedlings less than several weeks or months old may die from fire or if soils are dry (Myers, 1975, 1983) but soon after seedlings are able to withstand extreme conditions ranging from fire to total immersion for up to six months (Meskimen, 1962). Also, young saplings and seedlings respond to inundation by changing leaf shapes. Leaves become more linear when meristems are deeply flooded, while a rounded leaf forms when the submerged meristem is near the water surface. These water-level induced leaf forms may enable better light or nutrient utilization, or help the plants survive flooding (Lockhart, 1996). Therefore, timing of fire, frost, drought, herbicide application, breakage, and flooding events can determine whether melaleuca seedfall events lead to successful establishment and spread. One computer model predicted that 99 percent of seeds released from "one tree during an ordinary year" (Browder and Schroeder, 1981) would disperse no further than 170 meters, and of these only 5 percent would be viable. Hurricane (100 knot wind) events are predicted to cause maximum seed dispersal of 7 kilometers. Because of the small dispersal zones predicted, this study suggested that control of outlier trees would be an effective control mechanism.

B. EXTENT OF MELALEUCA INFESTATION IN FLORIDA

Amy P. Ferriter

History of the Introduction of Melaleuca to South Florida - In the early 20th century, several independent introductions of melaleuca were made in Florida, but John C. Gifford is commonly recognized as the first to introduce the species to southeast Florida in 1906 (Meskimen 1962). Seedlings were planted at his own home on Biscayne Bay in Coconut Grove, and at the Frank Stirling and Sons Nursery in Davie, Broward County. Austin (1978) reported that "shortly thereafter" (i.e. after introduction) trees originating from these plantings began to invade the wet prairies and marshes of the Everglades. On the southwest coast, melaleuca was introduced through a similar, but independent operation in Lee County near Estero. In the 1930s and 1940s, trees were planted along the rim canal of Lake Okeechobee, and at Monroe Station at Big Cypress National Preserve.

Rate of Expansion - Invasion potential of melaleuca tends to differ among plant communities. Wetter areas are more prone to melaleuca invasion than drier areas. In general, xeric communities such as scrub tend to be resistant, but not immune, to melaleuca invasion. When drier communities are wetter than normal however, they may become susceptible to invasion. Conversely, if a site is continually inundated for extended periods, seeds may be unable to germinate. Although prolonged inundation seems to limit seed germination, and thus seedling establishment, it does not effect established trees.

The rate of expansion of melaleuca varies by locality. Propagation of melaleuca is mainly by seeds. Ten to twenty percent fertility of seeds is reported (Meskimen, 1962), yet seed in seed capsules can remain viable for several years. Several million seeds can readily be held on each tree, of which hundreds of thousands could be fertile and viable at any time.

Generally, seedfall occurs within one to one-and-one-half tree heights (Meskimen, 1962). Woodall (1981b) hypothesized a population cell where expansion from a primary epicenter occurred by seed dispersal under ideal conditions such as"...a crown fire, followed by gale force winds, followed by sustained optional soil moisture conditions". Such theoretical expansion could allow establishment up to 200 meters from the epicenter every once-in-several years of ideal fire, wind and soil condition events. Maximal 2-km dispersal distance is postulated for once-in-twenty years combined events. Densities decrease exponentially with distance from the central population.

The spread of melaleuca has been described as explosive, with the rate of spread accelerating (Hofstetter 1991a, Cost and Carver 1981). A time-series examination of melaleuca (Laroche and Ferriter, 1992) documents its invasive capacity. Rates for invasion of melaleuca into a sawgrass (*Cladium jamaicense*) dominated community are described as exponential. Melaleuca population stabilizes as maximum potential coverage is attained. Laroche and Ferriter (1992) indicated that once the infestation of melaleuca reached 5 percent in a one square-mile area, it took about 25 years for 95 percent infestation to occur within the same area.

Current Melaleuca Population - The potential range of melaleuca in Florida is typically noted as the entire peninsula south of Highway 60, excluding the saline zone. This tree is seemingly kept in check by frost although Woodall (1981b) noted that most, if not all mature melaleuca trees had survived severe frost damage during a record-breaking freeze in Florida in 1977. A few saplings were killed all the way to the ground line. However, sprouts were soon noted growing from the root collars, and planted specimens have survived far north of the range of naturalized populations in Florida. This suggests that the potential range of melaleuca may, in fact, stretch further north than is currently accepted. Climatological models developed in Australia postulate that the entire Gulf coast of the United States provides conditions similar to those in the native Australian range of the tree (Center, 1993)

In south Florida, melaleuca generally grows in a variety of areas; along roadside, on ditchbanks, along rights-of-way, in lake margins, pastures, pine flatwoods, mesic prairies, sawgrass marshes and in stands of cypress trees. Although salinity is thought to be a limiting factor to the encroachment of melaleuca, it has also been reported as growing in mangrove areas (Center and Dray 1986). Habits in its native range indicate a degree of salt tolerance, as frequent reports term melaleuca a "backmangrove species", growing directly behind mangroves and surviving both fresh and brackish water inundation (Myers, 1975).

The known growth characteristics and habitat requirements of melaleuca do not adequately explain the observed differences in its pattern of spread of melaleuca in Florida (Myers 1975, Hoffstetter 1991b). In southeastern Florida, melaleuca not only invades areas where soil has been disturbed; rather, it invades essentially every existing community, including those in which native vegetation is seemingly healthy and vigorous. For example, melaleuca invades the ecotone between pine and cypress, successfully displacing cypress (Ewel et al., 1986). Because hydrologic patterns have been greatly altered in southeastern Florida, and no fresh-water wetlands remain in their natural (historical) state, virtually all of these communities could be considered indirectly disturbed to a significant degree, and perhaps increasingly susceptible to exotic invasion.

There has been several inventory surveys of melaleuca conducted for the entire region (Hofstetter 1991b, Cost and Carver 1981, Capehart et al., 1977, Arvanitis and Newburne 1984). The earliest large-scale attempt to survey the species in south Florida was conducted by Capehart et al. (1977). This effort utilized digital image analysis of LANDSAT data in an attempt to determine the areal extent of melaleuca. The original purpose of this study was to provide baseline data, which could be used in comparative studies of similar surveys conducted at a later date. However, "insurmountable obstacles" prevented the production of such a region-wide distribution map. These difficulties arose from the sizable variability of spectral reflectance recorded within melaleuca stands. Additionally, similarities in reflectance properties of other common south Florida vegetation (such as mangrove) and melaleuca caused erroneous classifications.

Arvanitis and Newburne (1984) evaluated the feasibility of using photographic remote sensing to define melaleuca locations within the region. This feasibility study was based on trials conducted on two test sites on both the southeast and southwest coasts of Florida. It suggested the use of color infrared photography at a scale of 1:12,000 for detection of melaleuca, both individual trees and larger populations. Due to the need for a high degree of contrast, winter photography was recommended for accurate interpretation.

The South Florida Water Management District (1992) completed an inventory of mature melaleuca monocultures within south Florida. This survey utilized false color infrared photography at a scale of 1:40,000 to delineate mature, monotypic stands, 2.5 acres or larger within south Florida. The acreage estimate for these stands which were more than 95% pure, mature melaleuca was 26,000 acres. This survey did not however, include any infestation, which were not pure or nearly pure, and fully mature. Single tree, outlier, and mixed infestation data was not included in this inventory.

Cost and Carver (1981) conducted a large-scale survey of melaleuca, and estimated that there were 40,300 acres of "pure" melaleuca in south Florida. This study covered 7.6 million acres, and observers in a fixed wing aircraft tallied the occurrence of melaleuca. Flight lines were spaced approximately five miles apart, and were flown in an east/west pattern. Pure melaleuca was defined as "Stands that are at least 16.7 percent stocked wherein melaleuca comprises at least 50 percent of the stocking". The result was a dot map, each mark roughly depicting the location of a melaleuca occurrence along the flight line. Acreage figures were interpolated through the use of statistical methods. This survey was repeated in 1987 and 1993. The total number of acres classified as "pure" melaleuca in the 1987 survey total 47,000.

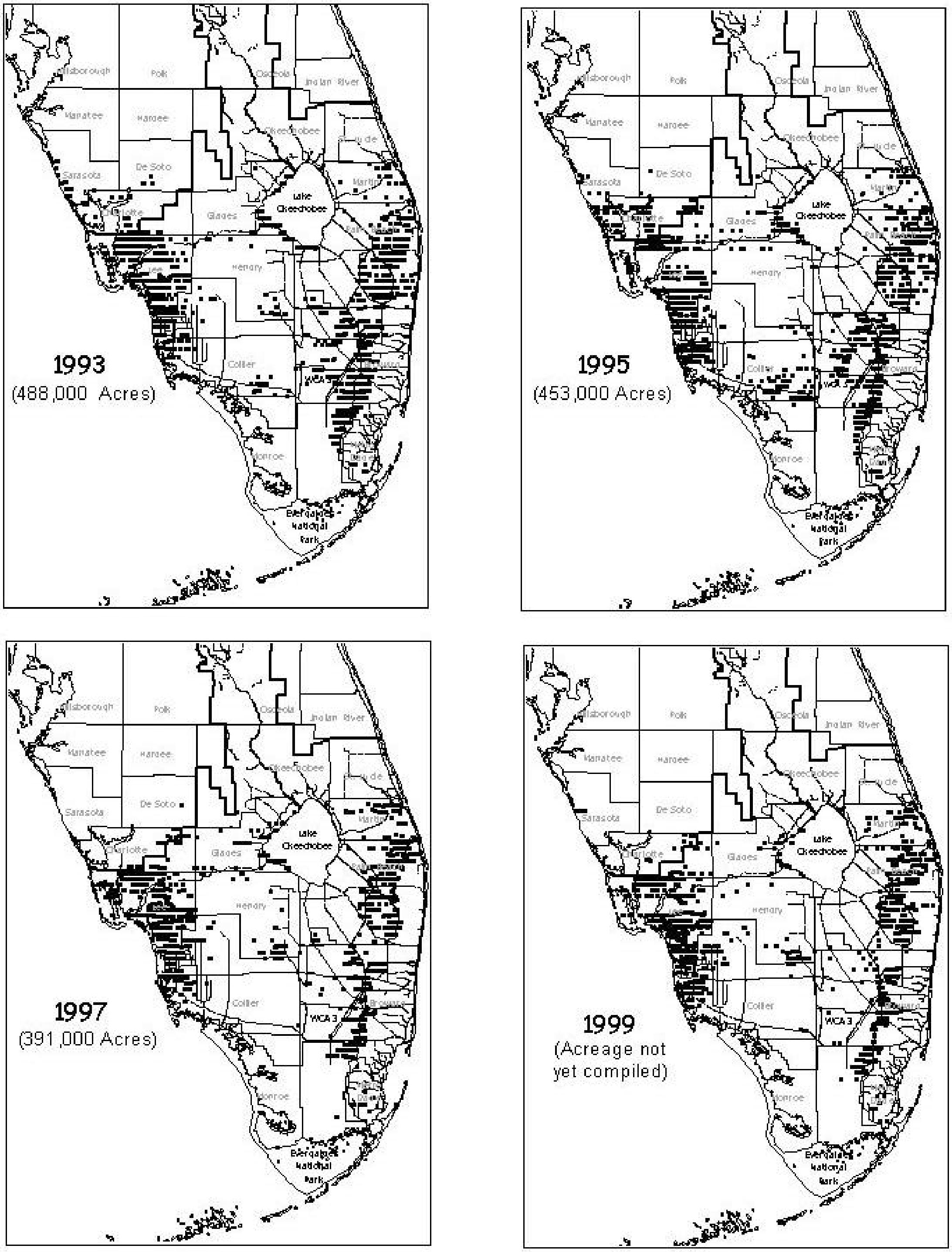
The 1993 survey was conducted through a cooperative agreement between the U.S. Forest Service the South Florida Water Management District and the Department of Environmental Protection. This survey varied from the two previous surveys in several ways. The flight line frequency was increased from 5 to 2.5 mile intervals. Global Positioning System (GPS) and Geographic Information Systems (GIS) technologies were used to navigate the aircraft and record accurate coordinates for each data point. In addition to recording the occurrence of the species, relative density information was recorded as well. Since 1993, the District continues to conduct this survey at two-year intervals. Results of the 1993, 1995, 1997 and 1999 surveys are shown in Figure 2. The 1997 survey indicated that melaleuca infestation in South Florida has decreased by 97,000 acres since 1993. Acreage data from the 1999 survey has not yet been compiled.

Several factors can explain the discrepancies in estimated melaleuca acreage totals calculated by these studies. First, the definition of "pure" melaleuca is inconsistent between the studies. Pure was defined as areas stocked with greater than 50% melaleuca in the Forestry Survey (Cost and Carver 1981), whereas the SFWMD (1992) survey considered monocultures to be greater than 95% stocked. Additionally, acreage estimates were derived from flight lines flown at five-mile intervals, and interpolated through statistical methods in the Forestry Survey. The SFWMD estimates were derived from the delineation and digitization of melaleuca areas from aerial photographs.

The general distribution of melaleuca in south Florida is predominantly centered around the areas of original introduction. The largest, most abundant monotypic stands of mature melaleuca in southeast Florida are concentrated west of urban southern Broward and northern Dade counties. Large, mature monotypic stands are dominant in the undeveloped land west of Pembroke Pines, Miramar, Cooper City and Hialeah. Water Conservation Area 2-B, located west of Ft. Lauderdale is the most severely impacted area of the everglades. It is characterized by very large, mature monocultures, as well as a substantial amount of seedlings, saplings and pioneering, or "outlier" melaleuca. Moderate to heavy infestations (many outlier, small and large heads) occur in the Loxahatchee National Wildlife Refuge, Big Cypress National Preserve and the eastern half of the East Everglades Acquisition Area. Light to moderate infestations (widely scattered outlier and small heads) occurred in WCA 3 and the western half of the East Everglades Acquisition Area. Very few outlier melaleuca have invaded the Holey Land, Everglades National Park, and WCA 2-A.

Detailed, large-scale outlier coverage data is not currently available for the entire area. However, as control operations proceed within the WCAs, Lake Okeechobee, Loxahatchee National Wildlife Refuge, Everglades National Park and Big Cypress National Preserve, coordinate and attribute data is recorded. This is, in effect, an "after the fact" mapping process as those trees which are mapped are also those which are treated, and presumably will die. This data could however, be used to supplement other, and less detailed mapping projects. This would allow an estimate of outlier coverage, and a more realistic depiction of the total area infested with melaleuca. For example, although the infestation level in WCA 3 is described as light to moderate, 500,000 mature trees, and 1.5 million seedlings were treated by the SFWMD within a 200,000 acre section of the area. This helps to illustrate the fact that even with relatively low levels of infestation, a significant amount of melaleuca is still present, and in fact spreading.

Figure 2. Occurrence of Melaleuca in South Florida in 1993, 1995, 1997and 1999.



C. ENVIRONMENTAL, ECONOMIC AND HUMAN IMPACTS

Don C. Schmitz and Ronald H. Hofstetter

Environmental Impact - Melaleuca has been described as an invader of disturbed areas, with most undisturbed ecosystems being largely resistant to, but not necessarily immune to, colonization (Ewel et al., 1976). For example, ecotones between wetland and upland forests (especially the southern Florida pine-cypress tree ecotones), although relatively undisturbed by humans, have been invaded by melaleuca (Myers, 1983, 1984). Melaleuca is more prevalent, however, in those wetlands where hydroperiods have been shortened through human actions (Hofstetter and Sonenshein, 1990).

Some additional factors should also be considered in explaining melaleuca's rapid spread in southern Florida. First, because most of the native plant communities experiencing melaleuca invasions are fire-maintained, melaleuca's success may also be related to its ability to be the first woody species to get its seed on the ground and germinate following a fire (Myers, 1983). Second, fuel conditions change significantly as melaleuca displaces sawgrass (Flowers 1991). Compared to fires in herbaceous dominated marshes, fires in melaleuca forests burn at temperatures high enough to dry out and ignite surficial organic soils (Hofstetter and Sonenshein, 1990; Flowers, 1991) creating depressions that may also have some impact on native seed bank capacity in the soils. In addition, ground fires, along with the high temperatures, rapid fire spread rates, and abundant smoke in burning melaleuca stands probably present new risks for wildlife in the Everglades wetland system (Flowers, 1991). The impact of land surface lowered by ground fires on the flow of surface waters and the shallow aquatic communities in the Everglades has not yet been investigated.

The predominant plant communities in the Everglades are graminoid marshes devoid of trees (except for those found in distinct tree islands). Once established, melaleuca eventually outcompetes the shorter species for available sunlight. As melaleuca replaces the natural marsh communities of southern Florida, ecological conditions greatly change. Differences in species composition and structure between marsh and melaleuca forest are obvious, but the ecologically functional consequences are not yet fully understood. Hofstetter (1991a) found that transpiration rates per unit area of leaf of sawgrass (1.913 $^{+}$0.578 ug $cm^{-2}sec^{-1}$, N=24) and of melaleuca (2.128 $^{+}$0.819 ug $cm^{-2}sec^{-1}$, N=37) are similar. The total leaf area (per unit area of ground surface) of melaleuca in dense stands of trees more than 4.5 meters tall, was at least four times that of robust sawgrass communities. Consequently, a stand of melaleuca may transpire more water than the robust sawgrass communities it replaces. The Biscayne Aquifer is nonartesian and underlies an area of approximately 8,288 square kilometers in Dade, Broward, and Palm Beach Counties (Klein and Hull, 1978). It is the sole source of fresh-water along the highly populated east coast. Invasion by extensive melaleuca populations into these counties will probably hinder the ability of the Biscayne Aquifer to recharge with more water being removed from the system through increased evapo-transpiration (Hofstetter, 1991a).

Melaleuca forests have displaced native southern Florida plant communities. By forming an almost impenetrable pure stand, melaleuca populations in prairie marshes have eliminated the indigenous plant genera *Sagittaria*, *Hypericum*, and *Stillingia* (Richardson, 1977). Alexander and Hofstetter (unpublished data) observed complete displacement by melaleuca of native species in the genera *Andropogon*, *Eragrostis*, *Eupatorium*, *Rhynchospora*, *Cladium*, *Panicum*, *Pluchea*, *Erianthus*, and *Setaria* in a prairie marsh. DiStefano and Fisher (1983) reported that melaleuca out-competed and displaced native plant species in a pine savanna, a cypress-hardwood forest, and an early successional grass-herb community. Richardson, (1977) noted that monospecific stands of melaleuca, especially in prairie marshes, are devoid of most ground cover plants. In a permanent 100 m^2 plot study by Alexander and Hofstetter (unpublished data), the interior flora of a melaleuca infested swamp forest (tail of a tree island) contained only scattered *Blechnum serrulatum*, *Cladium jamaicense*, *Proserpinaca*, *Ludwigia*, and seedlings of *Annona glabra* in 1972. This site had experienced previous disturbance having been partially cleared during the 1950's. At the start of their study in 1972, the previously cleared and uncleared parts of this tree island were botanically indistinguishable. In 1975, the only plant species found in the plot, other than melaleuca trees, were 5 individuals of *Blechnum serrulatum*. By 1983, there was some increase in plant species richness. The sparse forest floor cover consisted of mostly of *Blechnum serrulatum* and *Osmunda regalis*, with occasional plants of *Thelypteris kunthii*, *Acrostichum danaeifolium*, *Cladium jamaicense*, *Eulophia alta*, small *Cephalanthus occidentalis*, and seedlings of *Annona glabra*. The slight increase in species numbers in 1983 was believed to be related to a natural thinning process of the canopy of maturing melaleuca trees that allowed more light to penetrate to the forest floor.

Temperature and water are important in regulating the activities of ecosystem decomposers (Odum, 1971). In the absence of fire, it is not unusual to find a mature melaleuca forest (older than twenty years) containing a rich layer of undecomposed leaf litter. This creates an elevated tree island in wetlands where one had not existed previous to the invasion. Flowers (1991) noted ground fire fuel load changes when melaleuca trees displace sawgrass. He believed it was due to a continuous rain of leaves and small branches from melaleuca's tree canopy that results in a rich layer of undecomposed leaf litter beneath the trees. After a freeze killed melaleuca trees, Flowers (1991) noted the previous ground fuel load on the forest floor doubled to a 10.2-centimeter layer of dead leaves. Young melaleuca forests produce a relatively closed tree canopy and we speculate that this lowers ground temperatures by shading. Because of this shading, and combined with an increased evapotranspiration rate in areas like the wet prairie systems in the Everglades, melaleuca forests may have a long-term impact on the normal rate of soil decomposition found in these ecosystems. Further research is needed to document changes responsible for creating these melaleuca produced elevated soil conditions in wetlands.

Surveys of native arthropods associated with melaleuca trees in Florida have not been published. Of the anecdotal information available, herbivory and disease have not been observed to effect any significant control over melaleuca growth, vigor, and spread.

Although in some southern Florida locations, damage to melaleuca trees has been caused by the fusicoccum stage of the ascomycetous fungus, *Botryosphaeria ribis* (Center, 1992).

The Everglades has long been recognized for its unique species assemblages. Studies to date suggest little use of melaleuca stands in southern Florida by native wildlife. In a study that reports the results of two investigations in the Everglades Water Conservation Areas, Schortemeyer et al. (1981) found several bird species were utilizing melaleuca stands in areas where artificially deep water and extended hydroperiods had killed or damaged native trees, leaving melaleuca trees as the only dominant woody vegetation for these bird species. The majority of all birds observed in this study, however, were engaged in incidental activities in which the actual value of melaleuca was undetermined. Schortemeyer et al. (1981) suggested that melaleuca stands may provide nesting and roosting sites for anhingas (*Anhinga anhinga*), egrets, and herons in areas where management practices have increased water depths and lengthened hydroperiods resulting in the death of native trees. Bancroft et al. (1992), however, believed the current trend of increasing melaleuca cover along with formerly rare cattail (*Typha dominguensis*) populations in the water conservation areas of the Everglades, can be expected to degrade or reduce Wood Stork (*Mycteria americana*) habitat.

Small mammal populations are an important link in several food webs in the Everglades. Their displacement could seriously affect populations of plants and other animals (Ostrenko and Mazzotti, 1981). Ostrenko and Mazzotti (1981) found reproductive and juvenile stages of native cotton mice (*Peromyscus gossypinus*), cotton rats (*Sigmodon hispidus*), and transient rice rats (*Oryzomys palustris*) in melaleuca stands, although population densities were substantially lower than those reported by Smith and Vrieze (1979) for native hammock and tree island communities. Similarly, Sowder and Woodall (1985) reported rodent populations in melaleuca stands to be poor. They concluded that utilization of a melaleuca stand by small animals may depend more on the surrounding ecosystem than on the unique vegetational characteristics within the habitat. Mazzotti et al. (1981) suggested low plant species richness alone does not determine rodent distribution and abundance. Ostrenko and Mazzotti (1981) and Mazzotti et al. (1981) further noted that any capacity to support at least one rodent species should not be interpreted to mean melaleuca stands are good habitat for wildlife in southern Florida.

Although studies on food preference, or food habits, were not conducted for deer in melaleuca stands, Schortemeyer et al. (1981) reported that melaleuca's relatively low moisture and high crude fiber contents yield a low digestibility coefficient. Low levels of protein, phosphorus, potassium, magnesium, and sodium also indicate melaleuca may be deficient in a number of essential elements and compounds needed by deer. This study concluded that melaleuca stands would eventually eliminate adjacent essential wildlife habitats.

Even future ecosystem restoration efforts in southern Florida may be jeopardized by invasions of alien plant species such as melaleuca. For example, the potential for melaleuca to alter soil topography through the accumulation of leaf litter in the absence of normal fire regimes is a significant factor in future management efforts to remove this Australian tree and to restore native plant species assemblages that existed prior to invasion. Melaleuca tree islands newly opened by control efforts will probably be more prone to invasion by other alien plant species if the normal soil topography is not restored in areas dependent on long hydroperiods. In addition, the impact of Hurricane Andrew, which struck just south of Miami on August 24, 1992, may lead to an even wider colonization by alien plant species in south Florida (Doren, 1993). In terms of melaleuca expansion, hurricane force winds can theoretically transport viable melaleuca seeds a maximum distance of 7.1 kilometers (Browder and Shroeder, 1981). Further, increases in alien plant populations in southern Florida have been observed after previous hurricanes (Klukas, 1969; Alexander and Crook, 1973), which disturbed and destroyed native vegetation.

Economic Impacts - Melaleuca is believed to be an important component of Florida's bee-keeping industry. The tree is considered to be a prime source of nectar for honey, package bees, and wax. However, there is no indications that bees are flower limited in southern Florida during any season and that the emergence of melaleuca as a nectar source is a response to the tree's increased availability relative to traditional native sources (Diamond et al., 1991). Melaleuca honey is considered to be "baker's honey," not a table honey, and the dollar value of melaleuca honey is a relatively unimportant share of total production (Robinson, 1981). The larger value of this species to the beekeeping industry is in its maintenance of wintering hives, which in turn are responsible for honey production from other sources. While significant bee populations could be affected by the theoretical absence of melaleuca (it is considered to be impossible to eradicate from southern Florida), wintering bees would most likely find other sources of pollen (Diamond et al., 1991).

The benefits and costs for removal of melaleuca have been estimated by Diamond et al. (1991). The total annual benefits, especially to Eco-tourism, of preventing a complete infestation of melaleuca within the Everglades and south Florida's wetlands would be $168.6 million a year, whereas the resulting losses in honey production and pollination services would cost only $15 million a year.

Human Impacts - Morton (1966) first reported that melaleuca tree pollen may act as a human respiratory irritant in southern Florida's urbanized areas. Further research revealed that melaleuca pollens did exhibit a high degree of allergenic cross-reactivity with bottlebrush (*Callistemon citrinis*, family Myrtaceae), another widespread Australian alien plant invader in Florida (Stanaland et al., 1986). Individuals allergic to one grass or tree pollen may also suffer from allergic reactions following exposure to other grasses or trees where sensitization has occurred. Hence those individuals who are allergic to bottlebrush pollens in Florida, may have a similar reaction to melaleuca pollen (Stanaland et al., 1988). Diamond et al. (1991) noted that one in five individual in Palm Beach County is sensitive to melaleuca.

Of far greater concern are the highly volatile oils that comprise melaleuca leaves and branches. Wade (1981) described that land clearing before development in southern Florida promotes melaleuca colonization and, after a few short years, results in buildings "surrounded by a gigantic melaleuca torch waiting to be lit." Wade cited examples of this phenomenon that can be easily found in parts of Lee and Collier Counties. Melaleuca fires burn with great intensity and are difficult to combat and present a high degree of difficulty to fire-fighting agencies (Flowers, 1991). Out of control fires in melaleuca forests can and do frequently occur in southern Florida. Clearly, as melaleuca populations expand in southern Florida along with increased human population settlement, the risks increase for loss of human life and property from melaleuca fires.

D. MANAGEMENT TECHNIQUES

An integration of all available control techniques will be required to effectively eliminate melaleuca from natural areas. These control techniques include biological, mechanical, physical, and herbicidal methods. The current melaleuca management program in Florida is not truly integrated. Biological control is not yet available and physical controls, such as fire and flooding, are not completely understood or easily managed. Use of mechanical control has been mostly limited to felling trees on site and manual removal of seedlings in natural areas. Initial efforts and much of the current effort in developing control measures for melaleuca have been in the examination of herbicide methodologies. Herbicidal control currently offers the only practical and economically feasible method of limiting the further expansion of melaleuca in most areas.

Managing melaleuca requires knowledge of its biology. The reproductive potential of melaleuca is tremendous. A mature tree may retain millions of seeds, all of which may be released from their protective capsules following a stressful event. This stress may be caused by desiccation, fire, frost, physical damage or herbicide application (Meskimen, 1962). Once released, it is reported that these exceptionally small seeds do not remain viable for longer than one year (Woodall, 1983). This relatively short period of seed viability limits the time for new seedling establishment, also limiting the monitoring period at a site following herbicidal control.

Hypothetically, melaleuca can be eliminated from an area in just a few years. The first year of control would target all existing trees and seedlings in a given area. Using LORAN-C or Geographic Positioning System (GPS) coordinates as a guide, control crews return to the same site in subsequent years and remove any seedlings resulting from the previous year's work. Realistically, several years are required to eliminate melaleuca from a particular site to insure that all trees and/or new seedlings are controlled. Recent experiences indicate that seeds may remain dormant, and viable, for several years. If this is the case, then long-term monitoring is crucial. Additional research regarding the reproductive biology of melaleuca is needed to study the questions of seed viability in the environment.

1. Biological Control

Ted D. Center and F. Allen Dray, Jr.

Plants are often prevented from becoming serious weeds in their native countries by a complex assortment of insects and other herbivorous organisms that feed upon them. It is the absence of these species that permits some plants to become serious pests outside of their native range in areas where they have been introduced. "Classical" biological control seeks to locate such insects and import host-specific species to attack and control the plant in regions where it has become a pest. The "classical" approach has a proven safety record (none of the approximately 300 insect species imported for this purpose have ever become pests themselves) and has been effective in controlling almost 50 species of weeds. US Department of Agriculture (USDA) scientists have identified numerous insect species that feed on melaleuca in Australia.

This portion of the plan is aimed at developing biological control agents that will effectively control melaleuca or, at least, contribute towards control in an integrated management system. The scope is broad, covering a complete, beginning-to-end biological control project, including foreign exploration, overseas screening, quarantine follow-up, field colonization, performance assessment, and technology transfer.

The principal objective of the foreign exploration portion of the project is to find effective agents and provide evidence of their safety. This is needed to support requests to the Animal Plant Health Inspection Service (APHIS) to import superior candidates into U.S. quarantine facilities. The quarantine process, a continuation of the initial foreign screening procedure, is designed to corroborate the safety of promising candidates, particularly addressing potential risk of collateral damage to non-target native and economically important plant species. The domestic phase of the project transforms "potential" biological control agents into actual, usable instruments of control. This step mandates that the agents first be established in nature. Realizing the full potential of the agents necessitates evaluation of their impacts as well as recognition and assessment of their shortcomings.

Phase 1. Selection and preliminary study of candidate biological control agents. This phase is aimed at providing inventories of insects, pathogens, and other natural enemies of the target weeds, quickly culling this list to exclude unacceptable or ineffective species, then selecting from among those remaining to choose viable candidates for further development. This pre-quarantine process is normally completed in the native geographic range of the target. Sufficient study of the host-selection behavior follows to ensure that the top candidates do, in fact, harm the target and include only species with parsimonious host ranges. Those that appear to be the safest and most effective are then exported to U.S. quarantine. It is often considered advisable to also inventory the herbivorous fauna associated with the target plant within the adventive range so as to avoid dedicating resources unnecessarily studying species overseas that might already be present in the

U.S. This entire process may or may not involve submission of a written report and request to APHIS-PPQ. The reviewing official may or may not require review by the designated Technical Advisory Group (TAG). In any case, APHIS import permits must be acquired. Acquisition of these permits marks the successful attainment of this objective.

Phase 2. Clearance of candidate biological agents for field release. The objective of quarantine testing is to ensure that the candidate biological control agents do not utilize (as hosts) native species, economic species, ecological homologs, or other species that cannot be tested overseas. These species generally occur in the U.S. but not overseas, and so must be tested in the U.S. in specialized quarantine facilities. Species found to be specific in pre-quarantine screening would be unlikely to attack native plant species, but these additional precautions are mandatory. Often candidate agents will accept alternate host-plants in a laboratory environment, but reject them in natural settings. This dilemma cannot be resolved in quarantine. Blind acceptance of laboratory results leads to inappropriately high rejection rates of potential candidates. It is therefore sometimes useful to resume testing at the overseas laboratory so that results can be confirmed or refuted in open field experiments. This illustrates the clear advantage of simultaneously conducting both foreign and quarantine evaluation studies. This phase of the project always involves preparation of a complete report that objectively summarizes all available information on each candidate and a petition to APHIS requesting permission to release the subject candidate. The screening of each agent usually requires 2 years. Acquisition of permits to release the organism from quarantine marks the successful attainment of this objective.

Phase 3. Establishment of field colonies. The objective of this phase of the project is to increase the supply of available agents from the few transferred from quarantine to a quantity sufficient for widespread site inoculations. Although a marginal release program can be supported by laboratory colonies, it is much more practical to establish initial founder colonies in the field. These incipient populations serve as "nursery" colonies to provide organisms for further release and dissemination. They also provide nascent foci which fuel dispersal and subsequent unassisted colonization of remote sites. This necessitates initial establishment of laboratory colonies as well as development of release techniques, and might require periodic infusions of fresh germplasm from overseas sources. The persistence of self-sustaining field populations of the released organism marks the successful attainment of this objective.

Phase 4. Assessment and documentation of impact. Assessment of the impact of a biological control agent is required for a number of reasons. It provides feedback that can be incorporated into the program to determine if, for instance, additional agents might be needed to achieve the necessary level of control. It also is needed for publicity purposes, especially to advertise success. It also fulfills the scientific obligation to learn from each experience so as to enhance future projects. We also have a public obligation to determine the consequences of releasing each new organism into the environment. Most of all, however, we must be able to advise end-users as to the utility of the control measure and to alert them when a new biological control becomes "operational" as opposed to "experimental". This phase involves the development of various protocols for measuring success, the design of appropriate field experiments, site selection, the selection and measurement of relevant parameters and analysis of the results. The designation of a specific biological agent as "operational" marks the successful attainment of this objective.

Phase 5. Determine distribution of biological control agent and re-distribute. The objective of this phase is to ensure that effective biological control agents become disseminated throughout the range of the target plant. Successful attainment of the objective involves monitoring of the agent as it naturally disperses to other sites, surveying for the presence of the agent throughout the range of the host plant, identifying strategic locations for release within areas that lack the agent, and organizing collections of the agent from nursery sites for distribution to uninfested areas. This may also involve, where feasible and cost effective, mass-rearing efforts to augment field collections of the agent. Assistance with re-distribution efforts is usually provided by action agencies but, because it would be wasteful to distribute ineffective agents, this effort is normally restricted to those species that are of proven value. Saturation of the entire adventive range of the target species with populations of the biological control agent marks the successful attainment of this objective.

Phase 6. Conduct foundational studies to provide basic answers to technological problems that impede or interfere with progress towards accomplishment of primary objectives. New biological agents, at the time of their discovery, are often unknown entities. Virtually nothing is known about many aspects of their biology and behavior prior to laboratory testing or subsequent implementation. Also, lack of critical information, on the biology of the target plant or the ecology of the aquatic systems into which use of the agent is contemplated, can preclude attainment of key objectives. When these obstacles are encountered, it may become necessary to delay the overall program until this critical information is acquired. Foundational research may also be needed to enhance the effectiveness of established biological agents. For example, it might be possible to attain quicker or better control by augmenting existent insect bioagent populations. Augmentation is usually difficult, however, because of the problems associated with acquiring large numbers of the organism. Basic research to identify semiochemical attractants that could be used to trap large quantities of the bioagent or to lure them to target areas could overcome this obstacle. No specific milestone can be cited that would designate successful attainment of this objective other than the surmounting of obstacles encountered in the overall program.

Technical issues - The researchable technical problems of the project vary according to the project phase. Obviously, the first problem involves acquisition of the faunal list of organisms associated with the target species. Although acquisition of specimens from the plant is a simple matter, it is not so easy to discern the role of each species and to determine which actually utilize the plant as a host. Direct evidence of feeding on the living plant tissues is necessary, and this is often difficult in aquatic environments in foreign areas where a well-equipped laboratory is not accessible. Associated with this is the problem of ensuring that the final list is comprehensive, including all feeding "guilds". It might be relatively simple to collect leaf-feeders, for example, but much more difficult to sample root-feeders or stem-borers. It is also necessary to account for seasonal variability in the composition of the herbivorous faunas associated with the target species and phenological synchrony between the plant-feeders and the target plant. This necessitates long-term surveys or repeated trips to survey areas. Obviously, logistical problems occur when the native range of the target plant encompasses several continents. Strategies must be developed that effectively "sample" the insect fauna from throughout the range or narrow the focus of the surveys. This might necessitate climatic comparisons so that ecoclimatic regions similar to the region where control is desired can be selected , thus focusing on organisms most likely to perform well in the U.S. (Worner 1988, Dennill and Gordon 1990) and simultaneously narrowing the search area.

Availability of taxonomic expertise is critical. The organisms collected during the survey phase must be identified or, if they are unidentifiable, they must at least be recognized as a new or distinct species. At this stage the project is dependent upon taxonomists and delays in obtaining identifications can forestall further progress on evaluation of a potential candidate. This might necessitate funding of basic taxonomic research (Phase 6) to establish the correct identity of the organism of interest and possibly consider the existence of biotype, host races, and sibling species. Obtaining identifiable stages of the organisms can also be problematic. Some species may be recognizable solely as adults, for example, but collectable only as larvae. This necessitates partial laboratory rearing prior to seeking determinations, and many species (especially wood-borers and root-feeders) can be difficult to rear. An equally important taxonomic aspect is the accurate identification of the plant that each insect is collected from or reared on. This necessitates the availability and accessibility of botanical taxonomists. It also requires all personnel associated with the project to develop a superior level of expertise in distinguishing between the target plant and closely related species or even, perhaps, undifferentiated varieties.

A major difficulty encountered in the process of screening plant-feeding insects is ensuring that they are host-specific. This difficulty arises from the fact that these insects behave quite differently in small containers in a laboratory environment, where they are unable to escape, than in the open in nature. The artificiality of these tests leads to two types of errors. The first is the possibility of declaring a species to be host-specific when it, in actuality, is not. The second is the possibility of rejecting a good candidate based on an artifactual apparent lack of specificity. The second, and the most common type of misinterpretation, occurs because attraction to the host is eliminated as a variable in a contained environment. Resultant apparent host ranges appear to be broader in petri dishes and small containers than in nature. Rejection of species solely on the basis of laboratory studies leads to a highly conservative program and minimizes the "risks" of introducing a pest. However, it also leads to the loss of many potentially effective candidates and causes lost time and effort. As a result, it is advisable to mix laboratory tests with various field experiments designed to determine if species that appear to be hosts are actually utilized as such under field conditions. This step may necessitate a resumption of work in the foreign location after initiation of quarantine studies so that questions arising from the quarantine process can be addressed under natural conditions.

The ability to rear the subject insect is critical to all phases of the project, so early development of rearing techniques is essential. The overseas activities can sometimes proceed without colonies of the test subject, but progress becomes opportunistic and subject to the field availability of test organisms. The quarantine phase is even more cumbersome without quarantine colonies because testing becomes reliant on a continual supply of insects from abroad. The release phase is virtually impossible unless the agents can be reared. Developing the means of rearing these insects is somewhat of an art, though, requiring experience, patience, and often a great deal of trial and error. Nonetheless, development of rearing techniques must be afforded high priority at the earliest practical stage.

Another significant problem that must ultimately be dealt with, is the determination of the criteria for proof of host-specificity. There is no absolute test for this. Tests can only prove that an agent is "unsafe". The fact that host range encompasses more than the insect's ability to survive on a plant prompted Harris and Zwölfer (1968) to suggest that studies should include investigation of the chemical and physical basis of host recognition. A determination that an agent is safe therefore rests on an accumulation of many pieces of circumstantial evidence and necessitates an understanding of the mechanism of host specificity including the full repertoire of host-finding behaviors (Zwölfer and Harris 1971). Obviously, only a sampling of the thousands of plant species that are extant in nature can be tested. Fortunately, most plant-feeding insects display distinct patterns in their choice of food plants. When non-target species are accepted, they are generally those most closely related to the original host. Hence, testing is normally most intense on closely related species and less intense on distantly related species. Literature reports and museum records of similar and closely related insects also provide clues to possible alternate hosts. These, too, are checked quite carefully. Non-related plant species that occur within the same habitat as the target plant are also screened, as are economic species. These latter tests are necessary mainly to satisfy regulatory agencies, since the risk to these species is virtually non-existent. Attempting to assuage the concerns of multiple agencies, however, can lead to excessive levels of unnecessary testing. Thus, it would be prudent for the researchers and the regulators to jointly prepare guidelines for the testing program. Failure to do this in advance is likely to result in supplementary tests.

Agent establishment at field sites in the weed's adventive range is often a difficult and time consuming process but it can also be amazingly simple, depending on the biological attributes of the organism. Although there is general agreement that only parasite-free individuals should be released, and parasites can usually be easily eliminated in quarantine, the value of disease elimination is an unsettled issue (Shroeder 1983) and must be considered on a case-by-case basis. A complete knowledge of the basic biology of the organism can be crucial if establishment proves to be difficult. Failure to establish an agent can be due to any one of several factors, including disease, predators, and parasites, (Goeden and Louda 1976) and repeated attempts are often necessary.

The genetic stock used to develop founder colonies is normally obtained from the original quarantine colony, which might have been bred in captivity for several years. This excessive inbreeding is likely to produce laboratory-adapted strains that do not survive well in nature (Cullen 1981, Mackauer 1976, 1981). It is advisable, therefore, to obtain fresh germplasm from the overseas source for use in the establishment effort. This necessitates brief quarantine rearing while the identity of each specimen is confirmed and parasites and entomopathogens are eliminated. An alternative to continual replenishment of the germplasm is attention to quality control in the colonies so as to avoid genetic decay. This, however, pre-supposes knowledge of the characteristics needed for the agent to survive in the field. The number of organisms needed to attain establishment of founder colonies varies for different species, but, in general, the more that can be released, the better. This often requires an extensive rearing program designed to produce large numbers but, in general, the rearing process adversely affects quality. A trade-off is obviously required and attention to quality control is merited, if possible.

The selection of appropriate release sites is critical to the establishment of a biological control agent founder colony. However, this presupposes that the criteria are known that defines "appropriate". Oftentimes, this must be dealt with on a "trial-and-error" basis. Detection of the organism after establishment can also be difficult if it moves away from the initial release area or if it persists at very low levels. Various methodologies must be evaluated to determine establishment, including the use of cages or other enclosures and trapping of the mobile stages. Differing biotype of the target plant in its adventive range as compared to the area serving as the source of the bioagent can also thwart establishment attempts and must sometimes be thoroughly evaluated. Matching biotype is difficult, however, and oftentimes requires sophisticated genetic analysis.

Evaluating the efficacy of the biological control agent is an absolute necessity. Evaluations are rarely undertaken, however, because of the higher priority usually afforded the earlier project phases. This trend should not be allowed to continue, and assurance of support for evaluation studies should be pre-requisite to initiation of biological control projects. Evaluation studies can take many different directions, however. They can be aimed at economic issues, understanding the dynamics of the insect populations, the interaction between the host and the insect, or the dynamics of the plant population. They can also be much more practical and aimed at simply quantifying the level of control obtained (although useful for providing proof of effectiveness and advertising success, this approach offers little in the way of new scientific knowledge). Determination of criteria for success should involve the end-user groups and a consensus on objectives of the program should be obtained at the outset of the project. Failure to do so leads to later useless debates over the impact of the program.

The traditional approach to biological control is normally passive. The bioagents are normally released in an inoculative manner and then left to be as effective as they can be on their own. However, we've begun to realize during the past few years' desirability of managing and possibly augmenting bioagent populations. This is particularly desirable in perturbed ecosystems where periodic disruptions (such as herbicidal applications) prevent the biological control agent from attaining population levels capable of exerting sustaining control on the target weed. Integrated methodologies must be developed that focus on the management of the bioagent population to achieve integrated biological control. This should be contrasted to methodologies that focus on integrated herbicidal control or integrated mechanical control. The difference lies in the basic expertise needed to implement the strategy. Management of bioagent populations requires entomological or phytopathological expertise and should be undertaken by biocontrol specialists assisted by herbicidal/mechanical specialists, rather than the reverse.

Peter Harris (1989) of Agriculture Canada often comments that biological control is more than a science in applied ecology. It also has unique administrative and political attributes that must be balanced in order to attain a successful program. If these aspects are given due attention, biological control almost inevitably becomes a highly effective management technique. Attaining this balance is probably the most critical problem (albeit not necessarily a technical one) facing this project.

2. Mechanical Control

Daniel D. Thayer

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 would require a herbicide application to prevent root sprouts and re-growth from cut surfaces.

Increasing interest in uses of exotic pest trees for commercial purposes, such as mulch and boiler fuel, may lead to partnerships between the government and private industry. Innovative methods of removing trees from wetlands are being developed in timber growing regions of the southeastern U.S. This may make commercial exploitation profitable without environmental degradation.

Currently, felling trees in place and manual removal of melaleuca seedlings are the only forms of mechanical control being used in the natural areas of south Florida. Hand pulling of trees is generally restricted to trees less than two (2) meters in height.

3. Physical Control

Holly A. Belle, Ronald L. Myers and Dan D. Thayer

Woody vegetation can be stressed, or sometimes killed, by environmental alterations such as water level manipulation or fire. Constraints often limiting the usefulness of these methods include: the ability to maintain required water levels; the effects of these manipulations on desirable vegetation; having adequate conditions for prescribed burns; and the liability involved with burning. However, research, which incorporates physical stresses into other methods of melaleuca control, is important and ongoing.

All of the following control tactics should be considered experimental, as they have not been tested at the management level. Their application will require flexibility and knowledge on the part of the control program manager so that crews can take advantage of ephemeral site and stand conditions as they are identified. In other words, the tactics are targeted at specific states within an ever-changing array of environmental conditions, stand structures, seed sources, regeneration status, and fuel loads. The control manager must be able to anticipate and identify brief windows of opportunity where melaleuca may be most susceptible to treatment. Failure to time treatments properly may exacerbate rather than alleviate the problem. Failures in timing, however, should be expected. When they occur the manager needs to be prepared to identify and evaluate timing errors so follow-up treatments can be applied.

Results from a research project conducted by The Nature Conservancy (Myers and Belles, 1995) suggest that fire alone is not adequate. This is not an unexpected conclusion as melaleuca's ability to rejuvenate after fire is legendary. Recovery of melaleuca stands after fire and post-burn seedling establishment and growth were too rapid for our short-interval burn cycle to have any lasting impact. What remains unknown regarding fire and melaleuca is the response of melaleuca stands to a long-term pattern of repeated frequent burns. However, burning can be an important tool in melaleuca control efforts if timed appropriately.

Although this particular study failed to show differences in establishment success between unburned and burned sites (because nearly all seedlings died), there were notable differences in initial germination, with much greater germination occurring on burned plots than on unburned plots. Results from this study along with other life history information, strongly suggest that successful establishment is much less likely if the groundcover and periphyton mat remain intact. This being the case, then establishment from seeds released from a herbicide kill, cutting, or frost damage would be quite low relative to what would occur after fire-induced seed release on the same or equivalent site. Numerous casual observations made on herbicide treated sites are consistent with this assumption.

There are situations where fire can potentially be used to limit successful establishment of melaleuca, by releasing seeds at times when they are unlikely to encounter favorable conditions. Although there are periods during the year when such conditions are more likely, variability from one year to the next makes timing difficult.

When might seeds encounter unfavorable conditions? Burning in the late wet season when the water table is at or near the surface would release seed onto a wet to moist seedbed. Seedlings would appear within a week and if the soil remained moist for 4 to 6 weeks, most of the seeds would germinate. If the ensuing dry season is normal to protracted, many, if not all, of these seedlings would die. Periodic rains through the dry season, however, would allow considerable regeneration and many of the seedlings might be large enough to survive the ensuing period of flooding.

Another unfavorable period occurs immediately after the onset of consistent summer rains. In this scenario water levels would be rising, the soil would be wet, and flooding would likely occur within a few weeks. A burn at this time would get the seed on the ground while the soil is wet, germination would occur, then the seedlings would be submerged for an extended period. Results from the Loop Road and Monument Lake studies, Big Cypress National Preserve, show that many seedlings do not survive this extended flooding. Problems occur when either water levels rise too quickly or germination is delayed until the end of the wet season as the soils dry slowly, or water levels fail to rise altogether or fluctuate exposing the soil surface periodically through the wet season.

Results strongly suggest that every effort should be made to get seeds on the ground while the ground cover is intact, rather than following fire, both because of the limited establishment success on the former compared to the latter. Also, because of the availability of fuel to burn seedlings that do become established.

Results show that virtually all seedlings less than 6 months old can be killed by fire, and that in this study situations occurred where over 90 percent of seedlings two years or less were killed by fire. The likelihood of mortality decreases with seedling or sapling size. Fire is ineffective in killing most saplings greater than 2 to 3 m tall.

Sites with intact fuel beds offer the best opportunities for seedling and sapling control with fire. Burning could easily kill regeneration established from seed released due to herbicide-kill, frost-damage, or hurricane winds. The fire should be timed to ensure that most of the seeds have germinated but that the seedlings have not reached a size where many are likely to survive the fire. Remember, germination may be delayed for months due to either flooding or drought, and that growth after germination will vary greatly from site to site, so there is no set rule to follow regarding seedling age or time since fire. Sites where seeds have been released must be monitored to verify that germination has occurred and that the seedlings do not exceed a meter or so in height. This is your window for effective burning of seedlings.

Establishment from seeds released after a wildfire pose additional problems. The quantity of seedlings is likely to be huge, and initial growth may be rapid relative to what would occur on an equivalent unburned site. Furthermore, fuel loads may be too low to carry a second fire for 2-3 years. However, studies at Monument Lake did show that muhly prairie can be re-burned within two years under appropriate prescription parameters and that nearly all seedlings established after the initial seed release event could still be killed. In the event of a wildfire releasing vast quantities of seed, seed trees should be treated with herbicide within a year post-burn to prevent replenishment of seed stores, then the site should be re-burned as soon as fuels are available to get a complete burn. Follow-up inspections and treatments would probably be needed.

Although these studies showed that if you have seed trees present and a burn releases seed and establishment occurs, you can greatly reduce the number of seedlings resulting from the initial seed release event by burning within two years. The seed trees will replenish their seed stores during that short fire-free interval. This was the case with the Monument Lake burn plots. What we do not know is 1) whether repeated fire could be used to retard or inhibit the onset of flowering or 2) whether burning would in some way stimulate flowering. Neither of these hypotheses were tested in this study but if number one holds true, it may be possible to repeatedly burn young stands to limit or prevent flowering until such a time as they can be treated with herbicide.

In situations where there are sites supporting seed-laden outlying melaleuca, it is recommended to treat the trees first and monitor for germination, then burn. If prescribed burning is needed for reasons other than melaleuca control and there is neither the time nor the funding to treat the trees first, then burns should be conducted in the winter months while the soil is still wet, perhaps limiting germination success. Seed trees should be treated before they replenish their seed stocks, and the site re-burned as soon as fuel is available.

Treatment of an area affected by a wildfire should be given priority over all other sites as fire will have primed the site for the explosive spread of melaleuca. On a site with mature outliers, the management response should be to treat all mature trees before they re-flower and produce mature seed. Large trees should be stump cut and treated with herbicide within a year post-burn. Resprouts of sapling to pole sized trees that sprout only at the base should be foliar sprayed. Re-treatments will likely be needed. Seedling establishment should be monitored and the site re-burned as soon as fuels are available to carry the fire.

The results of "stump cutting and flooding" studies point to the possibility of treating "dog-hair" stands by timing mechanical treatments just prior to seasonal flooding. Where access permits, large mechanized brush cutters (brush hog, feller-buncher, etc.) could be used to sever stems in thick stands to near ground level as late in the dry season as possible. If water levels rise in a timely fashion and remain inundated for several months, many of the trees should die. If flood waters do not cooperate and some re-sprouting occurs, the trees could then be treated with a foliar application of ARSENAL or ARSENAL in combination with RODEO.

4. HERBICIDAL CONTROL

François B. Laroche

Exotic woody vegetation is most commonly managed by herbicide application. There are various methods by which herbicides can be applied to woody exotic pest plants (Langeland 1990). These are: basal bark, foliar, frill or girdle (hack-and-squirt). Early investigations (mid-1970s) into the herbicidal control of melaleuca in the Everglades using herbicides were conducted by the Florida Game and Fresh Water Fish Commission (GFC Files, 1975-1980). Many non-crop and forestry herbicides were tested to examine various application methods and application rates (Tables 1, 2, and 3). Often, herbicides were applied at rates far beyond those that would normally kill woody vegetation. Effectiveness of these high-rate applications varied. Results of these tests showed that melaleuca was going to be very difficult to control with available herbicides and conventional application techniques. These field trials were not monitored frequently and no quantitative data was collected; however, they did provide the foundation for future studies.

Table 1. Herbicide trials on melaleuca in the Water Conservation Areas, 1974-1977. For each treatment listed, two applications of the same herbicide were made on the same trees, at the rates listed, when resprouting occurred.

TRT	HERBICIDE	RATE	METHOD	NOTES
1	2,4,5-TP	5 GPA	Foliar	Refoliated After 6 Months
		5 GPA	Foliar	100% Mortality After 1.5 Years
2	AMS	100 Lbs/A	Foliar	Refoliated After 2 Months
		100 Lbs/A	Foliar	15% Mortality After 12 Months
3	2,4-D	5 GPA	Foliar	Refoliated After 2 Months
		5 GPA	Foliar	No Long-Term Mortality
4	Diuron	5 GPA	Foliar	Refoliated After 2 Months
		5 GPA	Foliar	10% Mortality After 12 Months
5	Diuron	600 Lbs/A[1]	Soil	Refoliated After 2 Months
		600 Lbs/A	Soil	100% Mortality After 12 Months

1- Treatment Rate is 10 Times Maximum Label Rate

Table 2. Herbicide trials on melaleuca in the Water Conservation Areas, conducted by the Florida Game and Fresh Water Fish Commission, 1974-1977.

HERBICIDE	RATE	METHOD	NOTES
2,4-D	1-30 mls/inch D	BHH & S	99% Refoliation After 2 Years
Garlon 3A	1-2 GPA	Foliar	A total of 15 treatments were established over a 12 month period. Mortality was high for trees less than 8 feet in height. All others had only dead branches.

In 1979, the USACE began herbicide effectiveness trials on mature melaleuca trees and on seedlings along the Herbert Hoover Dike near the towns of Okeechobee and Clewiston, respectively (Stocker, 1982). Prior to treatment, randomly selected melaleuca trees in each plot were tagged with identification numbers. At each evaluation, vitality (live versus dead) was determined for each tagged individual. Results of herbicide treatments (Table 4) to seedlings, indicated that 100% control could be obtained after one year with applications of 4.5 kg/ha active ingredient (a.i.) HYVAR X (bromacil), 4.5 kg/ha a.i. SPIKE 80W and 13.4 kg/ha a.i. SPIKE 40P (tebuthiuron) and 2.2 kg/ha a.i. VELPAR L (hexazinone). Mature trees proved more difficult to control (Table 5); no treatments gave 100 percent control after an evaluation period of one year. Only the application of VELPAR L at a rate of 4.5 kg/ha a.i. and SPIKE 40P at a rate of 11.2 kg/ha a.i. produced greater than 80 percent control. However, effectiveness ratings may have risen if treatment evaluations had continued for longer than one year.

More recent SFWMD sponsored cooperative agency herbicide trials investigated foliar active herbicides (Laroche et al., 1992). Foliar-active herbicides are generally more selective and have shorter soil residence times than soil active herbicides. Foliar applications are usually made by diluting herbicide in water and applying to leaves with ground or aerial application equipment. Dilution is usually about 20:1 for aerial applications and from 50 to 400:1 for applications from the ground. Foliar applications can either be directed to minimize damage to non-target vegetation, or broadcast. Broadcast applications are used where damage to non-target vegetation is not a concern or where a herbicide, which selects for melaleuca is used. Soil applications may be diluted or concentrated sprays applied directly to the base of individual trees, or granular herbicide formulations, which are applied directly to soils. Individual tree application methods expose the cambium layer and herbicide (concentrated or diluted) is applied directly to the cut surface at rates recommended by the herbicide manufacturer. Recommended rates of herbicide application are those which have been specified on the label, which is included with each product. Individual tree applications are labor intensive, and therefore costly.

Table 3. Herbicide trials on melaleuca in the Water Conservation Areas, conducted by the Florida Game and Fresh Water Fish Commission, 1974-1977.

HERBICIDE	RATE	METHOD	NOTES
Weedone 170	1 GPA	Foliar	Refoliated After 3 Months
Weedone 170	2 GPA	Foliar	No Follow-up
Weedone 1 BK	1 GPA	Foliar	Refoliated After 3 Months
Weedone 1 BK	2 GPA	Foliar	No Follow-up
Emulsamine BK	1 GPA	Foliar	Refoliated After 3 Months
Emulsamine BK	2 GPA	Foliar	No Follow-up
Silvex	1 GPA	Foliar	Refoliated After 3 Months
Silvex	2 GPA	Foliar	Refoliated After 2 Months
Banvel 720	0.5 GPA	Foliar	Refoliated After 3 Months
Banvel 720	1 GPA	Foliar	No Follow-up
Ammate X	30 Lbs/A	Soil	Refoliated After 3 Months
Ammate X	240 Lbs/A	Soil	No Follow-up
Bromacil	15 GPA	Foliar	50% Mortality After 3 Months
Bromacil	120 Lbs/A	Soil	Refoliated After 2 Months
Diuron	30 Lbs/A	Soil	Refoliated After 3 Months
Diuron	160 Lbs/A	Soil	Refoliated After 2 Months
2,4-D	2 GPA	Foliar	Refoliated After 3 Months
2,4-D	4 GPA	Foliar	No Follow-up
Glyphosate	0.5 GPA	Foliar	Refoliated After 3 Months
Glyphosate	1 GPA	Foliar	No Follow-up
Pramitol	15 GPA	Foliar	Refoliated After 3 Months
Spike	10 Lbs/A	Soil	Refoliated After 2 Months
2,4,5-T	1 GPA	Foliar	No Follow-up
Velpar	10 Lbs/A	Soil	Refoliated After 2 Months
Garlon 3A	2 GPA	Foliar	50% Mortality After 10 Months

Table 4. Mean percent melaleuca seedling mortality following herbicide application, Lake Okeechobee (Stocker 1981).

HERBICIDE	RATE (kg/ha A.I.[2])	MEAN PERCENT MORTALITY[1] June 79	Oct 79	Dec 79	Mar 80
Banvel 720[3]-liquid	3.4	33.3	43.3	43.3	43.3
	6.7	66.7	70.0	70.0	70.0
	13.4	80.0	83.3	86.7	86.7
Hyvar X[3]-WP	4.5	100.0	100.0	100.0	100.0
	9.0	100.0	100.0	100.0	100.0
	13.4	100.0	100.0	100.0	100.0
Roundup[3]-liquid	4.5	23.3	46.7	53.3	60.0
	9.0	70.0	90.0	93.3	93.3
	13.4	63.3	90.0	93.3	100.0
Spike[3]-WP	4.5	100.0	100.0	100.0	100.0
	9.0	100.0	100.0	100.0	100.0
	13.4	100.0	100.0	100.0	100.0
Spike[3]-pellet	4.5	50.0	73.3	76.7	76.7
	9.0	83.3	93.3	93.3	93.3
	13.4	83.3	100.0	100.0	100.0
Velpar[3]-WP	2.1	100.0	100.0	100.0	100.0
	4.5	100.0	100.0	100.0	100.0
	9.0	96.7	100.0	100.0	100.0
Velpar[4]-pellet	4.5	3.3	40.0	50.0	53.3
	9.0	3.3	56.7	60.0	60.0
	13.4	0.0	70.0	80.0	86.7
Control		11.1	17.8	18.9	25.6
Rinsewater					
I-after Roundup appl.		3.3	3.3	6.7	13.3
II-after Banvel appl.		13.3	30.0	30.0	30.0
III-after Spike appl.		6.7	13.3	13.3	20.0
IV-after Hyvar appl.		3.3	20.0	20.0	23.3

1- Each value represents mean of three replicates

2- Active ingredient

3- Applied on 27 April 1979

4- Applied 6 June 1979

Table 5. Mean percent melaleuca tree mortality following herbicide application, Lake Okeechobee (Stocker, 1981).

HERBICIDE	PERCENT MORTALITY			
	Oct 79	Dec 79	Mar 80	Jun 80
	Low Rate, 4.5 kg Active Ingredient per ha			
Velpar-liquid[1]	0.0A[2]	20.0A[2]	48.3A[2]	81.7A[2]
Spike-pellet[3]	0.0A	3.3B	10.0BC	66.7AB
Velpar-pellet[3]	0.0A	2.9B	13.3AB	65.0AB
Spike-wettable powder[4]	0.0A	10.0AB	23.3AB	43.3B
Hyvar X-wettable powder[4]	0.0A	0.0B	0.0C	0.0C
Banvel 720-liquid[4]	0.0A	0.0B	0.0C	0.0C
	High Rate, 11.2 kg Active Ingredient per ha			
Velpar-liquid[1]	0.0A[2]	35.7A[2]	71.7A[2]	96.7A[2]
Spike-pellet[3]	0.0A	5.0B	26.7B	83.3AB
Spike-wettable powder[4]	1.7A	30.0A	73.3A	81.7AB
Velpar-pellet[3]	0.0A	2.0B	18.3B	75.0B
Hyvar X-wettable powder[4]	0.0A	0.0B	1.7C	3.83C
Banvel 720-liquid[1]	0.0A	0.0B	0.0C	0.0C

1- Applied 11 June 1979.

2- Values within this column not sharing common letters are significantly different statistically ($p < 0.05$).

3- Applied 9 - 12 June 1979.

4- Applied 19 June 1979.

However, these applications have minimal adverse effect on non-target vegetation and generally completely kill the target plant. Soil applications are labor conservative and cost-effective, but negatively affect surrounding vegetation.

Ground Application: There are several methods by which herbicides can be safely applied for the management of invasive plants (Langeland 1990). To date, the "girdle" application technique of applying herbicide to cambium exposed around a tree's entire circumference, and the cut stump application have been the method of choice with the U.S. National Park Service in Everglades National Park, the U.S. Fish and Wildlife Service in the Arthur R. Marshall Loxahatchee National Wildlife Refuge and the SFWMD in the Everglades Water Conservation Areas and Lake Okeechobee, as well as many other resource management initiatives in the region. Based on the results of various studies, several herbicides were found to be effective for the control of melaleuca. These are hexazinone, tebuthiuron, imazapyr, triclopyr, and glyphosate, with hexazinone and tebuthiuron being the most effective. Results with imazapyr, glyphosate and triclopyr have varied with application techniques. Through several years of herbicide evaluation, imazapyr (240 g/l a. i., ARSENAL) in a 50% solution with water has proven to be the most consistently effective herbicide and is presently the most used herbicide in these areas. ARSENAL also has a "Special Local Need" label allowing this manner of use in flooded areas. Further studies indicated that a combination of imazapyr (240 g/l a. i.) at 25% with glyphosate (648 g/l a. i.) at 25% and 50% water could also be very effective while reducing cost and non-target damage (Pernas et al. 1994).

Aerial Application: Individual tree treatments are the most cost-effective and environmentally sound procedure for small-scale management and containment of melaleuca. However, these methods are too expensive and time consuming for large-scale control operations. Selection of appropriate herbicides for aerial control of melaleuca is difficult because the trees are often in aquatic habitats, saturated soil conditions, or sensitive natural areas where damage to non-target vegetation is of great concern. One of the major drawbacks to successful large-scale melaleuca management is the lack of selective, foliar-active herbicides that provide consistent results. Foliar-active herbicides are generally more selective and have shorter soil residence times than soil-active herbicides. The Florida Game and Fresh-water Fish commission (FGFC) and the U. S. Army Corps of Engineers (USACE) conducted early investigations into the herbicidal control of melaleuca (Stocker and Sanders 1981). Many herbicides were tested with various application rates and application methods. Results of these tests demonstrated that melaleuca was very difficult to control with available herbicides and conventional application techniques. Only hexazinone at 4.5 kg/ha a. i. and tebuthiuron at 11.2 kg/ha a. i. produced greater than 80% control.

The District, in cooperation with various other agencies, has been investigating the effectiveness of aerial application on melaleuca and its temporary effects on non-target vegetation of both foliar-active and soil-active herbicides. Laroche et al, (1992), evaluated hexazinone, imazapyr, triclopyr and glyphosate for aerial application. These studies indicated that hexazinone was effective at controlling melaleuca while imazapyr, glyphosate, and triclopyr yielded unsatisfactory results. Subsequent trials were conducted using hexazinone and tebuthiuron at the Strazulla tract near the LNWR and in WCA-2B. These trials indicated that hexazinone, at a rate of 4.5 kg/ha a. i. was more selective to certain native species such as slash pine and bald cypress and was less damaging to sawgrass than tebuthiuron (Hoyer and Fox 1992,). Based on this information, the District started operational aerial application on Lake Okeechobee in May of 1994. Approximately 526 hectares of melaleuca were treated with hexazinone west of the Moore Haven canal. This treatment was very successful in that. Over 90% of the trees were killed and regrowth of seedlings was minimal. However, the herbicide manufacturer did not renew the Special Local Need Label which allowed for the application of hexazinone to wetland areas during the dry season. Hexazinone has been off the market for melaleuca control since January 1, 1995.

Other studies conducted at the Big Cypress National Preserve (BCNP) in June, 1993 indicated that a combination of imazapyr at 1.68 kg/ha a. i. and glyphosate at 3 kg/ha a. i. applied with a methylated seed-oil surfactant provided 95% control of melaleuca. Additional treatments conducted in Lake Okeechobee and ENP in June 1994 with the same rates of these two herbicides were not as effective. On April 5, 1995 representatives from various agencies including the Florida Department of Environmental Protection (FDEP), University of Florida, ENP, BCNP, the District and several herbicide manufacturers met to evaluate and discuss aerial application of the combination of imazapyr and glyphosate for melaleuca control. The group toured the aforementioned treatment sites and determined that the lack of total coverage contributed to reduced efficacy in most of the trials, especially at ENP and Lake Okeechobee. The following recommendations were provided for future aerial application trials on melaleuca.

1- Use maximum label rates of both imazapyr (1.68 kg/ha a. i.) and glyphosate (5.7 kg/ha a. i.) with a methylated seed-oil or an organo-silicon/methylated seed-oil surfactant in a total volume of 140-188 L/ha. Previous treatments had been applied with 47-94 liters total volume per hectare.

2- Use a microfoil boom with small nozzles (0.020) and apply the herbicides at half rate while overlapping each swath by 50% to deliver the full dose. These two modifications, along with increased total volume, would greatly improve efficacy. It was determined that the use of smaller nozzles (0.020) at Big Cypress may have provided better coverage that resulted in increased efficacy. The treatments in Lake Okeechobee and ENP were applied with bigger nozzles (0.045).

The group also concluded that time of year might be an important factor influencing herbicide efficacy. Melaleuca exhibits a flush of new growth during January and February (personal observation), suggesting an active growing period. Therefore, a herbicide application during this time may be more effective. Three treatment windows, June-July, September-October, and January-February were proposed to determine if efficacy was improved by time of application. All previous aerial treatments were applied in late spring or early summer.

American Cyanamid received an Experimental Use Permit in June 1995, for the application of imazapyr in non-flowing water over a total area of 364 hectares in Florida. The District began applying the combination of imazapyr at 1.68 kg/ha a. i. and glyphosate at 4.5 kg/ha a. i. each over large areas in the WCAs and Lake Okeechobee. The objectives of these new treatments were to determine the feasibility of large-scale aerial application to melaleuca and to test four different surfactants, at 4.67 liter per hectare each, to achieve greater herbicide efficacy. All treatments were applied with a TVB (Waldrum Specialties) boom, with 0.030 nozzles, in a total volume of 94 L/ha. The helicopter overlapped 50% of each swath to provide a total volume of 190 L/ha. Each plot was approximately 20 hectares in size. Half of each of the plots were retreated one year later with the same rate of imazapyr and glyphosate and 9.4 liters of Sun-wet® per hectare. The application method and equipment remained the same. Each treatment was rated on a quarterly basis over a period of 18 months. Evaluations consisted of visual rating by three evaluators, at three intervals along an establish transect. Percent Defoliation was used to determine the effect of each treatment on the in-stand overstory and understory of melaleuca. The list of treatments, and percent defoliation for the single and double application are listed in Table 1. The repeated application resulted in over 85% control of melaleuca in all the plots at both locations. Additional aerial treatments were conducted in November of 1996 and February 1997 to determine if herbicide efficacy is influenced by time of year. Results from these treatments indicate better efficacy with the February treatment.

Table 6. Percent defoliation of melaleuca treated with a combination of imazapyr1.68 kg/ha a. i. and glyphosphate at 4.5 kg/ha a. i. once in 1995, and twice in 1995 and 1996.

	Water Conservation Areas		**Lake Okeechobee**	
Treatment	Once	Twice	Once	Twice
Sun-it®	54%	90%	43%	83%
Sun-wet®	65%	93%	58%	97%
Dyne-amic®	66%	96%	52%	87%
Rivet®	61%	81%	44%	89%

Labor intensive, manual herbicide applications to individual "outlier" trees and small tree groups continue to be the primary melaleuca control method throughout south Florida. Several south Florida agencies and herbicide manufacturers are cooperating to complete large-scale demonstration studies with ARSENAL and RODEO. Results of these tests may suggest that large-scale broadcast treatments with these two herbicides onto melaleuca forests can be made safely. This labor-conservative method will be adopted only if test results indicate acceptable herbicide persistence times and effects on native vegetation. Such affordable large-scale herbicide applications, could, if deemed environmentally acceptable, further melaleuca management in south Florida. However, perpetual control hinges upon establishment of effective biological control agents.

E. SURVEILLANCE AND INSPECTION, "MAINTENANCE CONTROL"

Tony J. Pernas and Jacqueline C. Jordan

The adopted strategy for managing melaleuca is based on treating outliers (single trees distant from primary strands) first, based on a "quarantine strategy" described by Woodall (1981a). Simply stated, melaleuca does not spread in a continuous way but in sporadic jumps. So as one proceeds toward the central denser portion of a melaleuca population, the relative benefits from killing individual trees decline. The greater benefit is from controlling the most isolated, most distant seed-trees. Conversely, ignoring outliers would result in an unchecked spread rate.

To be effective, melaleuca control efforts need to be applied long-term, and treatment areas must be monitored for reinvasion (especially after a major disturbance such as fire or a hurricane) and regrowth of treated individuals. It has not been uncommon that reports of successful control efforts frequently prove to be unwarranted because they were based on initial stem mortality and do not address the issues of resprouting or seedling establishment; the real result is no ground is gained (Myers, 1990). The length of time a site must be reinspected to ensure depletion of melaleuca in the seed bank is unknown and is the subject of ongoing research. There are indications that seeds may remain viable for several years.

An important component of a successful control program is a systematic survey and inventory of melaleuca infestations that ensures adequate coverage of the management unit. Small areas can be surveyed on the ground with an airboat or an all terrain vehicle, but larger areas, such as the Big Cypress National Preserve must be surveyed remotely. At the Big Cypress National Preserve, a program of systematic reconnaissance flights (SRF) utilizing the Global Positioning System (GPS) was developed and utilized to detect and quantify melaleuca population levels.

Approximately one-half of the Preserve, totaling five treatment units, is flown per year. Basic procedures are outlined as follows: Transect lines are established at 1000-meter intervals. These correspond to the Universal Transverse Mercator 1000-meter grid ticks on USGS maps. Flight lines are flown using a Trimble7 GPS for navigation information. Two observers on the aircraft spot for melaleuca targets within a half-kilometer of the aircraft (Targets are defined as isolated individual trees, areas of scattered trees, and dense stands). When a melaleuca target is sighted by one of the observers, the pilot is directed to deviate from the transect in order to directly fly-over each target. Once over the target the position is entered into the GPS as a way-point and the target is classified. The pilot then re-establishes the aircraft on the flight line.

Once back at the office, the GPS is connected to a computer via a serial port and the waypoint and transect data are downloaded and post-processed using the GPS manufacturer supplied software. Data is then incorporated into a PC based Atlas GIS7/Dbase 47 Geographic Information System.

Treatment crews on all terrain vehicles or in a helicopter enter the desired target coordinates into their GPS and utilize the navigation mode to locate and treat the trees.

Some important considerations for aerial survey:

* Altitude should be maintained at 400-500 ft AGL (above ground level) to ensure that melaleuca trees in association with pine and cypress will not be obscured by adjacent vegetation.

* It is important that the pilot maintain a near constant altitude to ensure that uniform coverage is obtained during each flight line.

* The air speed of the plane should be maintained at as low a speed as practicable for optimal observation and monitoring. Aircraft speed of 60-65 knots should typically be maintained.

* The pilot needs to be able to maintain straight flight lines, in order to ensure 100 percent coverage.

* The preferred time of day for flights is early morning, when there is a low oblique angle to the incident light. Melaleuca trees in the prairies cast distinctive shadows at this time, and the angled light enhances the difference in color between melaleuca trees and any associated pine and cypress.

* The preferred season for flying transect lines is during the winter months, in order to take advantage of the deciduous period for cypress trees. Melaleuca trees in association with cypress will be more readily visible during this time.

* The observer must have excellent visual acuity and be very familiar with the appearance of melaleuca from the air.

* Systematic reconnaissance flights detect approximately 80% of the melaleuca, small trees and seedlings will most likely be missed, especially if occurring in forest communities.

After initial treatment, especially in areas with seed bearing trees, a maintenance control program should be implemented. Maintenance control is defined as a method for the control of nonindigenous 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. This method of control has been legislatively mandated (Section 369.22(3)) for nonindigenous aquatic plants and has been used by aquatic plants managers to control waterhyacinth and waterlettuce with good results.

Systematic survey and inventory is imperative to the success of maintenance control. Previously treated sites should be thoroughly surveyed at least once a year. All new plants should be hand pulled or chemically treated. If after three years there is less than a ten percent regrowth and germination, the survey can take place every two years. Since there is some question about the length of time seeds are viable after they are released from the tree, infested areas that are at a maintenance control level should be surveyed indefinitely.

F. PROPOSED AND ENACTED LAWS

Jacqueline C. Jordan

Within Florida, widespread recognition of the severe threat posed by melaleuca is evident in the many laws enacted throughout the state to prohibit the sale and cultivation of this plant. There is now a state law prohibiting the sale, cultivation and transportation of melaleuca. In 1990, Section 369.251, was passed by the legislature and in 1993, 16C-52, Florida Administrative Code, was amended putting melaleuca on the state's prohibited plant list. In 1992, melaleuca was added to the United States Department of Agriculture's Federal Noxious Weed List.

Several counties also restrict the sale, transportation or cultivation of melaleuca by law. Many of these counties also control it variously by omission from tree protection ordinances or require removal upon site development. Some counties have permitting requirements before removal is allowed. Broward, Charlotte*, Collier*, Dade**, Highlands, Hillsborough, Indian River, Lake, Lee, Manatee, Martin, Monroe, Orange, Osceola, Palm Beach, Pinellas, Sarasota, and Seminole counties have ordinances that regulate melaleuca in some way. These counties have prohibited other exotic invasive plant species. Also, many cities throughout the state have ordinances that regulate melaleuca. The most notable among these is the City of Sanibel Island, which has prohibited this plant for over twenty years.

* Permit required to remove melaleuca.
** Oldest county ordinance in the state.

VII. RESOURCE MANAGEMENT APPROACH

Dan D. Thayer and Roger S. Clark

The integrated management of melaleuca requires a combination of control techniques to be effective. Essential elements of effective management include biological, herbicidal, mechanical and physical control. Comprehensive descriptions for each of these management techniques for melaleuca are located in Section VI, D.

Prior to implementing melaleuca controls the following factors must be considered and used in developing a site specific control plan:

1) **Occurrence -** Extent of infestation, density, spatial distribution and other plant communities that are present.

2) **Topography and soils -** How does occurrence relate to elevation and soils? What are the characteristics of the soils - organic, sandy, hydric?

3) **Hydrology -** Has the site been impacted by drainage? Are there canals, agricultural fields, or wells nearby that may have caused a drawdown of the water table on the site?

4) **Available management techniques -** Which method of treatment or combination of methods is most suitable to the site being treated?

5) **Economic factors -** How much will it cost to exert initial control and then provide a long term follow up? What are sources of funding? Grants? Mitigation? Will the work be done by agency staff or by a contractor?

6) **Public perception -** Will public reaction cause bad publicity? What can be done to educate the public to avoid negative reaction?

7) **Work schedule -** Determine a reasonable time schedule as a goal for initial treatment and plan for routine maintenance control.

The key to an effective and long-lasting management program for melaleuca is the introduction of biological control agents. Without biological control, melaleuca elimination will be much more expensive and could not be truly integrated. The current investigation into biological organisms will most likely result in the introduction of seed and sapling feeders. The first introductions began in April, of 1997. Once introduced, several years are generally required for populations to build to effective levels. In the interim, and throughout the biocontrol introduction phase, herbicidal and mechanical controls will be required to reduce current infestations and prevent spread into currently uninfested areas. Manual removal of seedlings in combination with single tree herbicide applications is the most conservative approach in natural areas. However, individual tree treatments are costly. Thus, less costly methods of herbicide application are constantly being investigated. Direct herbicide application can still result in non-target effects, as much as a year after treatment, depending on the herbicide used. Aerial application of herbicides may in some cases cause less non target damage to native and herbaceous groundcover. Aerial application may result in less herbicide being used on a site and in some situations may lower the cost of initial treatment. Manual removal of seedlings may not be advisable in all situations due to the percentage of roots broken below the ground surface. In addition the soil disturbance that results may stimulate more seeds to germinate. Mechanical removal using heavy equipment is best suited for rights-of-way and other similar areas where routine maintenance follows and site disturbance is not a concern.

A melaleuca management program should be based on the quarantine strategy described by Woodall (1981a). The least infested areas (outliers) are addressed first, in order to stop the progression of the existing population. The first phase of control targets all existing trees and seedlings in a given area. Using navigational equipment, crews return to the same site in following years to remove any resulting seedlings from control activities of previous years. A successful control operation consists of three phases.

Phase I. This phase focuses on the elimination of all mature trees and seedlings present in an area.

Phase II. Previously treated sites are revisited for follow-up treatment to control trees previously missed and remove seedlings which may have resulted from control activities of the preceding year.

Phase III. This phase entails the long-term management of melaleuca, surveillance and inspection of previously treated sites to monitor the effectiveness of the melaleuca control program and maintain reinfestation levels as low as possible.

VIII. MELALEUCA MANAGEMENT EFFORTS

A. BIOLOGICAL CONTROL RESEARCH

Ted D. Center, F. Allen Dray, Jr., Gary Buckingham, Susan Wineriter, Min B. Rayachhetry, and Matthew F. Purcell

1. BIOLOGICAL CONTROL PROJECT STATUS

The cornerstone of an effective and long-term management program for melaleuca is the introduction of biological control agents. Successful establishment, increase in population densities, and dispersal of biological controls will be important in reducing the exponential rate of melaleuca expansion now occurring in south Florida wetlands (Laroche and Ferriter, 1992) and in preventing re-invasion of cleared areas. In Australia, *M. quinquenervia* seedlings are much less common than in the melaleuca-infested areas of Florida. Furthermore, mature plants produce far fewer seed capsules, possibly due to attack of growing shoot tips (the point of flower production) by plant-feeding insects. The United States Department of Agriculture (USDA) has been investigating insects that feed on melaleuca seedlings, saplings, and new shoot growth in Australia (Balciunas and Center, 1991). The USDA group has now begun to introduce some of these insects to south Florida and anticipate a reduction in the rate of spread of these trees. The intention is not to duplicate the diverse system of repressive forces that keep melaleuca in check in Australia, but rather to utilize a few, highly host-specific species of insects. These species, when introduced without their own natural enemies, should ultimately be limited mainly by food supply and thereby become much more abundant than in Australia. At this stage, they should become highly effective regulators of melaleuca populations in Florida, reducing seed production, survival of seedlings, and weakening mature trees. The first insect released, the weevil *Oxyops vitiosa*, is already severely impacting melaleuca trees at some locations and mortality of seedlings has been documented. Testing is completed on a second species, the sawfly *Lophyrotoma zonalis*, and it will be released during summer 1999. In addition, testing of the melaleuca psyllid *Boreioglycaspis melaleucae* is nearly complete and requests for release will be submitted prior to the end of 1999.

Overseas research - Information pertaining to herbivorous insects attacking *M. quinquenervia* in Australia was very limited prior to this project. The Queensland Department of Primary Industries reported *Aterpus griseatus* (Curculionidae), *Cryptophasa nephrosema* (Xyloryctidae), *Rhyparida limbatipennis* (Chrysomelidae), and various scale insects from Melaleuca spp. (P. McFadyen, pers. comm.). Species listed in "The Insects of Australia" (CSIRO 1979) include *Sphaerococcus* sp. (Eriococcidae), and Pterygophorinae (Pergidae).

In 1977, Dr. Dale Habeck (University of Florida, Department of Entomology & Nematology) conducted surveys in Australia and New Caledonia and found a large number of insects attacking *M. quinquenervia* (Habeck 1981). However, the majority of these insects were immature, and because of limited time, most were not reared for complete identification. Insects found attacking the seeds included a small fly *Fergusonina* sp. (Fergusoninidae), a lygaeid bug *Eurynysius meschoides* Ashlock, an unidentified thrips, and an anobiid beetle. The larvae of a tortricid moth *Bathrotoma constrictana* Meyrick were found feeding on seed capsules of the related *M. ericifolia.* Habeck (1981) also found unidentified species of Noctuidae, Geometridae, Pyralidae, Tortricidae, and Oecophoridae webbing and feeding on the flowers and flower buds. He further noted larvae of a gall midge (Cecidomyiidae) in the flowers and a gall forming eriophyid mite which prevented flower formation. Habeck (1981) found many species of leaf feeding insects including at least seven species of Lepidoptera, four species of beetles, gall-making thrips, psyllids, aphids, and scale insects. He noted a gregarious sawfly *Perga* sp. that caused severe defoliation and would almost certainly be host-specific. He also noted extensive signs of damage by a mirid bug *Eucerocoris* (*Ragewellus) suspectus* Distant. Stem-feeding insects included sap-feeders in the Cercopidae, Membracidae, Eurmelyidae, Psyllidae, Aphididae, Cicadidae, Ricaniidae, and scale insects. Adults of a weevil *Aterpus griseatus* were found feeding on the highest branches of saplings and the larvae of this species purportedly feed on the roots. An unidentified Lepidoptera larva bored the stems and killed developing tips.

Surveys conducted by Dr. Joe Balciunas and associates from 1986-1989 resulted in the recovery of 409 insect species from *M. quinquenervia* and related species (Balciunas, 1990; Balciunas and Burrows 1993; Balciunas et al. 1993a, b, 1994a, b, 1995a, b, c; Burrows et al., 1994, 1996). Leaf-feeders were most abundant and included larvae from about 93 species of moths, 30 species of chrysomelid beetles, 27 weevil species, and 5 pergid sawflies. Sap-feeding insects were common with flatids, fulgorids, and scales well represented in the collections. Galls were common, but because of the high rates of parasitization (95-99%) of the gall-making insects, the causative agent for some of these galls is not yet known. Numerous species of fruit and flower-feeding insects were also collected.

Clearly not all of the insects associated with melaleuca will be useful or appropriate as biological control agents. So it is important that we know how many potential bioagents are available and the order in which they should be tested. Unfortunately, the task of evaluating each of these species as to its biocontrol potential is an impossible one. Surveys conducted thus far have concentrated largely on insects damaging exposed portions of the plant (i.e. leaves, flowers, and fruits). Wood-borers and root-feeders could be very useful biocontrol candidates, but these important guilds have received scant attention. In lieu of ranking all of the species found on melaleuca, only a dozen or so species that seemed the most promising were ranked in terms of their potential to damage the plant and their apparent host specificity.

The two most promising insects were a pergid sawfly, *Lophyrotoma zonalis*, and a weevil, *Oxyops vitiosa*. Host screening of these two candidates began in 1989 and

1990, respectively. *L. zonalis* is a leaf-feeder that completely defoliates Australian melaleuca on occasion (Burrows and Balciunas, 1997). Severely damaged trees fail to flower or set seed during the affected growing season. Field-collected *L. zonalis* larvae and eggs are heavily parasitized, suggesting that populations of this sawfly should increase rapidly in the U.S. where they would be free from these parasites. Initial laboratory feeding trials in Australia implicated three species of Myrtaceae, two species of *Melaleuca* and a *Backhousia*, as food hosts.

Because the *M. quinquenervia* in Florida is thought to have originated from seeds collected in southern Queensland or New South Wales, where *L. zonalis* does not occur, there was concern that the U.S. plants would be unacceptable to this sawfly. Consequently, Dr. Gary Buckingham (USDA. Agricultural Research Service) at the Gainesville Florida Biological Control Laboratory quarantine facility was sent a shipment of *L. zonalis* in May 1992. These readily oviposited on Florida plants. Further, those egg cases hatched, and the larvae readily accepted the Florida plant material. Larval mortality was high (not unusual when trying to establish a new laboratory colony with an unfamiliar insect), but the surviving larvae pupated, and adults emerged. Initially all adults were male but by 1995, mating was common and both sexes were produced. This resulted in laboratory colonization. We are confident now that the Florida melaleuca is indeed an acceptable host.

Host range studies were then conducted in quarantine with native and cultivated plant species Dr. Buckingham conducted multi-choice and no-choice oviposition tests with 36 species of Myrtaceae and with 18 species in other families. Besides melaleuca, larvae from eggs laid on 23 species of Myrtaceae developed to prepupae and adults only on 3 species of bottlebrushes, *Callistemon*, Medium-sized larvae, the stage that might wander from defoliated trees to other nearby plants, were provisioned with bouquets of plant cuttings as well as potted plants. Noticeable feeding, but much less than on melaleuca, was restricted to the Myrtaceae, except for a few individual larvae that fed on wax myrtle, *Myrica cerifera* L. Medium-sized larvae became prepupae only on *Melaleuca decora* (Salisb.) Britten (73%) and on wax myrtle (10%). However, neither of these plants provided acceptable egg deposition sites during oviposition trials. These studies confirmed the narrow host range of *L. zonalis* as previously reported from field and laboratory studies in Australia and permission to release this insect has now been requested.

An important question remained to be addressed concerning this biocontrol candidate, aside from its host specificity. The question centered around whether or not *Lophyrotoma zonalis* produces lophyrotomin, an octapeptide found in three sawflies from Australia, South America, and Europe. Australian cattle sometimes eat larvae of a related sawfly (*L. interrupta)* when they migrate from the eucalyptus trees to the ground as they prepare to pupate in the soil. Consumption of these larvae is sometimes fatal and costs the Australian livestock industry about $1.1 million annually. Ingestion of larval *Arge pullata* (Argidae) by sheep in Denmark has also proven fatal. In both cases the octapeptide lophyrotomin has been identified as the toxin responsible for the deaths. South American pergid that has been implicated in livestock death produces small amounts of this toxin along with the toxin pergidin (Oelrichs et al., 1999). All three of these species pupate in the soil where they are more vulnerable to predators than are the *Lophyrotoma zonalis,* which pupate in the bark. However, in light of this evidence, it was critical that we determine whether larvae of *Lophyrotoma zonalis* were toxic. Freeze dried larvae were therefore fed to blackbirds and mice by two independent cooperating laboratories. No toxic effects were noted. The Australian chemist who studied the preceding sawflies, P. B. Oelrichs, was contacted several times but was unaware of any reports of toxicity in Australian species other than *L. interrupta.*

Initial host screening began with *Oxyops vitiosa*, the second high-priority candidate, during 1990. This species feeds on leaf buds and young foliage. The resultant damage stunts the growth of the affected branches, and can be fatal to seedlings and saplings. During laboratory trials *M. quinquenervia* and *M. dealbata* received extensive feeding damage, *M. viridiflora* and *M. leucadendra* suffered moderate damage, and four other Myrtaceae sustained very mild damage. Females accepted *M. quinquenervia* and *Callistemon viminalis* as ovipositional hosts in the Florida laboratory. During extensive field studies, *O. vitiosa* attacked only *M. quinquenervia*. This suggests that other plant species were damaged during the laboratory trials largely as a result of the artificial conditions, and not because they are truly plant hosts of this weevil. Permission to release *O. vitiosa* was granted during 1997, and the first release was made during April of that year (Wineriter and Buckingham, 1997; Wood, 1997).

Populations established initially at nine sites in Dade, Broward, Lee, Collier, Palm Beach, and Glades Counties. Short hydro period habitats with intermediate stages of a melaleuca invasion and dry winter conditions engendered development of *O. vitiosa* colonies, whereas populations failed at fully aquatic sites. Even relatively small releases (60 adults) produced nascent populations when site conditions were favorable.

An abundance of young foliage facilitated establishment, while soil type seemed unimportant: colonies developed at typical "glades" sites characterized by highly organic (muck) soils as well as at pineland sites characterized by sandy soils. Larvae predominated during October to May, coincident with abundant young foliage. In contrast, only adults were present during summer, the exception being a site that was periodically mowed. Mowing induced coppicing of the cut stumps producing an unseasonal abundance of new growth. This stimulated reproduction, which induced a persistent larval population during summer months. More than 12,000 coppices exhibited damage during Oct. 1998, one year after initial releases at this “mowed” site. Transect sampling estimated the population at more than 2000 adults and 22,000 larvae. Weevils had dispersed throughout the 7.3 ha site but remained concentrated near original points of release.

Ease of establishment and slow dispersal suggested an optimal strategy of numerous small releases at carefully selected but widely dispersed sites. Nearly 3000 adults and more than 1000 larvae were therefore relocated from the “mowed” site to 29 additional sites during Nov. 1998, and *O. vitiosa* is now established throughout the range of melaleuca in southern Florida. However, because of their slow dispersal, a concerted release effort will be needed to ensure that all melaleuca populations become infested.

Tests of the host range of the melaleuca psyllid were conducted by Ms. Susan Wineriter from Dec 1997 through June 1999 after preliminary tests in Australia (Purcell et al 1997). Her studies indicate that this, too, is a highly specific agent that should be acceptable for release. It also appears to be one of the most potentially effective agents yet studied because large numbers severely damage or kill young plants and saplings in the laboratory. The data show *B. melaleucae* has a very narrow laboratory host range. It completed development one time on one myrtaceous test species, *Callistemon rigidus*. Efforts to colonize *C. rigidus* with large number of psyllids failed. Non-myrtaceous plants of concern in Florida including *Citrus* spp., sugarcane, and wax myrtle, were tested also. The data show no apparent damage or detrimental effects to any of these. However, a concern by Florida agricultural officials that the melaleuca psyllid could vector pathogens to citrus during dispersal or migration still remain. To resolve quickly this concern, additional choice and no-choice feeding tests have been set up on citrus by S. Wineriter at the request of the Division of Plant Industry’s plant pathologists. Also, DNA analysis of psyllids for internal microfauna, including pathogenic organisms, is being conducted by Dr. Barbara Frederick (USDA, Sidney, MT).

During quarantine testing of the psyllid, plants were first screened for oviposition. Plants were exposed to females for 3 days. Right before expected hatch, 14 days later, branches were removed to count eggs. These eggs still attached to plant pieces were held to determine if they would hatch and if nymphs would survive a week. Any nymphs that survived on test plant cuttings were then placed on test plants and checked weekly for survivorship. Most eggs hatched, but nymphal survivorship during the first week was low (higher on melaleuca controls but still low). In only four *Callistemon* spp. did nymphs live longer than a week (development time on melaleuca controls was 4 weeks). Since mortality could have been due to handling or confinement to plant cuttings rather than plants, an additional test was performed. Females were allowed to oviposit for 3 days on potted test plants, and then plants were held for seven weeks, the amount of time required to complete one generation on melaleuca. Then plants were examined for presence of F_1 nymphs, F_1 adults, and F_2 eggs. For this test, 5 plants of each species were tested except for 4 species where fewer than 5 plants were available. In those cases, plants were retested with different psyllid colonies. No F_1 adults or F_2 eggs were found on any plants except melaleuca controls and 1 *C. rigidus* plant. Female survivorship on plants was determined both from oviposition tests and the 7 week tests and was always higher on melaleuca controls. Since high numbers of eggs were laid on melaleuca controls in oviposition tests compared to test plants, the extra eggs laid on melaleuca were utilized to give hatchlings an additional and more certain opportunity to contact test plants. The melaleuca plant material with eggs about to hatch was placed in vials, and vials tethered to test plants. As the plant material dried out, nymphs could leave the vials, if they chose to do so. Plants were checked at 3, 4, 5, and 6 weeks after first hatch. Psyllids only survived beyond 3 weeks on *Callistemon* spp. None of those became adults. Any species on which psyllids were able to complete development in any of the tests (only *C. rigidus*), or which were otherwise considered to be at high risk, were tested further (*Callistemon* spp. and *Melaleuca decora*). Plants were exposed to large numbers of psyllids in an effort to colonize them (none were). In total, tests of female survivorship, oviposition, egg hatch (if eggs were laid), nymphal survivorship, and development were conducted on the 37 myrtaceous species and 9 non-myrtaceous species. In addition, oviposition tests on cuttings were conducted on 1 additional myrtaceous species and 16 non-myrtaceous species. As was expected, small numbers of eggs were found on some species. When numbers were of concern, choice tests and 7 week tests were performed. None of these plants was a suitable host. Permission to release this insect will be made in the fall of 1999.

A tube-dwelling moth (*Poliopaschia lithoclora*) is being intensively studied at the Brisbane laboratory. The larvae feed on the leaves of *M. quinquenervia*, forming shelters constructed of webbed-over leaves. Initially the larvae are communal, usually with at least half a dozen living in the same colony. Each larva forms a tube, which appears to be constructed from frass and leaf portions, held together by silky threads. Larvae leave the tubes to feed on leaves or form new tubes. Due to the distinctive form of the tubes, they are easily located and frequently found at field sites. The moth attacks and occasionally kills small saplings of *M. quinquenervia*, although it also occurs on older trees. Larvae and pupae collected from field sites are frequently parasitized by *Carcelia* sp. (Diptera: Tachinidae) and to a lesser extent by one Ichneumonidae (Hymenoptera) species.

Field host-range studies of *P. lithochlora* were conducted at Caloundra (69 km north of Brisbane) and Morayfield in southern Queensland, repeating a similar survey conducted in 1997. At each site all plants along a transect were searched for the presence of *P. lithochlora* colonies. The plant species and the number of colonies per tree were recorded. The transects included 137 plants from 8 species at Caloundra, and 139 plants from eight species at Morayfield. All of the *P. lithochlora* colonies were found on *M. quinquenervia*. Tube-dwelling moth colonies were also found on *Acacia hubbardiana*, *Allocasuarina littoralis*, *Alphitonia excelsa*, *Grevillia leiphylla* and *Pulteriaea* sp., though none of these specimens were *P. lithochlora*. Since 1996, all field host-range surveys have indicated that *P. lithochlora* only occurs on tree species in the *M. leucadendra* complex, including *M. dealbata*, *M. leucadendra*, *M. quinquenervia* and *M. viridiflora*. The restricted host-range of this moth is encouraging and further laboratory tests are planned during 1999.

At Morayfield the field population increased dramatically in January of 1998 and remained high through April when numbers peaked at 41 colonies/100 trees. In May numbers began to fall and very few colonies have been located at this site since July. Since the larvae feed mainly on older leaves, there are no restrictions on their food resources throughout the year. Higher numbers appear to correspond with higher temperature and rainfall over the summer period. In contrast, the field population at Tyagarah in New South Wales remained relatively constant through 1998 indicating no seasonal trends. Since January, numbers have fluctuated between 9-19 colonies/100 trees. No colonies were found at Byron Bay for the first two months of the year and the population peaked in May at only 7 colonies/100 trees. Surveys were terminated at this site in August after the field population had only averaged 3.6 colonies/100 trees during the previous 12 months.

Fergusonina sp. is a fly that forms a fleshy tip gall on *M. quinquenervia.* Other species have reduced flowering and seed production of *Eucalyptus* trees. About 23% of young melaleuca tips were found affected by galls at one site in Australia during 1993. *Fergusonina* sp. form galls in the leaf and flower buds of *M. quinquenervia* in a unique association with *Fergusobia* nematodes in what appears to be a symbiotic relationship. However, there is limited published material on the taxonomy and biology of this fly/nematode system. The galls vary greatly in size and color, depending on the growth stage and type of buds being attacked and on the developmental stage of the gall. Bud galls have exciting implications for biological control of *M. quinquenervia* because of their potential for preventing further branch growth and retarding flower and foliage production. Galls can also act as nutrient sinks reducing plant vigor. Dr. Gary Taylor, a taxonomist familiar with these flies, believes that only one species of *Fergusonina* occurs on *M. quinquenervia*.

The association of *Fergusonina* with *Fergusobia* nematodes appears to be species specific and restricted to plants within the family Myrtaceae, particularly *Melaleuca* and *Eucalyptus*. This association may represent an example of coevolution between insects and nematodes. In northern Queensland, bud galls were collected from other *Melaleuca* spp. in the *M. leucadendra* complex, though there is a different *Fergusonina* sp. for each tree species.

During 1998 Matthew Purcell and associates repeated field host-specificity surveys at a park at Hawthorne near the inner city of Brisbane. The site was chosen because of the presence of *M. quinquenervia*, its close relatives from the *M. leucadendra* complex as well as other *Melaleuca* spp., and *Callistemon viminalis. C. viminalis* is an ornamental plant grown commercially in Florida for the nursery trade. One hundred and thirty-five trees from at least four families were surveyed. One hundred and fifty-eight bud galls were found on *M. quinquenervia* while non galls were found on the remaining plant species. All plants, except for those of one undetermined species, had new shoots and/or leaf buds needed for oviposition by the *Fergusonina* and gall development.

Both surveys conducted at this site indicate that this insect is highly specific to *M. quinquenervia*.

From March through October there is an abundance of leaf buds being produced by *M. quinquenervia* plants at most field sites in Australia. Bud galls are generally larger in size during this period and greater numbers of flies and parasites emerge from these galls. From November through February most galls are smaller with fewer internal chambers. Because of their size, these galls are difficult to detect at field sites but can be detected by the presence of curled leaves on the terminal end of the branch. No flies have emerged from these galls in the laboratory, though dissections have revealed the presence of nematodes and first instar fly larvae. It is possible the galling system is in diapause awaiting the plants to start actively producing buds, which are not prevalent from November through February. However, flies have been reared from the larger galls throughout most of the year, as at least some buds are actively growing year round.

At least 12 parasitic Hymenoptera species have been reared from bud galls *on M. quinquenervia*: Pteromalidae, *Coelocyba* sp.; Eurytomidae, *Eurytoma* sp.; Eulophidae, *Cirrospilus* sp. and *Euderus* sp.; Torymidae, *Megastigmus* sp.; Braconidae, *Bracon* sp.; Eupelmidae, *Eupelmus* sp. and *Neanastatus* sp.; Ichneumonidae, *Poecilocryptus* sp; and three undetermined species. *Coelocyba* sp. is confirmed as a parasite of the flies themselves, having emerged from a *Fergusonina* pupa. It has yet to be determined whether the remaining species are parasites, hyperparasites or inquilines.

In order to examine the relationship between the fly and nematode, 38 female flies were dissected in distilled water and the number of parasitic-stage nematodes was recorded. In the 38 flies dissected, 2 to 15 parasitic nematodes were extracted (mean = 8.7 nematodes/female).

Only F1 generation galls were produced in the laboratory during 1997. The emerging flies were released onto potted *M. quinquenervia* plants, but no F2 galls were produced. Efforts to colonize *Fergusonina* later met with much greater success. We currently have over 30 F2 galls and are hoping to sustain this colony through summer. In 1998 we tried several techniques to cultivate galls including: adding flies directly to cages containing potted saplings; placing galls within cages allowing flies to emerge and move directly onto the potted saplings (eliminating the need to handle the flies); and adding flies to a small gauze sock isolated over a single branch of the sapling. All of these techniques were used in the greenhouse, laboratory and constant temperate cabinets. Galls were produced under all conditions and over 50% of attempts yielded a return of galls. As seen in the field, more of the smaller "curl" galls developed as we moved into summer, even in the constant temperate cabinets where both temperature and day length had been reduced to simulate winter conditions. Each of the potted plants had actively growing buds.

A joint grant proposal between the USDA Australian Biological Control Laboratory and the University of Adelaide was submitted to Australian Research Council (ARC) in April and was accepted in December. Dr. Gary Taylor, Dr. Kerrie Davies and Prof. Robin Giblin-Davis will cooperate on the project. Prof. Giblin-Davis will travel to Australia in March 1999 on sabbatical for six months based at the ABCL. He will study the biology of the bud gall fly/nematode system and oversee DNA analysis of the flies and nematodes for taxonomic purposes. Dr. Sonja Scheffer, USDA Systematics Entomology Laboratory in Washington, and Dr. Kelley Thomas, University of Missouri in Kansas City, have agreed to directly undertake the DNA analysis of the Fergusonina flies and *Fergusobia* nematodes respectively. The expected outcomes from the ARC project are listed below:

1. Clarification of respective roles of flies and nematodes in gall induction, and correct description of the interaction (as mutualistic or parasitic)
2. Understanding of the host specificity of flies and plant species
3. Confirmation of the host specificity of flies and associated nematodes
4. Elucidation of the taxonomy of *Fergusonina* collected from various *Melaleuca* spp., with formal descriptions of species and preparation of a key
5. Elucidation of the taxonomy of *Fergusobia* from *Melaleuca*
6. Establishing methods for culturing *Fergusonina* galls
7. Understanding the effects of galls on growth and health of *Melaleuca* saplings
8. Assessment of the suitability of *Fergusonina* as a biocontrol agent for *M. quinquenervia*

(Exerpt from ARC Strategic Partnerships with Industry - Research and Training application, prepared by Dr. G. Taylor, University of Adelaide, 1998).

Several other insects have been or are currently under investigation. *Lophyrotoma* sp. B, from *M. quinquenervia*'s southern range, is very similar to *L. zonalis*, both in terms of biology and damage inflicted upon its host. Initial host screening conducted in 1992 suggested that *Melaleuca viridiflora* might be an acceptable ovipositional host. Larvae failed to develop on this species, however.

The cerambycid beetle *Rhytiphora* sp. bores in live melaleuca stems and branches. This activity kills stem portions distal to the damage, and thus prevents flower production and seed set. Laboratory colonization has proven very difficult. Larvae fed an artificial diet entered what proved to be an 8-9 month diapause. Several emerged from this diapause during late 1993 whereupon they pupated. One adult has now emerged.

One of the leaf-feeding lasiocampid moths, *Porela* sp. C, was offered 18 plant species in feeding trials during 1992. Unfortunately, this species was found to prefer lemon guava (*Psidium pyriferum*) and grumichama (*Eugenia dombeyi*) to melaleuca. It has been dropped from further consideration.

The mirid bug *Eucerocoris suspectus* was one of the most damaging insects found attacking *M. quinquenervia* during Australian surveys (Burrows and Balciunas, 1999). Adults and nymphs feed on the leaves causing leaf blotching that can distort the growth of young stems. This insect fed upon 24 plant species and preferred *Melaleuca fluviatilis* to *M. quinquenervia* in laboratory studies. Six other species sustained appreciable feeding damage. However, this at first appeared to be an artifact of the laboratory setting. Therefore, during 1996 a garden plot experiment was initiated in Brisbane to provide a means of obtaining experimental host-range data in a more natural environment. Numerous species of Myrtaceae were planted after being sprayed with insecticide to eliminate existing insect infestations. The experiment was designed as a randomized, complete block array of nine plant taxa in five blocks. The nine Myrtaceae taxa planted were: *M. quinquenervia* ex. Florida, *M. quinquenervia* ex. Queensland, *M. alternifolia* (Tea Tree), *Callistemon viminalis* (Weeping Bottlebrush), *Eucalyptus cinerea* (Silverdollar Tree), *Eugenia uniflora* (Surinam Cherry), *Myrciaria cauliflora* (Jaboticaba), *Psidium guajava* (Guava), and *Syzygium jambos* (Rose Apple). These were chosen on the basis of taxonomic representation and varying degrees of relatedness to *M. quinquenervia*, economic importance and availability in Australia. Results indicated that *E. suspectus* will feed and survive on a number of Myrtaceae when adjacent *M. quinquenervia* trees are heavily damaged. This insect is no longer being considered due to its apparent broad host range

Melaleuca trees produce flowers nearly year-round in Florida, so we are very interested in finding insects that will attack these flowers directly, thereby reducing seed production. Several of the flower-feeding insects recovered from melaleuca during the surveys warrant further study. Unfortunately, melaleuca trees in Australia only produce flowers once a year and the flowering season is relatively short and synchronous. Thus, melaleuca flowers are not available on a regular basis to support colonies of flower-feeding insects. Consequently, conducting investigations of these insects requires first developing methods whereby melaleuca trees under cultivation in greenhouses can be induced to routinely produce flowers.

Pathogen research – The fungal work on melaleuca in south Florida is discussed in the following papers: Rayachhettry and Webb, 1993, 1994; Rayachhettry and Elliot, 1996, 1997; Rayachhettry et al. 1996a, b, c, d, 1997, 1999.

Canker fungus. Eight isolates of a canker fungus, *Botryosphaeria ribis* (six from *Melaleuca quinquenervia*, two from *Rhizophora mangle*) were obtained from south Florida. Morphological characteristics of these isolates were studied on various culture media and excised leaves and stems of *M. quinquenervia* ramets. Mycelial morphology, sporulation attributes, dimension of conidiomata, and growth rate varied among isolates. Conidiophores were short and hyaline with a bulbous base arising from the lining of the stromatal locules. Fresh macroconidia were fusiform, truncate at the base, obtuse at the apex, hyaline, aseptate, but some of them developed 1-3 septa when retained in pycnidia on aged and dried culture media or germinated in water under coverslips. Regardless of septation, 1-5 germ tubes were produced from the polar as well as the lateral sides of conidia. Microconidia were rarely produced by most isolates. Microconidia did not germinate. The percentage of macroconidia germinating within 4-8 h was greatest at 25-35°C, was rare or absent at 5°C, and viability was lost at 45°C. The teleomorph stage was not observed on any growth media regardless of incubation conditions. These morphological characteristics support the characterization of the isolates as the *Fusicoccum* anamorph of *B. ribis*; also, many characteristics overlap with reported characteristics of the *Fusicoccum* and *Dothiorella* anamorphs of *B. dothidea.*

These eight isolates of *Botryosphaeria ribis* from *M. quinquenervia* and *Rhizophora mangle* were evaluated for pathogenicity to *M. quinquenervia* clones under greenhouse conditions. Stem-inoculations revealed: 1) *B. ribis* induced cankers on stems which were similar to those observed in natural infections under field conditions, 2) the mid-height segment of the main stem was more readily colonized than the root collar, 3) a slightly positive correlation occurred between diameter of stems at the point of inoculations and canker lengths, 4) hyphae and macroconidia were similarly effective as inocula for stem cankers, 5) more pronounced callusing occurred following inoculations during March than during October, 6) all isolates initiated cankers on stems of all clones, but some isolates exhibited greater aggressiveness, 7) *M. quinquenervia* clones showed a differential susceptibility to infection by *B. ribis*, and 8) establishment of this fungus in stem tissues requires a wound or some form of injury that stresses the tree

Under greenhouse conditions, the disease-causing ability of *B. ribis* on melaleuca was studied with respect to stress from simulated drought, low temperature, and defoliation treatments. Low xylem water potential was related to increased level of canker development and subsequent tree mortality. Canker development was enhanced by low temperature treatments with alternating exposure to 6°C for 3 d followed by 4 d at 30 ($\pm$5)°C for 8 wk. Partial defoliation did not affect canker development but complete defoliation of *B. ribis*-inoculated ramets resulted in tree mortality within 4 wk. Callusing of melaleuca wounds was either reduced or prevented in stressed trees. These observations suggest that stress induced on the tree enhances the effect of the pathogen.

The mode of action of *B. ribis*-invasion of stem tissue and *M. quinquenervia*-response was studied under laboratory and greenhouse conditions. Infection of excised leaves in a moist chamber occurred through wounds and stomata, and tissue discoloration followed. Development of callus tissue on wounded stems was more pronounced after spring inoculations than after autumn inoculations and, likewise, more on nonstressed ramets than on stressed ramets. Callus ridges on *B. ribis* -inoculated wounds were surrounded by 2-3 celled suberized layers which were also present on callus ridges of non-inoculated wounds and healthy bark. Cells in callus ridges of *B. ribis* -inoculated wounds had lignified cell walls and contained tanninoid substances, which were invaded by hyphae. Invasion of callus tissue occurred through the interface between the callus ridges and the sapwood. Invasion and discoloration of phloem, cambium, and xylem occurred beyond the margins of callus ridges. In noncallused wounds, hyphal colonization was extensive in the cambium and phloem regions. In both callused and noncallused stems, hyphae grew inter- and intracellularly in the cortex, cambium, xylem, and pith. Callus did not limit fungal invasion of newly formed tissues or the tissues formed prior to wound inoculation. Stem girdling by the fungus appeared to be delayed by callus formation.

Possibility of the integration of *B. ribis* with commonly used herbicides to enhance melaleuca control efforts in south Florida was investigated. Hyphal inoculum of four *B. ribis* isolates were evaluated *in vitro* for compatibility with imazapyr, glyphosate, and a surfactant. Imazapyr at 12 to 60 mg ai/ml did not cause significant loss of inoculum viability in all four isolates within 2 h after mixing though after 24 h, inoculum viability of some isolates was reduced. Glyphosate at the lowest concentration (32 mg ai/ml) significantly reduced inoculum viability of all isolates within 2 h. Initially, the inoculum viability of all isolates remained unaffected by 1, 5, and 10% (v/v) surfactant concentrations. After 24 h, the surfactant slightly reduced inoculum viability of three isolates; the viability was significantly reduced in one isolate at all concentrations. Mixture of the lowest imazapyr, glyphosate, and surfactant concentrations significantly reduced inoculum viability within 2 h. This corresponded with the results obtained for glyphosate alone. These results showed that hyphal inoculum of *B. ribis* may be mixed with imazapyr and surfactant for field applications, but mixing the fungus with glyphosate may not be as efficacious.

The fungus was field evaluated with or without mixing with herbicide, imazapyr. There was no mortality among non-defoliated trees inoculated with *B. ribis* alone. Mortality of *B. ribis*-inoculated trees was increased by three complete defoliation cycles. Defoliated trees inoculated with isolate BR-5 exhibited 100% mortality compared to 17% for defoliated but non-inoculated trees. Wounds inoculated with *B. ribis* during winter produced longer cankers than did non-inoculated wounds. Stump-regrowth reduction by treatment with *B. ribis* alone was less effective than treatment with imazapyr herbicide alone. Mixtures of *B. ribis* with imazapyr or imazapyr alone at comparable concentrations were not significantly different in stump regrowth control. Overall efficacy of *B. ribis* may be further enhanced by improved formulations and better delivery systems.

Rust fungus. During January 1997, severe incidence of a rust disease was detected on new growth of about 70% of the melaleuca trees over a 2-km strip in Broward and Dade Counties. These top-pruned trees were 3 to 5 m tall with bushy appearance and had relatively large number of new shoots. This rust was recorded on melaleuca saplings and trees in a 20-km radius in January through March 1997. Leaf lesions began as halos that expanded, produced spores and developed into necrotic spots. Infected leaves were severely distorted. Succulent stems bearing immature leaves were often girdled causing dieback of the new growth. Branches were severely defoliated and bark-limited cankers were formed on stems with living bark. Yellow uredinia were observed on 100% of young leaves and some petioles and succulent twigs. Urediniospore morphology and dimensions (17-27 x 15-24 ?m) are comparable to the description for *P. psidii* and the University of Florida's herbarium material of *P. psidii* on *Pimenta dioica* (allspice). An inoculation test was conducted using 40-cm tall melaleuca seedlings. Fully expanded leaves and terminals of these seedlings were brushed or sprayed with freshly collected urediniospores, covered with plastic bags, and placed in a growth chamber maintained at 16 C (night) and 26 C (day) with a corresponding 12-hr light cycle for 72 hrs. The plastic bags were then removed and the seedlings maintained in high humidity and ambient temperatures in a shadehouse. Typical *P. psidii* induced symptoms and sporulation occurred after 10 and 12 days, respectively, following inoculation. Although *P. psidii* has been recorded on 11 genera in Myrtaceae in the Americas, including melaleuca, an epiphytotic of this magnitude on melaleuca has not been recorded. This rust may have potential as a microbial biological control agent of melaleuca, if its host range is narrow. Two races of this rust, one on *Pimento* and one on *Eugenia* species have been reported incapable of infecting guava (*Psidium* spp.) (1, 2). A different race of *P. psidii* has been suspected to cause sudden epiphytotics on *P. officinalis* in Jamaica. Further research related to host range is warranted to determine the specificity of *P. psidii* on melaleuca.

2. ECOLOGICAL GENETICS RESEARCH

Melaleuca importation history - It has long been assumed that Florida melaleuca was derived primarily from two sources (Turner et al. 1998, Kaufman 1999), although other introductions were known (Meskimen 1962, Morton 1966, Turner 1998). East-coast populations were assumed to have come from seeds imported from the Royal Botanical Gardens in Sydney, Australia, by John Gifford during 1906. West-coast populations presumably came from seeds imported from a Melbourne, Australia seed house during 1912 by A.H. Andrews. However, careful scrutiny of early horticultural catalogs and USDA plant introduction records has suggested that earlier importations contributed at least as strongly to Melaleuca's invasion of Florida as did the Gifford and Andrews introductions.

The first broad-leaved paperbarks recorded in Florida were seedlings offered for sale during 1887 as *M. leucadendron* by the Royal Palm Nurseries near Oneco, Sarasota Co., Florida. The source of these early plants is unknown, though it is likely that they were acquired from an Australian botanical garden. The second known introduction was in 1898 by Henry Nehrling, a teacher whose passion was horticulture. Material obtained as seed from Sir Thomas Hansbury's La Mortala Gardens (currently: Giardini Botanici Hanbury at the University of Genoa) in Ventimiglia, Italy, was cultivated at Nehrling's nursery (Palm Cottage Gardens) in Gotha, Orange Co., Florida. A severe frost in 1917 prompted Nehrling to transplant many species, including some melaleuca, to a second nursery (Tropical Gardens & Arboretum) near Naples, Lee Co., Florida in 1919. This site is currently Caribbean Gardens.

Three other early introductions derived from "Les Tropiques" in Nice, France. This was the private botanical garden of a physician, Dr. A. Robertson-Proschowsky. USDA records indicate that seeds from the first shipment, received during 1900, were successfully cultivated and seedlings distributed to individuals in the local area. Some of the distributed seedlings were apparently planted in Coconut Grove, because David Fairchild observed an 18-ft tall broad-leaved paperbark growing in the Grove during 1906 (Rothra 1972). Also, the French seeds were likely the source of seedlings planted by John C. Lang in Davie, Broward Co., Florida (Pritchard 1976).

Melaleuca population variation - The fact that Florida's melaleuca forests derived from several different sources suggests the possibility that existing populations are genetically distinct. Insects from different plant populations can vary in their acceptance of and performance on host plants (DeBach and Rosen 1991, Bernays and Chapman 1994). Thus, identifying any genetic structure among Florida's melaleuca populations could be important to understanding differences in performance by biological control insects. We have therefore initiated studies to investigate genetic variation among Florida's melaleuca populations.

Early results of isozyme analysis using cellulose acetate electrophoresis techniques indicate that population differentiation is indeed present among Florida's melaleuca populations. Completion of this research will allow us to quantify the amount of differentiation. We will also employ RAPDs (randomly amplified polymorphic DNA) techniques and chemotyping techniques to help us differentiate distinct Melaleuca biotypes in Florida. RAPDs profiles of Melaleuca populations in Australia will then help us identify the origins of Florida's plants and permit us to collect biocontrol insects from Australian plants most genetically similar to our own.

3. Biological Control Project Needs

Overseas research needs - The release of the first biological control agent of melaleuca during 1997 and the introduction of several candidate species into quarantine for host range testing are important milestones in this program. This in no way diminishes the need for further research in Australia, however. Control of a woody species like melaleuca will undoubtedly require more than just two or three insects. In fact, at the outset of this project we estimated that at least 8-12 insects would be necessary. Thus, the overseas research program will need to continue for the foreseeable future. For this, we need continued support at consistent levels.

Quarantine research needs - The quarantine studies needed for this project necessitate specially designed facilities. Presently, this research is being conducted at the Gainesville quarantine facility, which was designed for work with much smaller organisms. Less than 1000 ft^2 of space is available which is inadequate for the development of research colonies of the bioagents and for production of the large woody plants used in testing and needed to feed the insects. As a result, personnel in Gainesville rely on shipments of melaleuca plants, from the USDA-ARS laboratory in south Florida, as a supplementary source of food for these insects. Many of the test plants are also supplied from the Fort Lauderdale area. While progress has been made despite these space limitations, it has not been as rapid as it would have been with larger greenhouses. These limitations were recognized during the formative stages of this project, and it was recommended that a specialized facility be built in south Florida. This facility would be dedicated to the development of biological control agents for the large woody species of exotic pest plants that are particularly troublesome in the area.

In November 1990, an Interagency Steering Committee was established to direct USDA-ARS research and to address the need for a quarantine facility. The committee was composed of members from the US Army Corps of Engineers, USDA-ARS, National Park Service, Florida Department of Natural Resources, Florida Department of Environmental Regulation, University of Florida, and SFWMD. A congressional aide (Michael Harrington) from the office of Congressman E. Clay Shaw (District 22, FL) also attended this meeting. The steering committee encouraged construction of this quarantine facility and suggested that the US Army Corps of Engineers engineer and design the facility for construction at the University of Florida's Fort Lauderdale Research and Education Center in Davie, Florida (the location of the USDA-ARS Aquatic Plant Management Laboratory).

Congressman Shaw spearheaded efforts to obtain funding for construction of this facility, which was estimated in 1991 by the Corps of Engineers to cost about $2 million. Initial efforts failed but, with the force of the entire Florida delegation behind him, Congressman Shaw obtained authorization for construction during the 1993 budget process and an appropriation for $1 million in the 1994 budget. An additional $1 million was included in the House version of the 1995 budget, but was eliminated prior to passage. However, inflation and revised building codes have steadily increased the cost of the facility beyond this initial estimate. In addition, ARS has increased its commitment to Everglades' issues and is adding staff to the Fort Lauderdale location. The additional laboratory and office space needed to accommodate this increase also adds to the cost of the building.

A portion of the first appropriation was used for planning and design of the building. This is now complete. Construction can not begin, however, until receipt of the full amount needed. The estimated construction time is about 16 months.

Florida field research needs - Success of biocontrol programs is generally measured in terms of the reductions that the agent(s) elicits in the target weed's geographic coverage, reproductive capacity, growth, and/or rate of spread. Gauging whether such reductions have occurred requires that a detailed understanding of the biology of the weed in its adventive range be gained prior to release of the biocontrol agent(s).

Unfortunately, few if any of these parameters have been studied for melaleuca in Florida. Thus, obtaining funds to study the demographics and population biology of melaleuca in Florida is perhaps the most pressing need facing this program after adequate funds have been acquired to construct and operate a quarantine facility.

Pathogen research needs - The presence and pathogenicity of canker fungus, *B. ribis*, and rust fungus, *P. psidii* has stimulated questions regarding the possibility of using melaleuca pathogens from Australia to combat this tree in Florida. Preliminary surveys in Australia yielded no prominent melaleuca pathogens, but these efforts were cursory. A more thorough survey should be conducted before abandoning this avenue of melaleuca biocontrol research. Further studies on the biology and host range of *P. psidii* are needed to evaluate its potential use as a bioherbicide.

B. OPERATIONAL EFFORTS

1. ARTHUR R. MARSHALL LOXAHATCHEE NATIONAL WILDLIFE REFUGE

Bill Thomas

Arthur R. Marshall Loxahatchee National Wildlife Refuge (the Refuge) consists of 58,000 hectares of northern Everglades' habitat. This area is contained within a 90-kilometer levee and an associated borrow canal. Another 1,000 hectares outside the levee are maintained as small impoundment and cypress swamp. The land elevation of the Refuge varies from about 5.0 meters m.s.l. at the northern end of the Refuge to about 3.4 meters m.s.l. in the south.

The habitat of the main impoundment, also known as Water Conservation Area 1 (WCA 1), is characterized by the interspersion of four main plant communities: sloughs, wet prairie, sawgrass and sawgrass-brush, and tree island or boyhood. The main soil type on the Refuge is white water lily peat, also known as Loxahatchee peat. Peat depths within the refuge vary between 1 and 4 meters.

WCA 1 is owned by the State of Florida and is part of the Central and South Florida Flood Control Project. At the direction of the U.S. Army Corps of Engineers, the South Florida Water Management District (SFWMD) manages water levels in the area for flood control, water storage, and the maintenance of a healthy Everglades community. Under the current regulation schedule, water levels are allowed to fluctuate between 4.3 meters and 5.2 meters m.s.l. Water levels are scheduled to be highest from late October through December and lowest from May 1 through June 30. In 1990, the refuge proposed to modify the schedule to allow for longer hydroperiods. This plan is anticipated to be implemented in 1994.

Melaleuca invasion of the refuge became apparent in the late 1960's. Melaleuca is currently present within approximately 50% of the refuge. 8,000 hectares are considered to be moderately to heavily infested and 16,000 ha are infested with 50 or fewer trees per 40 ha. The abundance of bayheads with deep peat sediments in the interior is unique to the Refuge. These tree islands are being invaded by melaleuca. Melaleuca has become a threat to the character of this irreplaceable Everglades community.

Past and Present Control Efforts - Between 1983 and 1988, approximately 40,000 melaleuca trees, ranging in size from 1-meter tall seedlings to mature trees were treated or removed from the Refuge. This was accomplished through Refuge research programs, the awarding of contracts, and the use of Refuge personnel to treat and remove trees. The work was performed on more than 1,620 hectares of the eastern portion of the Refuge. In November 1983, a management study was initiated to identify an effective and environmentally acceptable method for controlling melaleuca. The study was aimed at testing various control techniques to determine those that would be effective in the unique and very wet habitat found on the Refuge. Special attention was focused on effectiveness, adverse impacts to surrounding habitat, and labor-saving techniques.

The results of this study indicated that melaleuca in the Refuge remains alive for an extremely long period following chemical treatment. In many sites, trees were showing signs of life in the cambium for over one year after treatment. VELPAR L, a photosynthetic inhibitor, was determined to be the most effective product for controlling melaleuca on the Refuge during the early phases of this research. Subsequent to this, ARSENAL, an amino acid synthesis inhibitor, was determined to be the most effective product at killing melaleuca trees when applied using the hack-and-squirt method.

As a result of the initial management study, two contracts were awarded for the treatment of melaleuca on the Refuge. The first went to Florida Aquatics, Inc. in September 1985. The contract specified that 10,000 melaleuca trees were to be chemically treated with VELPAR L. The treatment area encompassed 1,376 hectares on the East Side of the Refuge. The initial treatment was completed in April 1986. A prescribed burn was conducted in the treatment area in July 1987 to kill seedlings, which resulted from the initial treatment. An inspection in August 1987 revealed that as many as 60% of the trees survived the initial treatment. Because the contractor guaranteed the death of 80% of treated trees, the contractor was required to retreat surviving trees. This work was completed by January 1988. The work of the contractor was passed during an inspection in July 1988.

The second contract was awarded to Mr. Darryl Jones of Arkansas. This contract required that all melaleuca trees over 1.52 meters tall, on the day Refuge personnel inspected the work, be treated in a 280 hectare area. The contractor was permitted to use either VELPAR L or ARSENAL. With few exceptions, the contractor used VELPAR L or pulled and removed trees from the marsh. The work took place between July 1987 and November 1987. The VELPAR-treated trees required 6 months or longer to drop their seeds, whereas Arsenal required less than two months. The total cost of the two contracts was $68,000; $20,000 came from the SFWMD and the balance came from the U.S. Fish and Wildlife Service (USFWS).

Testing of herbicides and application techniques for the control of melaleuca continued through 1987 and 1988. In June 1987, three small sites were treated with ground applications of SPIKE 40P pellets produced by DowElanco Co. Preliminary results indicated this is an effective product for controlling melaleuca. SPIKE 40P, a photosynthesis inhibitor, reportedly maintains activity in the soil for three years following treatment. This is beneficial because it provides for control of seedlings in treated areas. In 1988, Elanco donated approximately $1,000 worth of SPIKE 40P, which was used to treat two hectares of melaleuca-infested areas in April. These trees began browning within three weeks and within 12 months all treated trees were dead.

In 1987, ARSENAL was issued a supplemental label for use with hack-and-squirt treatment of trees that were not in "flowing water". This increased the flexibility of using ARSENAL on the Refuge. In April 1988, ARSENAL and GARLON 3A were aerially applied by helicopter to two islands with 24 hectares and 16 hectares of melaleuca, respectively. Trees sprayed with GARLON 3A browned within six weeks of treatment, while those treated with ARSENAL remained green for up to eight months following treatment. Ten months after treatment, 50% of trees treated with GARLON 3A were declared dead, with feathering (i.e. small numbers of green leaves) occurring on fewer than 10% of treated trees. ARSENAL treatment resulted in less than a 50% tree kill. SPIKE 40P applied with a backpack blower caused the trees to brown within three weeks and to die within 12 months.

In early 1989, numerous melaleuca trees widely scattered around the Refuge were browning with no obvious cause. After studying the trees, Dr. Roger Webb of the University of Florida diagnosed it as *Botryisphaeria ribis*, a fungal pathogen usually found in highly stressed trees. The trees had been recently stressed by cold. More research is needed to determine if the fungus can be used to control melaleuca. Also in 1989, Dow Chemical donated another 180 gallons of GARLON 3A and SFWMD donated $1000 of helicopter time to treat melaleuca on the Refuge. Twenty-four hectares containing melaleuca heads of 0.2-2.0 hectares were treated.

In 1990, GARLON 3A was used to aerially treat eight hectares of melaleuca on the Refuge; half were retreatment sites. Dow Chemical and SFWMD donated some of the chemicals and SFWMD provided the helicopter. During the summer, four Youth Conservation Corps (YCC) crewmembers and a Refuge Biological Technician pulled over 40,000 seedlings.

The Refuge received a matching grant in 1991 for $275,000 from the Florida Department of Environmental Regulation ($50,000) and the SFWMD ($75,000/year for three years). Refuge and YCC crews treated 24,906 melaleuca and pulled 3,354 seedlings that year. Also, 26.4 hectares were aerially treated using 37 gallons of GARLON 3A.

The SFWMD granted $75,000 to the Refuge for control of exotic plants and the USFWS provided an additional $40,000, enabling the Refuge to hire a full-time exotic plant removal crew in April 1992. Using several techniques and a variety of chemicals, the crew treated 125,398 melaleuca trees and pulled 31,190 seedlings that year.

The SFWMD again provided $75,000 in 1993 for exotic plant removal and the USFWS provided $60,000. Approximately 57,545 melaleuca trees were treated by the hack-and-squirt method with ARSENAL, and 167,015 seedlings were pulled. An additional 15,000 melaleuca trees were treated with 80 lbs. of SPIKE 40P pellets. In August 22, hectares in the northwest corner were treated aerially with 90 gallons of GARLON 3A. This was a coordinated effort between the SFWMD, the Refuge, and a private contractor (Helicopter Applicators). The SFWMD donated the use of the helicopter and the Refuge donated the herbicide. The treated heads will serve as test plots to monitor the effectiveness of foliar applications of GARLON 3A. In November, eight hectares were retreated using 55 gallons of GARLON 3A. A second full-time exotic plant removal crew was hired in November 1993.

From 1994 to 1998, refuge staff treated melaleuca using a grid system. The four corners of a cell, approximately 41 hectares in size, are located using a Magellan GPS navigational device. The corners are then posted, or staked for high visibility. Crew members systematically treat all melaleuca located within a given cell and when finished, the process is repeated. The time period required, to complete a cell is dependent on three factors: (1) melaleuca density, (2) crew size, and (3) weather.

During mid 1994, crews abandoned the old “hack/squirt” technique, or frill and girdle, in favor of using chain saws to fell large seed-laden trees into the water. The use of chain saws allowed the crew to effectively triple the amount of melaleuca they treated on a daily basis. It was hoped that this modified technique when combined with the new water regulation (higher interior water levels) schedule adopted by the refuge in May of 1995 would help prevent seed germination at treatment sites. Refuge staff also experimented with varying concentrations of the herbicide Arsenal® before settling on a 50% solution in water. The cost of this herbicide skyrocketed $50 per gallon over a four -year period and this cost has a great impact on fixed budgets. This herbicide has proved to be the most effective against melaleuca.

An intensive aerial survey was conducted in 1995 and this survey revealed that melaleuca impacted (49%) of refuge lands, or 71,000 acres. Thirty-six (36,000) thousand acres are considered to be moderately to heavily infested, and 35,000 acres are lightly infested. When compared to a survey conducted in 1992, it was determined that the melaleuca was spreading at the rate of eleven acres a day. This was particularly discouraging at it was estimated that refuge crews could only treat from 2 to

1 acre of melaleuca per day. Monotypic heads are treated by first clearing the outskirts, manually pulling seedlings which may number in the thousands, and placing them on stands formed by breaking over small saplings using physical force (hands), or hatchets. This often involves walking and sifting through thick sawgrass, or a tangled maze of buttonbush, smilax, and wax myrtle. When the crew is satisfied that the outskirts have been cleared, they begin to fell the larger trees associated with the main head into the water using chain saws. Cuts are made high enough so that the stumps are highly visible to airboat operators. A 50% solution of Arsenal® is then applied to the stump and the cut end of the tree. Refuge staff felt that by dropping trees into the water that they would prevent wind dispersion of the tiny seeds, and contain them to an area immediately around the treatment site. Dense stands of pulled seedlings may provide a shading effect helping to prevent the germination of seeds and formation of new seedlings in a treatment area.

Inspections of older treatment sites where seed-laden trees have been felled in the water have experienced little to no seed germination and few if any seedlings are present. Those that are present were usually missed during the initial treatment.

Additional control techniques included hand broadcast of Spike 40P® herbicide pellets to dense heads along the L-40 levee and a portion of Strazzulla Marsh. These treatments had varying degrees of effectiveness. The herbicide seems to control large trees but seems to have little, or no effect against seedlings, or their formation.

In 1997, USDA researchers released approximately 342 melaleuca snout beetle (*Oxyops vitiosa*) larvae at several sites in the refuge interior. The experiment was deemed a failure, as larvae were unable to pupate in the soil at the base of trees due to high water levels. It was hoped that the larvae would pupate behind the bark of the tree but this did not happen. Evidently, the larvae dropped into the water and drowned. The experiment indicated that releases in areas which, experience extended hydroperiod would not be feasible. Additionally 12 adult beetles were released at the same site in 1998, but USDA researchers found no evidence of the adults upon a subsequent visit. Mass releases of adults at the Refuge may be the only way to establish a viable population but these quantities of adults cannot be produced at current quarantine facilities. The future of biological control at the Refuge may lie with the release of the defoliating sawfly. The sawfly's entire life cycle takes place within the confines of the tree and should not be affected by high water levels.

The exotic plant control program at Loxahatchee NWR can be considered a limited success. The small crew size cannot theoretically, or effectively treat melaleuca faster than it is spreading. Areas treated after the adoption of the new water regulation schedule in May 1995 have experienced little, or no regrowth helping to contain the spread of melaleuca. Areas treated prior to 1994, using the frill and girdle technique and where Spike 40P® pellets were used, have experienced rapid regeneration, developing into dense, monotypic heads. Another problem facing the Refuge's program was maintaining a full labor workforce. Lack of benefits produced a high turnover rate often leading to a skeletal work crew. Given the fact that crews can only treat 2 to 1 acre per day depending upon density, a more effective, or integrated means of control needs to be adopted.

It was decided in late 1998, that the refuge would switch to private contractors for melaleuca eradication in 1999. This was decided after discussions with personnel from other state and federal agencies, such as Big Cypress NP, Everglades NP, and the SFWMD. These three agencies have achieved excellent success using private contractors. The awarding of the refuge's first private contract in eleven years should be completed by early summer of 1999.

Since April of 1992, over $1,167,000 have been budgeted toward exotic plant control and over 2,225,000 trees have been killed (treated + pulled) on refuge lands at an average cost of $0.54 per tree. The Refuge's annual budget for the control of melaleuca averages $175,000. The SFWMD contributes $75,000 annually to the Refuge for the specific control of melaleuca. An estimated 6,458 acres have been cleared of melaleuca. The future of melaleuca control at the Refuge is dependent upon private contractors, the release of additional biological controls, such as the defoliating sawfly and sap-sucking psyllid, and continued increases in funding for exotic plant management.

2. Big Cypress National Preserve

Antonio J. Pernas and William A. Snyder

Background - *Melaleuca quinquenervia* (Cav.) S.T. Blake was introduced into the Big Cypress area in the mid-1940s (Meskimen 1962). Through wind dispersion and spread by off-road vehicles, melaleuca continued to grow unchecked. By 1979, in what is now the 728,000 ac Big Cypress National Preserve, melaleuca covered over 38,000 ac. In 1984, an exotic plant control program was initiated and focused on melaleuca. Traditionally, National Park Service (NPS) crews working seasonally were used exclusively to treat melaleuca. Since 1995, private contractors have been used to treat areas that contain moderate to dense monocultures of melaleuca. Outliers are treated by groups of 1-3 persons consisting of NPS employees and/or volunteers. The result has been an increase in treatment efficiency and cost effectiveness. To date, the combined efforts of NPS crews and private contractors have resulted in the treatment of over 10 million melaleuca stems at a cost of almost three million dollars. Funding currently exists to complete the initial treatment of all melaleuca in the preserve in the 1999 fiscal year.

Introduction - The integrity of Big Cypress National Preserve's native flora and fauna

is threatened by a variety of exotic pest plants that have been introduced into southern Florida, primarily for horticulture. Several of these plants have demonstrated the ability to spread into natural areas, displacing native plant communities and disrupting natural processes such as fire and water flow. A few species have already replaced native plant communities in the preserve and have changed the landscape both visually and ecologically. These species are melaleuca (*Melaleuca quinquenervia* (Cav.) S.T. Blake), Brazilian pepper (*Schinus terebinthifolius* Raddi), Australian pine (*Casuarina* spp.), cogon grass (*Imperata cylindrica* (L.) P. Beauv.), Cuban laurel fig (*Ficus microcarpa* L.f.), Java plum (*Syzygium cumini* (L.) Skeels), and air potato (*Dioscorea bulbifera* L.). The most troublesome of these is melaleuca.
Melaleuca, an Australian tree species, was introduced into southern Florida in the early 1900s as an ornamental and a possible source of lumber. An aggressive, invasive plant, it has since spread throughout the region, replacing native plant communities with dense monotypic forests that provide little value to wildlife (Schortemeyer et al. 1981). The spread of melaleuca constitutes one of the most serious threats to the greater Everglades ecosystem, a region that includes Big Cypress National Preserve and Everglades National Park (Thayer 1990).

In 1979, varying densities of melaleuca infested an estimated 38,000 ac of the preserve (Gunderson 1983). The preserve initiated an exotic plant control program in 1984, with primary emphasis on melaleuca. By 1992, systematic reconnaissance flights revealed 119,000 ac of infestations within the preserve. For the period 1984 to 1995, National Park Service (NPS) work crews spent nearly all of their time treating outlying populations of this species. The goal of this strategy was to limit the further spread of melaleuca into unimpacted areas of the preserve.

Management Strategy - Resources management at the preserve is permanently committed to exotic pest plant control. Public Law 93-440, which established the preserve, requires “the preservation, conservation and protection of the natural, scenic, hydrologic, floral and faunal, and recreational values of the Big Cypress Watershed." NPS management policies mandate the control of exotic species up to and including total eradication, whenever such species threaten the protection or interpretation of resources being preserved.

One of the keys to a successful exotic plant control program is the use of an integrated pest management (IPM) approach. This approach uses a combination of mechanical, physical, chemical, and biological control methods while minimizing impacts to non-target vegetation and soils. Other important elements of IPM include a systematic approach, long-term commitment, and consistent follow-up.

Resource managers in the preserve have adopted an incremental strategy for the control of melaleuca. In this strategy, the preserve is divided into 10 treatment units and melaleuca is identified and eliminated from one treatment unit at a time. Units that pose a potential threat to Everglades National Park and other important resource areas have received the highest priority. Once initially treated, units are monitored and retreated on a three-year cycle. This allows seedlings an opportunity to reach a height that will facilitate detection with a minimal chance of these plants producing seed. The goal of the control program is to bring melaleuca to a “maintenance” level. A maintenance level is considered achieved when all mature melaleuca have been cut and treated and seedlings resulting from previous treatments and seed banks have been controlled for a minimum of five years.

Monitoring - Systematic reconnaissance flights are utilized to detect and quantify melaleuca populations. Approximately half of the preserve, or five treatment units, are surveyed by this method each year. Flights are conducted from December to March to coincide with the deciduous period of the cypress, facilitating the identification of melaleuca. Flight lines are flown using a Trimble global positioning system (GPS) for navigation information. Two observers on the aircraft spot for melaleuca targets within a half- kilometer of the aircraft (“targets” are defined as isolated individual trees, areas of scattered trees, and dense stands). The type and position of the target is then entered into the GPS unit as a waypoint. Data collected from the flights are transferred to a personal computer database, post-processed using Trimble software, and manipulated using the ArcView geographic information system (GIS) Figure 3.

Control Methods - Seedlings (plants under 1 m in height) are hand-pulled and stacked in a pile to prevent resprouting. Plants taller than 1 m are cut using a machete or chain saw and the cut stumps applied with herbicide (25% Arsenal® or Rodeo®) diluted in water. Treated areas are then burned approximately two months to one year after the initial treatment to reduce post-treatment seedling establishment (Myers and Belles 1995). Universal Transverse Mercator coordinates are obtained for all treatment sites using GPS receivers Figure 4.

The U.S. Department of Agriculture has released the first insect in a proposed suite of biological controls. The melaleuca snout beetle (*Oxyops vitiosa*) feeds on the delicate new leaf growth at the end of melaleuca stems. In sufficient numbers, this beetle could greatly reduce melaleuca seed production. When this reduction occurs cannot be predicted because of varying geologic, hydrologic and climactic conditions that affect beetle establishment.

Partnerships - In 1994, Big Cypress National Preserve and Miami-Dade County entered into a partnership in which the preserve developed and implemented a mitigation plan satisfying the permitting requirements for a joint Miami-Dade County with Florida Department of Corrections jail facility.

The mitigation plan provided the preserve with $1,581,000 for the treatment, retreatment, monitoring, and evaluation on 21,498 ac of the preserve. A private contractor completed the initial treatment of all the melaleuca in the project area in February 1997. This phase of the project resulted in the treatment of 3,999,535 melaleuca stems at a cost of $973,000. The second (retreatment) phase of the project commenced in early 1998. Results of the melaleuca treatment program from 1984 to 1997, including funding levels, are summarized in Table 7.

The Miami-Dade County Wetland Trust Fund is expected to match the preserve's existing exotic plant control budget to provide for the initial treatment of all known melaleuca remaining in the preserve. A private contractor will perform the work under the supervision of NPS staff. The private contractor is currently under a "time and materials" contract with the preserve to control exotic vegetation within the boundaries of both the preserve and Everglades National Park. This contract allows the NPS to issue individual task orders for five years (base year, plus four option years), as funds become available.

Figure 3. Melaleuca density and Treatment status at the Big Cypress National Preserve.

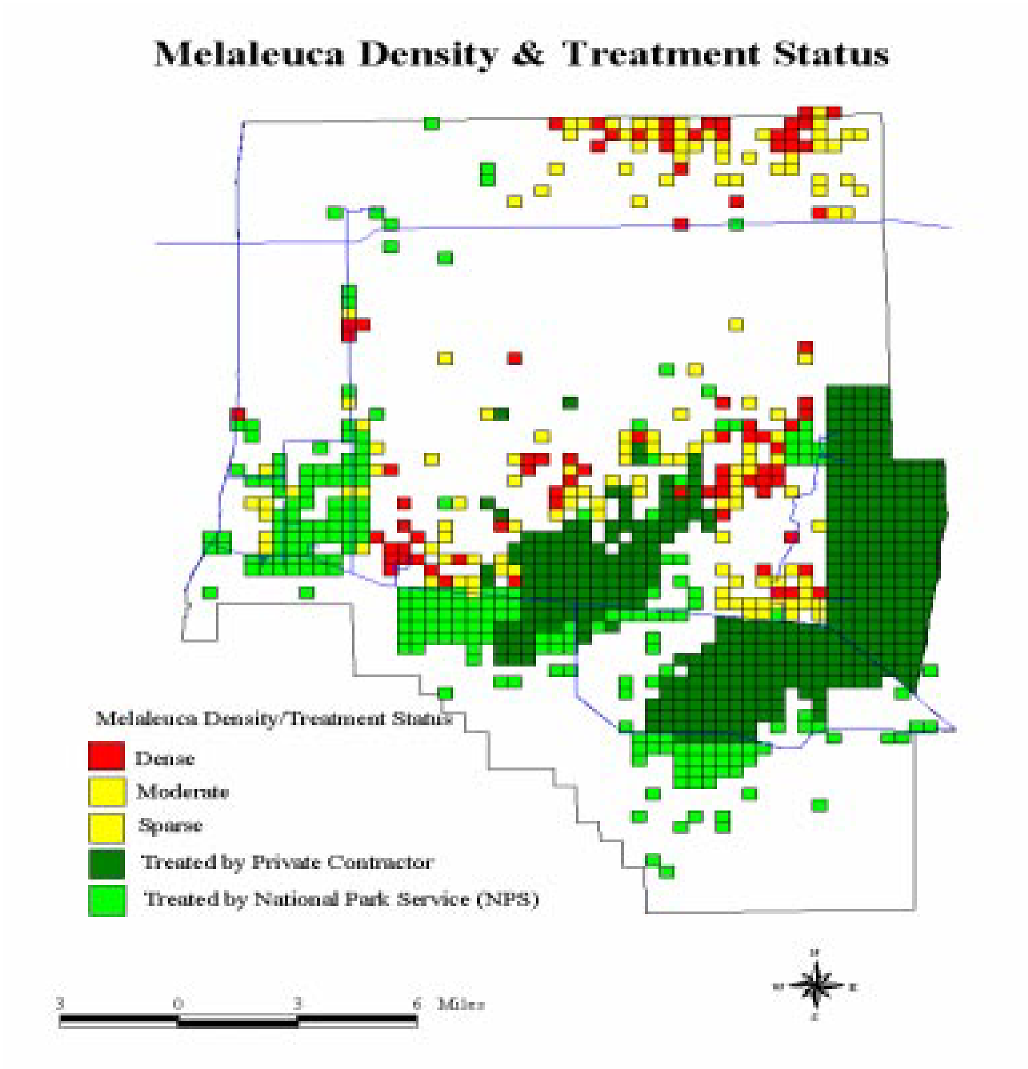


Figure 4 Map of melaleuca stems treated in the Big Cypress National Preserve (1984 – 1998).

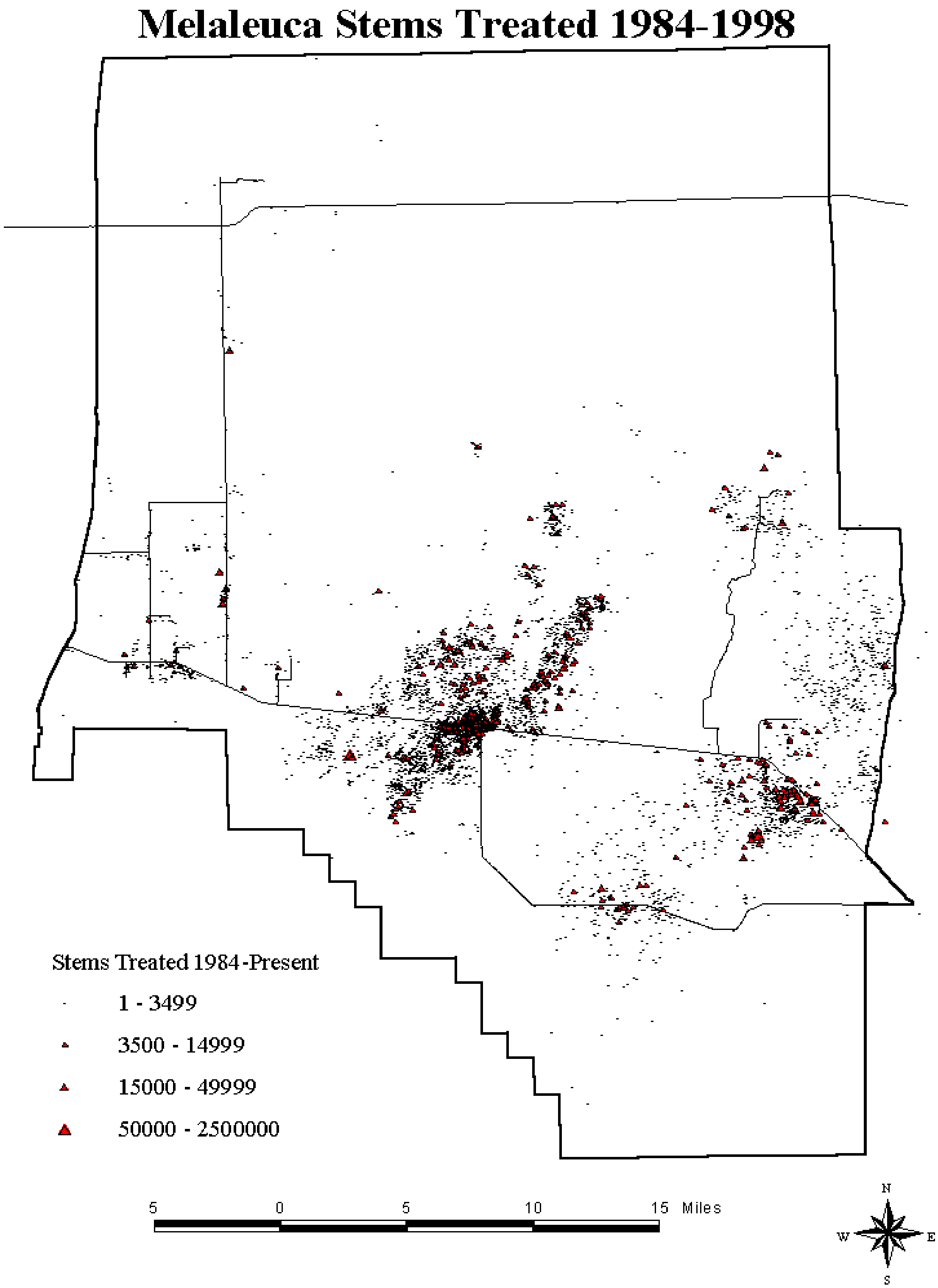


Table 7. Summary of melaleuca management efforts in the Big Cypress National Preserve.

Year	Number of stems treated by:			Funding ($)
	NPS Crew	Private Contractor	Aerial Application	
1984	49,120	0	0	50,000
1985	25,704	0	0	50,000
1986	20,502	0	0	0
1987	151,872	0	0	40,000
1988	27,750	303,281	0	87,000
1989	189,489	0	0	60,000
1990	161,131	0	0	100,000
1991	126,484	0	0	100,000
1992	373,455	80,902	0	170,000
1993	134,640	0	0	100,000
1994	244,234	0	2,474,400	183,000
1995	73,343	2,106,555	0	470,000
1996 (Monroe)	0	3,999,535	0	973,000
1996 (Loop Rd.)	0	966,750	0	200,000
1996 (Corn Dance)	0	347,455	0	220,000
1997	33,014	437,997	0	62,480
Totals	**1,610,734**	**8,242,475**	**2,474,400**	**2,928,840**

Discussion - The preserve's exotic plant control program has reduced the aerial extent of melaleuca from 119,000 ac to approximately 48,000 ac, through the cutting and treatment of over 10 million trees. Private contractors are now used exclusively for the treatment of moderate to dense melaleuca infestations. NPS employees and volunteers continue to target sparse melaleuca populations. This approach has reduced the cost of melaleuca treatment from 66 to 24 cents per stem.

The removal of melaleuca from the preserve's sensitive wetlands will permit the reestablishment of native plant communities and increase plant and animal diversity.

Federally listed species found in the area, which will benefit from melaleuca removal, include the red-cockaded woodpecker, wood stork, and Florida panther.

3. Everglades National Park

David T. Jones

Background - Melaleuca was first reported in the park in 1967 and occurred as isolated trees along the eastern boundary (LaRosa *et al*. 1992). Treatment before the mid-1970s consisted of felling the trees and applying herbicide to the cut stumps. Between 1979 and 1984, some 8,300 individual trees were treated, mostly seedlings that were pulled up by hand; larger individuals were treated using the “hack and squirt” (frilled) method (Doren and Jones 1997). The primary concentration of melaleuca in the park is in the East Everglades Acquisition Area (EEAA or “East Everglades”) where over half of the 42,700 ha (165 square miles) area is infested with this species. This infestation consists of single plants, even-aged stands, and monotypic stands or “heads” of several age classes. Because the expansion of melaleuca in this area is a threat to native sawgrass, mixed marshes and prairies, and tree island plant communities, intensive efforts to control its spread have been carried out there since the mid-1980s.

Mapping - The first, parkwide distribution map of melaleuca utilizing aerial photography was produced in 1988 using color infrared photographs (1:10,000 scale) recorded in 1987 (Rose and Doren 1988). Melaleuca, found to only occur in or adjacent to the EEAA, fell into two density classes: single trees and small monotypic stands. Aerial reconnaissance in 1993 revealed approximately 200 monotypic (high-density) stands, ranging from less than 1 ha to more than 20 ha, in the northeastern corner of the EEAA alone. The most recent attempt to map melaleuca in the park utilizes 1994-95 USGS NAPP color infrared photography (1:40,000 scale) and is part of a cooperative vegetation classification and mapping effort between the National Park Service and The University of Georgia (Welch et al. 1995). For the “South of Coopertown” quadrangle (15,721 ha), representing nearly 40% of the EEAA and occupying its northeastern quarter, low to high-density melaleuca was found to infest 11,370 ha (or 72% of the quadrangle’s area). In addition, this project included the mapping of melaleuca in a 1.5 x 10 km strip (equivalent to 1,500 ha) of the EEAA known to have some of the largest and densest melaleuca stands in the area; using low altitude, false color photography (1:7,000 scale), low to high density melaleuca was found to infest 1,425 ha or nearly 95% of the strip. This kind of high resolution mapping is being used to monitor melaleuca extent (by density and height classes), before and after control impacts on native vegetation, and treatment efficacy for a small area.

Funding - The development of and funding for a melaleuca management program for the East Everglades began with the establishment of the East Everglades Exotic Plant Control Project by the multiagency East Everglades Resource Planning and Management Committee in 1985, with the assistance of the Exotic Pest Plant Council (EPPC). The

Florida Department of Community Affairs through the Areas of Critical Environmental Concern Trust Fund provided initial funding in 1986. Since 1987, treatment of melaleuca in the East Everglades has been funded largely from non-NPS sources through agreements with contributing agencies, namely Dade County Department of Environmental Resource Management (DERM), Florida Department of Corrections (FDOC), Florida Department of Environmental Protection (FDEP), Florida Department of Transportation (FDOT), National Fish and Wildlife Federation (NFWF), and the South Florida Water Management District (SFWMD). Table 8 shows funds contributed to the program annually for the period 1987-1998, by contributing agency; in-kind services (staff salaries, administrative overhead) provided by the NPS contribute an additional one-quarter to one-third of the totals to the program annually.

Table 8. Annual Project Funding for Melaleuca Management in East Everglades (1987-1998), in thousands of dollars.

Agency	87- 89	90	91	92	93	94	95	96	97	98	Total
FDOC		264	264	264							792
DERM	75	40	60	200	200	200	200	200	200	200	1,575
FDEP	20	20									40
FDOT						200					200
NFWF										20	
SFWMD			60	60	60	60	60	60	60	60	480
Total	**95**	**324**	**384**	**524**	**260**	**460**	**260**	**260**	**260**	**280**	**3,107**

Treatment - Melaleuca is treated in the EEAA using the "quarantine strategy" of Woodall (1980). This approach emphasizes the location and removals of isolated "seed trees" or outliers, to halt the advance of existing populations, and progressively treat trees towards the source of the infestation. Management strategy is carried out in two phases: Phase I is the initial treatment of all plants in an area, and Phase II is the resurveying of previously treated areas to remove missed plants and treat regrowth.

In each treatment year (the season runs for about 21 weeks, from December to May), control is achieved by treating regrowth and new recruits at previous sites and expanding the treatment of new sites easterly in one mile increments. Surveillance conducted annually by helicopter, and removal work is carried out simultaneously by 2-4 person crews. Outliers and low to high density stands of melaleuca are treated as found along linear transects established throughout the EEAA. The park utilizes "best management practices" for the control of melaleuca as developed by EPPC's Melaleuca Task Force. Data collected at treatment sites includes location (using GPS), seed tree height, habitat type and condition, and numbers of stems treated by each treatment method (hand pulling, cut stump, foliar spray); data is entered into a computerized spreadsheet for project tracking and data analyses Figure 5. Treatment of melaleuca in 1997 was confined to aerial spraying (see below). Annual reports detailing progress made during the year have been produced since 1992.

The aerial application of various herbicide formulations on melaleuca in the EEAA began in 1994 after tests conducted in Big Cypress National Preserve (BICY) the previous year yielded promising results. Approximately 65 ha of high density melaleuca were sprayed with an Arsenal-Rodeo formulation. Because of high water levels in the park, aerial spraying did not resume until 1996 when 40.5 ha were sprayed with Arsenal-Krenite and Arsenal-Rodeo mixtures. In 1997, an additional 81 ha were sprayed with Arsenal-Rodeo; 95% mortality of melaleuca stems was observed after 60 days. While aerial applications of herbicides do not yet constitute a significant part of melaleuca control in the EEAA, the efficacy and low cost of this treatment method will warrant its extensive use in the near future. A detailed account of the aerial application program for melaleuca control in the EEAA is found in Devries and Jones (1997).

In 1998, melaleuca management in the EEAA changed dramatically: control works, was contracted by the park for the first time (this approach was recommended by resource managers from BICY who have utilized contract work successfully in their melaleuca control program). Under this approach, only low to medium density melaleuca stands were treated manually by ground crews; high density heads will be treated by the aerial application of herbicides in the future. In addition, surveillance of previously treated areas, usually carried out at the beginning of each treatment season and before control expands to new sites, was not extended to areas treated six years ago or longer; a review of treatment data for a seven year period (1989-95) indicated that a "maintenance" level of control is achieved after six years or more of treatment (Devries 1998). Contracted labor will continue to be used for melaleuca control in the EEAA in future years.

Table 9 summarizes the results of melaleuca management actions, including aerial spraying, for the period 1986-1998. Figure 5 shows the locations of all treatment sites, for the same period. Approximately 36,700 ha (142 square miles), or 84% of the EEAA, have been treated initially for melaleuca.

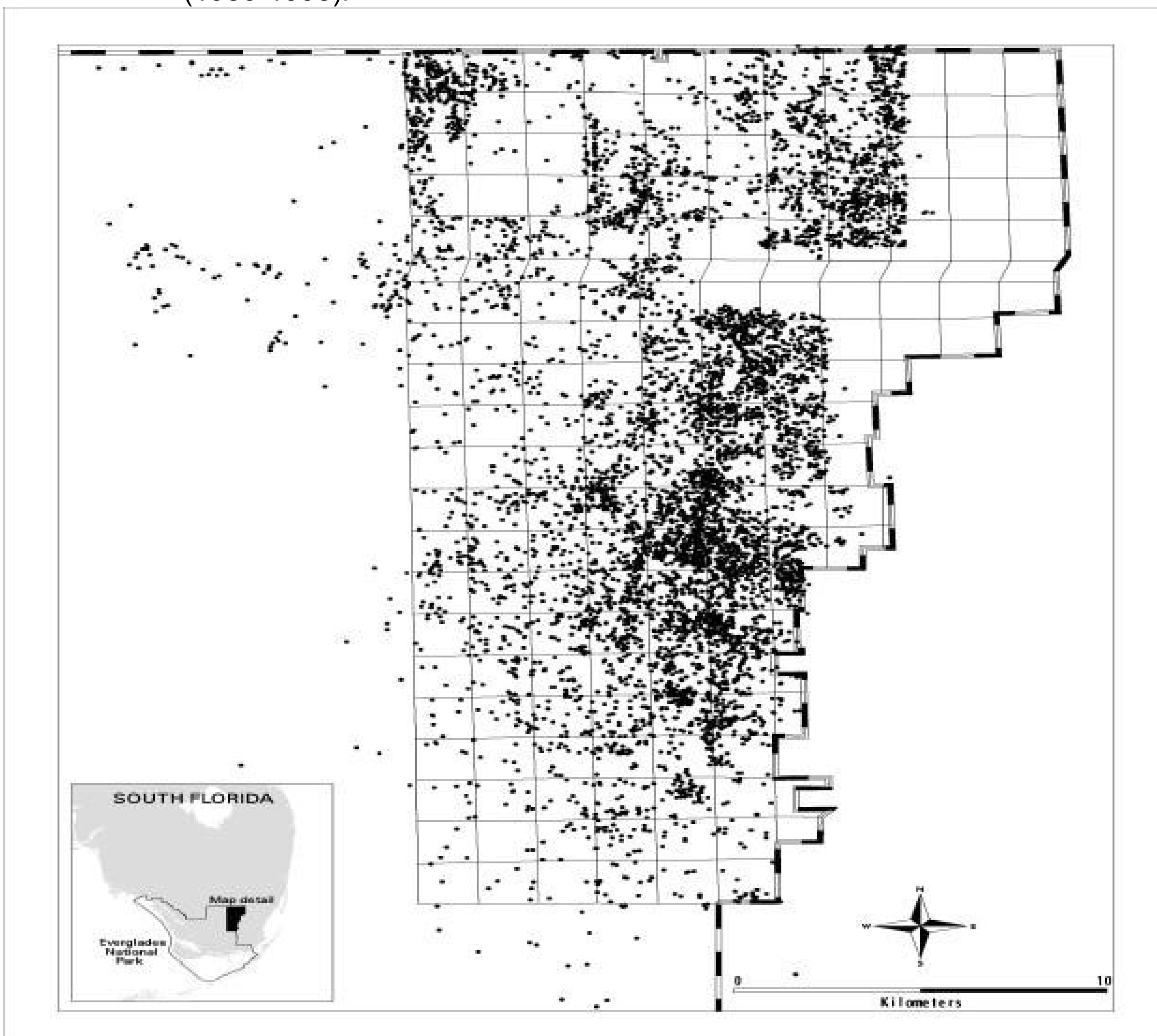
Table 9. Results of Melaleuca Management Actions in east Everglades (1986-1998).

Fiscal Year	Treatment Area (Ha)[1]	Aerial Spraying (Ha)	New Sites (No.)	Old Sites (No.)	Total Stems (No.)[2]
1998	3003	0	1,000	154	1,369,395
1997	0	81	16[3]	0	1,100,000
1996	1,748	40.5	1,182	339	307,327[4]
1995	712	0	1,336	252	194,132
1994	5,348	65	1,167	985	352,453[4]
1993	777	0	10	791	92,288
1992	3,885	0	330	340	2,044,112

1991	5,310	0		715	1,595,241
1986-90	15,929	2			108,150
Total	**36,712**	**188.5**	**5,041**	**3,576**	**7,163,098**

[1] area under "initial" treatment only; [2] includes trees, saplings, and seedlings; [3] represents monotypic stands, 1-15 ha in size; [4] excludes stems treated by aerial spraying

Figure 5. Locations of all melaleuca treatment sites in the Everglades Acquisition Area, (1986-1998).



Program Costs - Treatment costs and labor hours for the program, for the period 1986-1998, are summarized in Table 10. The rise in annual costs reflects the increase in melaleuca densities in the EEAA as the work progressed eastward. Increasing helicopter and herbicide costs have been the chief expenses. Labor costs have fluctuated over the years; some years have utilized volunteers and Americorps members when available.

Table 10. Melaleuca Management Program Costs and Labor Costs in East Everglades by year (1986-1998).

Fiscal Year	Helicopter Costs ($)	Herbicide Costs ($)	Cost/Year	NPS Labor (Hrs.)	Non-NPS Labor (Hrs.)	Hrs./Year
1998	0	0	257,843[1]	700	3,484[1]	4,184
1997	0	60,000[2]	60,000	0	0	0
1996	101,381	15,740	117,121	3,517	0	3,517
1995	145,000	9,000	154,000	2,789	0	2,789
1994	110,000	11,358	121,358	4,509	0	4,509
1993	93,553	11,540	105,093	2,252	1,160	3,412
1992	146,295	7,400	153,695	4,492	64	5,006
1991	111,053	7,744	118,797	2,755	72	2,827
1990	70,451	788	71,239	1,419	112	1,531
1989	55,198	442	55,640	926	442	1,368
1986-88	40,721	746	41,827	964	416	1,380
Total	**873,652**	**124,758**	**1,256,613**	**24,323**	**5,750**	**30,523**

[1] represents totals for contracted work; [2] includes all aerial spraying costs

Future Prospects - The remaining, untreated 7,250 ha (28 square miles) of the EEAA contain the largest and densest melaleuca populations in the entire EEAA. Assuming that funding levels and management approaches remain constant, the initial treatment of melaleuca in this area can be completed within 10 years. However, the prospect of expanding the aerial spraying program to treat all remaining high density stands, coupled with the continued use of contracted labor for treating all other trees from the ground, should allow the work to be completed within five years. Inspection of treatment areas for missed trees, new recruits, and regrowth will have to be carried out minimally for an additional five years after new sites are initially treated. Prescribed burns in the EEAA, while acknowledged as an effective melaleuca control method when applied properly, have not been utilized to the park's advantage. The park should begin integrating prescribed fires into future melaleuca management plans for the entire treatment area. In addition, the release of the melaleuca snout beetle (*Oxyops vitiosa*) into a small area of the EEAA by the USDA in December 1997 and February 1998 (additional releases are planned in the future) is an additional tool in the park's arsenal to combat melaleuca. The effects of this biocontrol agent may not be fully realized for 8-10 years after introduction, making it particularly important at the "maintenance" level of melaleuca control.

Factors Contributing to Successful Program Implementation - Consistent and dedicated funding for melaleuca control in the EEAA has been the single most important factor contributing to the success of the park's program to date. This funding has come almost entirely from non-NPS sources (see Table 8); among the six contributing agencies so far, DERM and SFWMD have contributed annually to the program since 1989 and 1991, respectively, accounting for 50% and 15% of the program's total funding to date. Because of this consistent flow of funds to the program, control actions in the park have been carried out every year without disruption since the program was initiated in 1987. In addition, interagency cooperation with regard to information sharing has been very beneficial. In this regard, the park has adopted best management practices recommended for the control of melaleuca by Florida EPPC. Specifically, the park's cooperation with SFWMD and BICY in the testing of aerial spraying formulations for melaleuca treatment has enabled the park to make significant progress towards eradicating the largest, densest stands of melaleuca more efficiently and economically using this method. Where control efforts on the ground are still required, the park gained from the experiences of SFWMD and BICY and changed its control operations in 1998 by contracting treatment work rather than using NPS crews. The result has been increases in worker efficiency, project productivity, and cost-savings. The park will continue to use contracted labor in future years.

4. FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

Jacqueline C. Smith

The Florida Department of Environmental Protection (FDEP) has been deeply involved with the melaleuca control program since 1988 when it began funding overseas research for biological control agents in Australia. In 1989, the FDEP's Bureau of Invasive Plant Management supported legislation to have *Melaleuca quinquenervia*, along with three other invasive exotic plants, regulated as to sale, transportation, collection, cultivation or possession. This legislation passed the Florida Legislature during the 1990 legislative session. In June 1993, Chapter 16C-52 of the Florida Administrative Code was amended, and melaleuca was added to the prohibited plant list. It is now a second degree misdemeanor to possess melaleuca through any means other than natural dispersion without a permit from the FDEP.

The FDEP was also instrumental in having melaleuca added to the Federal Noxious Weed List of the United States Department of Agriculture. In the future, this may allow for greater federal funding for melaleuca control if funds become available. In addition, FDEP has been supportive of federal funding for a quarantine facility in Ft. Lauderdale for biological control research for melaleuca and other invasive exotics in south Florida. FDEP funds are being spent on temporary personnel for melaleuca biocontrol research presently being conducted.

In 1992 the Florida Legislature increased funding to the Bureau of Invasive Plant Management and mandated that $1 million of the increased amount be spent on melaleuca eradication. The Bureau has been actively working to fulfill this mandate which started in Fiscal Year 1993/94. That year FDEP implemented a matching program with the South Florida Water Management District for the control of melaleuca. A total of $400,000 was obligated by contract to be spent on operational control activities in Lake Okeechobee and the water conservation areas. Since that time, $1 million has been allocated yearly in the matching program for melaleuca control. Although Lake Okeechobee and the water conservation areas have been the main emphasis of the control program, several other areas within these watersheds have been targeted.

5. LEE COUNTY

Roger S. Clark

Lee County continues to find controlling melaleuca to maintenance level a major challenge. This is primarily due to the continued addition of conservation lands to the inventory through the county's environmental land acquisition program while still committing resources to existing preserve and park areas. To that end, use of a variety of funding sources, contracts with other government agencies to assist in control and taking a site specific approach in choice of control methods has been implemented.

Funding Sources - Lee County has been fortunate in obtaining funding through the U.S. Army Corps of Engineers, the South Florida Water Management District and the Florida Department of Environmental Protection for offsite mitigation requirements for environmental permits for both private developers and government agencies. These funds are specified by the agency for use in a certain county preserve and in some cases a specific area within the preserve is designated for control when acreage requirements are specified by the permit. Monitoring of control success is often required by the permit and is performed by Lee County Parks & Recreation staff. A price per acre has been determined to allow this approach to work. Lee County is also pursuing establishing a mitigation bank within a portion of the Six Mile Cypress Sloughs Preserve. A private group has been selected and is seeking permits for the bank.

Contracts With Agencies - Lee County has had a contract with the Florida Division of Forestry since 1990 for land stewardship activities including exotic plant control. Staff specific to the Lee County project are hired and supervised by DOF staff. Lee County reimburses DOF for expenses related to salaries and equipment.

Lee County also has had a contract with the Florida Department of Corrections for exotic plant control since 1998. DOC provides an officer and inmates who are able to work independently once they are oriented to the project area. This has worked out well, particularly for containment and maintenance projects.

Site Specific Approach - Lee County has developed an exotic plant control prescription form that considers soils, hydrology and vegetation community for determining the best methods and season for control on a specific site. Arsenal, Velpar ULW, Round-up Pro and Rodeo have all been used to balance cost effectiveness, efficacy, label restrictions and limiting non-target damage. Lee County does not use or recommend either of the Garlon formulations for melaleuca control.

6. MIAMI-DADE COUNTY

Laurie McHargue

The Miami-Dade County Department of Solid Waste Management (DSWM) manages melaleuca on three sites totaling approximately 100 acres and is considering management options for a fourth site totaling 300 acres in south Miami-Dade County. The DSWM also provides funding, through an interagency agreement with the Park and Recreation Department, to control melaleuca on 130 acres of M .E. Thompson Park, a site containing a 27-acre fill pad that is used for camping and recreational vehicles. Funds for melaleuca control are allocated annually with a budget that is prepared and reviewed for the proposed work each year.

The Natural Areas Management Section of the Miami-Dade County Park and Recreation Department began controlling melaleuca at M. E. Thompson Park in the spring of 1994, with a nine-person crew. Treatment techniques and timings have been modified during the course of the past five years, and a standard methodology is now routinely implemented. Trees and saplings are cut-stump treated with Arsenal®. Cut trees and saplings are left on site as are seedlings that are hand-pulled. Originally, the concentration of Arsenal® used for cut-stump treatments was 15% but was later increased to 20%. Managers are considering increasing this to 25%, which appears to yield 100% mortality of treated individuals. Aerial applications of an Arsenal®/Rodeo mix were proposed at one time for treating dense melaleuca heads with less than 10% native species, but this technique was never implemented.

As of February 1999, all 130 acres of the M .E. Thompson Park wetland have received initial and several follow-up treatments. Monitoring data from permanent transects recorded a 97.3% decrease in the density of melaleuca from the first transect data collected in February 1994. There has been a concomitant increase in the number of native species and an increase in the density of sawgrass (*Cladium jamaicense*) in the permanent transects, as well as throughout the site, as melaleuca density has declined.

Through an interagency agreement, the Miami-Dade County Department of Environmental Resources Management (DERM) and the Park and Recreation Department are managing melaleuca within 54 acres of the South Dade Wetlands.

Funds are from a SAMP grant to DERM for melaleuca control in the South Dade Wetlands. The treatment technique is the same as described for M. E. Thompson Park except that the concentration of Arsenal® used in cut-stump treatments is 25%. Work began early in the spring of 1999.

7. PALM BEACH COUNTY

Brenda Hovde

The Palm Beach County Natural Areas System is comprised of those environmentally sensitive lands that are owned or leased by the County and managed by the County's Department of Environmental Resources Management (ERM). These natural areas were selected on the basis of their biological characteristics and were acquired to preserve the rare and diverse native ecosystems on these sites. Where ecosystems within a natural area have been impacted by invasive, non-native plant infestations, land-clearing activities, drainage or flooding, attempts are being made to restore those ecosystems to their previous condition.

One of the most invasive, non-native plant species present on the natural areas is melaleuca. As of April 1999, the County has acquired 16 sites, 9 of which support significant stands of melaleuca. It is estimated that out of 23,535 acres of natural area owned and managed by the County, in excess of 2,800 acres are moderately to heavily infested with melaleuca. Since 1992 ERM's Resources Maintenance staff have been targeting melaleuca for eradication. To date, approximately 450 acres of melaleuca have been treated with herbicides.

Melaleuca seedling are typically pulled by hand or with a weed wrench and are stacked into large piles. This technique smothers the seedlings in contact with the ground and causes the above-ground seedlings to die from desiccation. Widely distributed seedlings are occasionally left hanging on remaining vegetation to reduce the possibility of regrowth. Saplings and larger trees are hand-treated with a 15-25% solution of Arsenal, using the hack-and-squirt or cut-stump method. Larger seedlings are also treated by having their tops snapped over and the exposed surface hand-sprayed with herbicide.

Because fire controls small melaleuca seedlings, prescribed burning is scheduled whenever possible within 18 months of completing treatment of a melaleuca concentration or a burn unit. If a wildfire occurs in an area infested with untreated melaleuca, all seed-bearing trees will be cut down within a week after the fire when possible to prevent wind dissemination of seeds and to localize seed falls for future treatments.

ERM's Resource Maintenance section is comprised of 9 staff members. With the increasing amount of property the County is acquiring, and the exponential spread of exotic vegetation, ERM is now hiring contractors to perform exotic removal activities on the larger, wetter natural areas. This strategy is expected to be a quicker and more effective method for controlling exotic vegetation.

8. South Florida Water Management District

François B. Laroche

Background - Until recently melaleuca (*Melaleuca quinquenervia*) was spreading, at a rate faster than it was being controlled throughout the boundaries of the South Florida Water Management District (District). Although melaleuca is a difficult species to eradicate, it appears District efforts, along with those of other governmental agencies and private groups are containing its spread within the Everglades Water Conservation Areas (WCAs) and the marsh of Lake Okeechobee. Melaleuca has been completely cleared from Water Conservation Area 2A, 3B, and 3A, south of Alligator Alley. These areas are now under "maintenance control". Maintenance control means applying management techniques in a continuous basis to keep an invasive plant population at its lowest feasible level. Today, the melaleuca infestation is no longer increasing. In many areas it is being reduced. Preliminary results from the latest District survey indicate melaleuca infestation has decreased considerably in South Florida especially in public lands. Following is an assessment of progress made by the District's melaleuca control program over the past ten years.

Introduction - The Melaleuca Task Force (MTF), composed of representatives from various local, state and federal agencies, was formed in 1990 to develop a management plan and to make recommendations for the management of melaleuca. These recommendations for management and research efforts included biological control using Australian insects, herbicide applications, fire, and flooding (Laroche 1994). Consequently, the District launched an aggressive melaleuca control project in the Water Conservation Areas (WCAs) in 1990 and in Lake Okeechobee in 1993. Prior to the recommendations of the MTF, the District initiated a melaleuca control project in Water Conservation Area 2-A in 1980. This project was part of a larger environmental study evaluating the effects and impacts of a planned drawdown on marsh ecology. Efforts were directed at eliminating the existing melaleuca seed sources to prevent its further spread while the marsh was dry. Approximately 200 trees were treated with the frill and soil application technique with 10 ml of Velpar L®.

The strategy for managing melaleuca is modified, as control methodologies are developed, to improve efficacy and cost effectiveness. The frill and girdle method, in which the bark around the circumference of each tree is completely removed to expose the cambium for application of the herbicide solution, is the primary tool used in the least infested areas. Aerial application is the most economical method for large melaleuca monocultures. The District has been actively involved in the investigation of control methods for mature and seedling trees. Research needs to continue to improve control methods at reduced costs.

Funding - The District's melaleuca control funding is derived from several sources (Table 11). In the past eight years $14,277,794 has been budgeted by the District to fight melaleuca infestations. Approximately $8,312,794 (58%) of this amount has come from sources other than District resources. These include, the Florida Power and Light mitigation Funds (FP&L), the Surface Water Improvement and Management fund (SWIM), the USACE and a FDEP cost sharing program, with District ad valorem taxes providing the balance. SWIM and USACE funds are available for work in Lake Okeechobee only. Several of the current funding sources may be unable to continue supporting the project in future years. SWIM funding was lost in 1996 and the FP&L support ceased in 1994. Fortunately the FDEP and the USACE and the District are continuing to fund the project. Continued availability of funds is essential for the success of the melaleuca management program. At the current level of funding, melaleuca could be eliminated from the Everglades Water Conservation Areas and the marshes of Lake Okeechobee within the next ten years.

Table 11. South Florida Water Management District's melaleuca management funding sources.

FY	FP&L	DEP	SOR	SWIM	COE	DISTRICT	TOTAL
91	$500,000	--	--	$300,000	--	$170,000	$970,000
92	$500,000	--	--	--	--	$250,000	$750,000
93	$500,000	--	--	$200,000	--	$800,000	$1,500,000
94	--	$400,000	--	$200,000	--	$885,000	$1,485,000
95	--	$1,000,000	--	$400,000	--	$885,000	$2,285,000
96	--	$1,000,000	--	$400,000	$68,000	$885,000	$2,353,000
97	--	$1,000,000	--	--	$300,000	$1,045,000	$2,345,000
98	--	$1,000,000	$300,000	--	$244,794	$1,045,000	$2,589,794
Total	**$1,500,000**	**$4,400,000**	**$300,000**	**$1,500,000**	**$612,794**	**$5,965,000**	**$14,277,794**

The District continues its support at $150,000 per year to the U. S. Department of Agriculture research for biocontrol for melaleuca. The District is also providing $60,000 to the Everglades National Park and $75,000 to the Loxahatchee Wildlife Refuge, each year, for their melaleuca control programs. (Table 12).

Management Strategy - The integrated management of melaleuca requires a combination of control techniques to be effective. Biological control methods are not readily available for melaleuca. Therefore, the District's efforts in developing melaleuca control methods have been concentrated around herbicidal control and the limited use of mechanical and physical control methodologies. Melaleuca control strategies were developed by the MTF. The District first implemented these strategies in the southeast corner of WCA-3B in November 1990 (Laroche 1994). Effective melaleuca management requires knowledge of its biology. The reproductive potential of melaleuca is tremendous.

Table 12. South Florida Water Management District melaleuca management expenditures.

FY	WCAs	L. O.[1]	PENNSUCO	BIOCONTROL	SUPPORT[2]	TOTAL
91	$614,437	--	--	$75,000	$15,000	$704,437
92	$823,552	--	--	$75,000	$75,000	$973,552
93	$904,923	$211,159	--	$165,000	$75,000	$1,356,082
94	$634,337	$538,841	--	$150,000	$135,000	$1,458,178
95	$1,025,109	$573,859	--	$195,000	$135,000	$1,928,968
96	$1,460,098	$1,064,216	--	$150,000	$135,000	$2,809,314
97	$970,243	$1,042,037	--	$150,000	$135,000	$2,327,643
98	$449,698	$1,074,813	$301,398	$150,000	$135,000	$2,450,888
Total	**$6,882,397**	**$4,504,925**	**$301,398**	**$1,110,000**	**$840,000**	**$13,638,720**

1- Lake Okeechobee

2- Support to Loxahatchee Wildlife Refuge and Everglades National Park

A mature tree may retain millions of seeds, all of which may be released from their protective capsules following a stressful event such as, desiccation, fire, frost, physical damage, and herbicide application (Meskimen 1962). Once released, 15 to 20 percent of the seeds will germinate. These new trees take approximately two years to mature and produce viable seeds (Woodall 1981a). Follow-up treatment within the second year after the initial treatment is essential to eliminate new seedlings before they can produce viable seeds. Under ideal conditions, melaleuca can be eliminated from an area within two years. The first phase of control targets all existing trees and seedlings in a given area. Using navigational equipment, crews return to the same site to remove any seedlings resulting from the control activities of the previous year. The District's control operations consist of three phases:

Phase I. This phase focuses on the elimination of all mature trees and seedlings present in an area.

Phase II. Previously treated sites are revisited for follow-up treatment to control trees previously missed and remove seedlings which may have resulted from control activities of the preceding year.

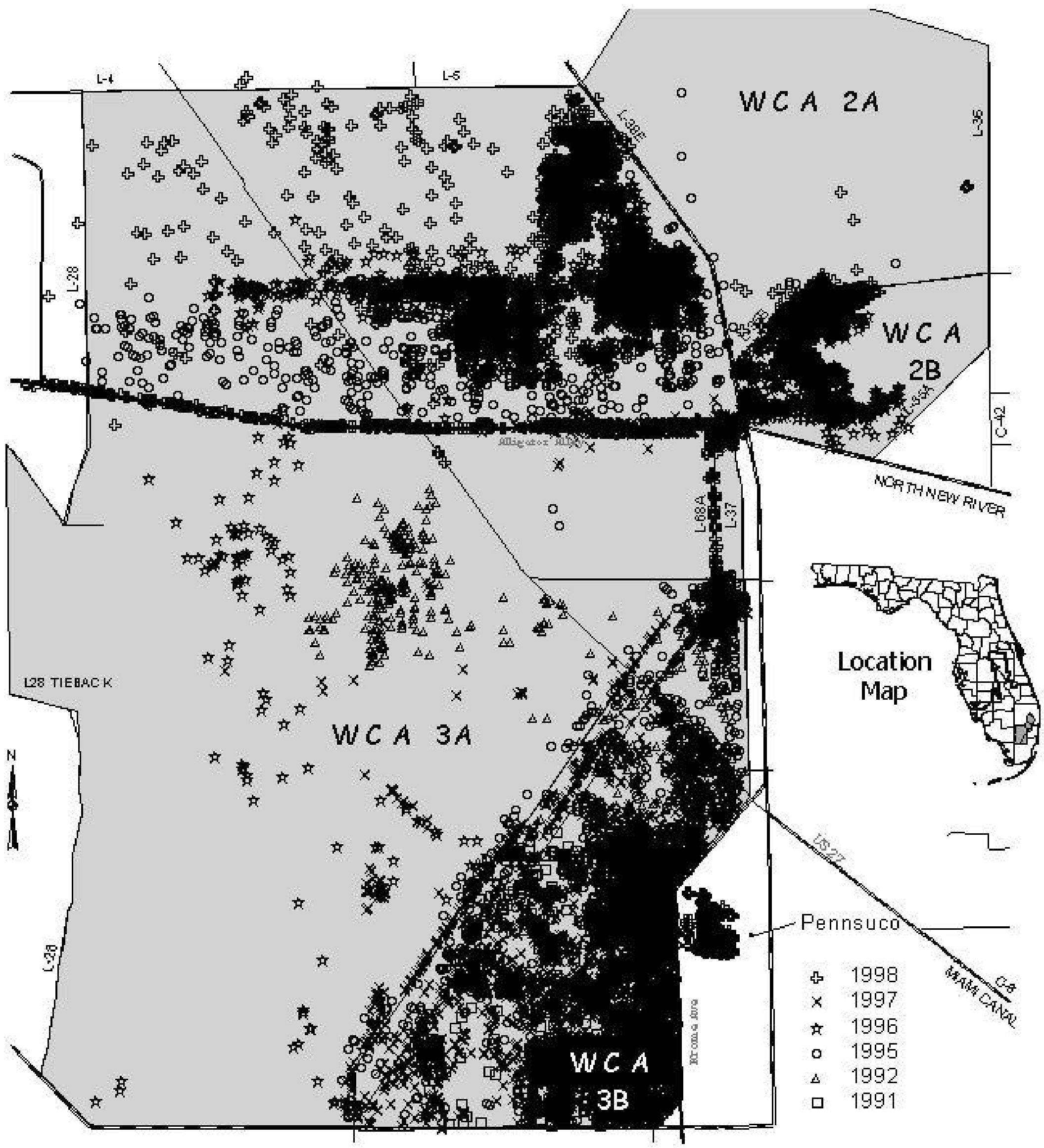
Phase III. This phase entails the long-term management of melaleuca, surveillance and inspection of previously treated sites to monitor the effectiveness of the melaleuca control program and maintain reinfestation levels as low as possible.

The goal of the current melaleuca management program is to contain melaleuca on all District land and to maintain infestation levels as low as possible while minimizing impacts to non target vegetation. The melaleuca management strategy is based on the quarantine strategy described by Woodall (1981a). The least infested areas (outliers) are addressed first, in order to stop the progression of the existing population. Frill and girdle application of a herbicide solution (25% Arsenal®, 25% Rodeo® and 50% water) is the primary method used to kill mature trees. However, the Cut/Stump application of herbicide is also very effective, but remaining stumps may create a navigation hazard for airboat traffic when the marsh is wet. This type of application is used only on trees with base stem diameter of less then three inches. Melaleuca seedlings in mixed communities are usually hand-pulled in an effort to minimize the impact of herbicides on non-target vegetation. Seedlings are left hanging on remaining vegetation or put in a pile to reduce the potential for regrowth. Until recently, aerial applications of tebuthiuron, hexazinone, triclopyr, imazapyr, and combinations of imazapyr and glyphosate have been used on an experimental basis only. While more information is generated from experimental trials, this type of application is becoming essential as control operations are closing in on large areas of melaleuca monocultures.

Regardless of the control method used, a comprehensive data collection and evaluation plan is essential for the success of melaleuca management initiatives. Record keeping is invaluable for making future management decisions. Data collection in the District's program includes: longitude and latitude coordinates at each treatment site, date and time of control, type of control method, type of herbicide and amount, method of application, number of trees and seedlings or hectares treated at each site and, labor and equipment hours. This data is used to produce maps (Figure 6 and 7) of treatment progress and to keep track of melaleuca control sites.

Water Conservation Areas. Melaleuca occurred throughout all the WCAs, with degrees of infestation ranging from ten to greater than twelve thousand trees per hectares. The trees in WCA-2A were widely scattered compared to light to moderate infestation in WCA-3A and 3B. The infestation level in WCA-2B is severe, with nearly 30% of the area containing melaleuca. Much of this area is solid forest and individual tree treatment is not cost effective. Depending on accessibility and remoteness of control sites, a helicopter, airboats, and/or all terrain vehicles are used to transport crews and supplies. Once on site, crews perform melaleuca treatments with the use of the girdle or cut-stump method of herbicide application. Each crew may consist of three to eight people, depending on the

Figure 6. Melaleuca infestation and control efforts from 1991 - 1998 in the Water Conservation Areas and Pennsuco.



density of melaleuca infestation at the site being treated. The melaleuca control project began at the southeast corner of WCA-3B in November of 1990 and proceeded northward through WCA-3B and 3A, south of Alligator Alley. These two areas are currently under Phase III operations. The melaleuca snout beetle (*Oxyops vitiosa*) was released in WCA-3B near Holiday Park in Ft. Lauderdale, FL in April of 1997. From November 1990 to October 1998 approximately 9,042,556 trees and 23,866,760 seedlings have been controlled within the WCAs at a total cost of $6,414,531 (Table 13, Figure 6). Phase I work will continue in WCA-2B and phase II work will begin in 3A north during FY 99. Aerial applications in the WCAs are being performed on a limited basis for the control of large melaleuca monocultures. To date, a total of 665 hectares have been successfully treated by aerial application at a cost of $462,663 (Table 14). Experimental use of aerial application will continue in WCA-2B to control large monocultures.

Table 13. Melaleuca control summary for ground based application in the Water Conservation Areas.

FY	TREES	SEEDLINGS	LABOR[1]	COST/PLANT[2]	TOTAL COST
91	156,001	1,103,073	3,970 h	$0.48	$614,437
92	388,324	547,448	8,775 h	$0.88	$823,552
93	1,391,095	12,142,900	26,241 h	$0.07	$899,690
94	1,571,535	5,439,843	24,000 h	$0.09	$634,337
95	1,336,394	1,603,997	29,045 h	$0.33	$964,734
96	1,551,969	1,877,654	47,241 h	$0.39	$1,267,394
97	1,671,106	884,093	33,709 h	$0.30	$760,689
98	976,132	267,264	22,243 h	$0.36	$449,698
Total	**9,042,556**	**23,866,272**	**195,224 h**	**$0.20**	**$6,414,531**

1- labor hours 2- cost per mature trees - cost per trees and seedlings

Lake Okeechobee. The U.S. Army Corps of Engineers originally introduced melaleuca to Lake Okeechobee in the late 1930s (Bodle et al. 1994). These trees were planted on low-lying islands immediately lakeward of the levee to protect the levee system from storm generated wind and wave erosion. From these limited plantings, melaleuca spread into many thousands of hectares of marsh in the lake. There were two main areas of melaleuca infestation on Lake Okeechobee. The first area includes the levee and marsh zone near the original planting sites. These sites are characterized by large, mature, extremely dense monocultures. The second includes the shallow marsh region of the lake where trees have spread lakeward. Melaleuca infestations in the outer marsh typically consisted of outliers and small groups of trees (heads) of varying ages. The lake has been divided into seven management sections, each with varying degrees of infestation.

Table 14. Melaleuca Control Summary for Aerial Application in the Water Conservation Areas and Lake Okeechobee From 1994 to 1998.

Water Conservation Areas

Year	Hectares treated	Cost/hectares $	Total cost $
July 1995	101	$601.34	60,375
June 1996	240	$679.39	163,054
November 1996	41	$723.17	29,650
February 1997	283	$740.47	209,554
Total	**665**		**462,633**

Lake Okeechobee

Year	Hectares	Cost/hectare	Total cost
May 1994	526	$285.32	$150,000
July 1995	81	$596.29	$48,300
June 1996	165	$677.15	$111,731
February, 1997	121	$742.21	$89,808
December 1997	41	$777.09	$31,473
March 1998	609	$759.43	$462,114
Total	**1,543**		**$893,426**

Melaleuca control operations on Lake Okeechobee began in August 1993. The goal of the melaleuca management program on Lake Okeechobee is to first contain, then progressively reduce populations within the littoral zone. To date, significant headway has been made on the outlier trees and heads in the outer marsh of sections 1, 2, 3, 4 and 6 (Figure. 7). From July 1993 to October 1998, a total of 12,166,112 trees and 9,178,209 seedlings have been eliminated in the lake at a total cost of $3,611,500 (Table. 15). The U.S. Army Corps of Engineers has begun removing melaleuca, Australian pine and Brazilian pepper from the land-ward side of the rim canal in section 1. The USACE is also providing funds to the District to eliminate melaleuca trees along the lake-ward side of the rim canal in sections 1, 2 and 3. Phase I work along the lake-ward side of the rim canal in sections 2 and 3 was completed in late September 1997. During FY 98 Phase II was completed in sections 2, 4 and 6, and 609 hectares melaleuca monoculture were treated by aerial application, in section 3 to complete Phase I. As in the WCAs, this program is primarily ground-based herbicide application, although the development and implementation of a safe and effective aerial application for melaleuca control is critical to this project. A total of 1,543 hectares of mature melaleuca monoculture have been successfully treated by aerial application on Lake Okeechobee (see Table 14).

Figure 7. Melaleuca infestation and control efforts from 1991 - 1998 in sections of Lake Okeechobee.

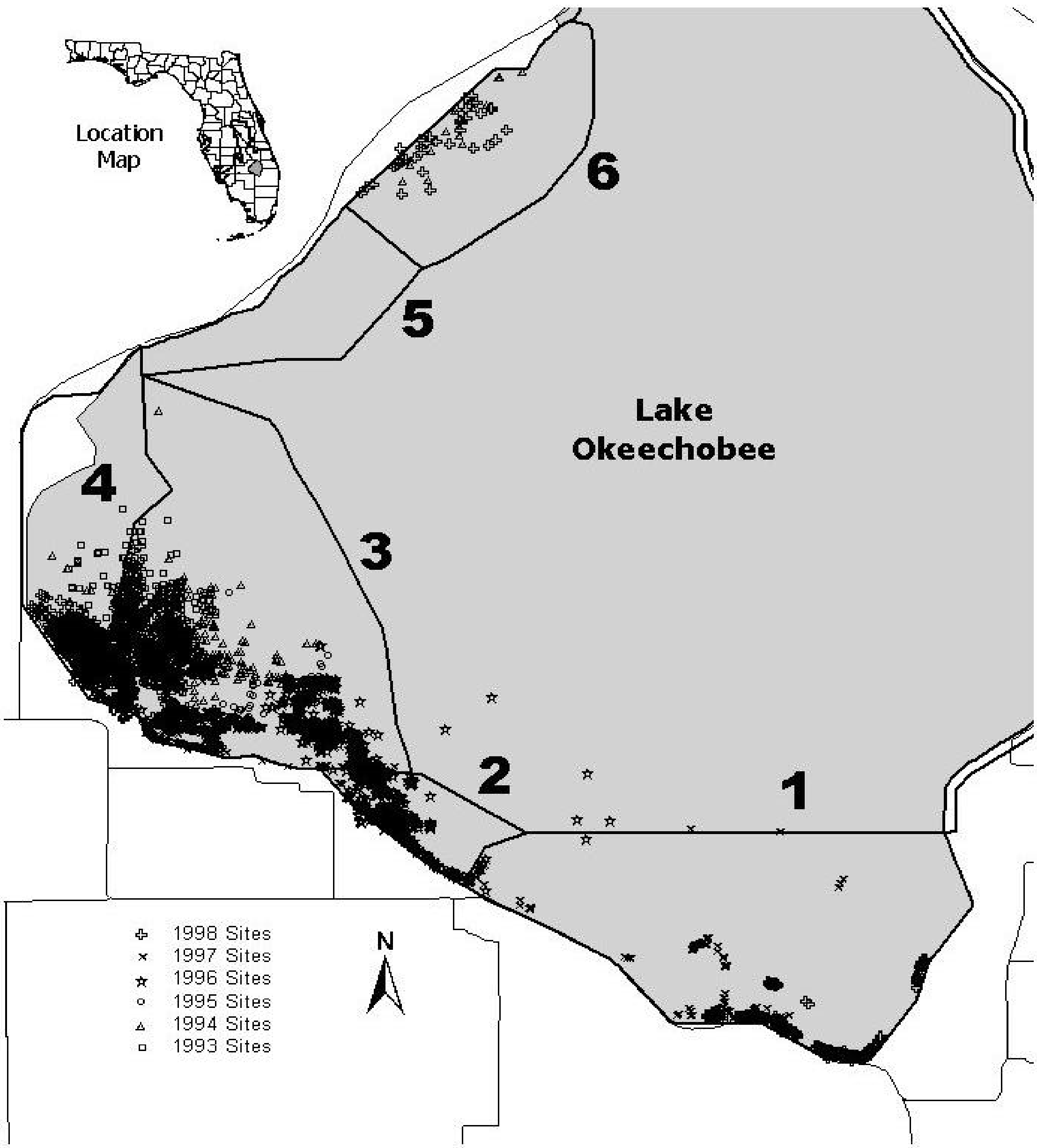


Table 15. Melaleuca control summary for ground based application in Lake Okeechobee.

FY	TREES	SEEDLINGS	LABOR[1]	COST/PLANT[2]	TOTAL COST
93	523,461	1,134,468	9,292 h	$0.07	$211,159
94	1,751,510	4,473,004	22,011 h	$0.06	$388,841
95	2,871,825	1,537,966	24,742 h	$0.12	$525,559
96	3,214,546	1,288,292	43,726 h	$0.21	$952,485
97	2,141,026	562,569	43,724 h	$0.34	$920,756
98	1,663,744	181,910	28,312 h	$0.33	$612,700
Total	**12,166,112**	**9,178,209**	**162,515 h**	**$0.17**	**$3,611,500**

1-labor hours 2- cost per mature trees - cost per trees and seedlings

Pennsuco Mitigation area. Mitigation funds are used to acquire and enhance lands within the Pennsuco project located in Dade County, Fl. The benefits of utilizing this project area for mitigation include eradication of exotic vegetation to ensure the enhancement, preservation and maintenance of the wetland systems.

The eradication of melaleuca is the only wetland enhancement activity that is planned for this area. The purpose of the exotic eradication effort is to effectively manage melaleuca by containing and progressively reducing melaleuca populations within the Pennsuco Project. The control program consists primarily of a ground based herbicide application and some use of aerial application in the dense monocultures

Approximately 1332 acres of melaleuca were treated by ground application. The exotic treatment consisted of hand pulling seedlings and girdle treatment for isolated individuals and smaller infestations. Approximately 3,412,548 trees and 1,757,502 seedlings were treated at a cost of $301,398 (Table 16). A total of 150 acres of dense melaleuca monoculture will be treated by aerial application during the first week of February 1999. Additional aerial application need, will be determined later.

Table 16. Melaleuca control summary for ground based application in the Pennsuco mitigation area.

FY	TREES	SEEDLINGS	LABOR[1]	COST/PLANT[2]	TOTAL COST
98	3,412,548	1,757,502	13,175 h	$0.06	301,398
Total	**3,412,548**	**1,757,502**	**13,175 h**	**$0.06**	**301,398**

1-labor hours

2- cost per mature trees - cost per trees and seedlings

Future Plans include completing the initial treatment of melaleuca throughout another 1,500 acres of the Pennsuco wetlands. Melaleuca control will continue as the District continue to buy more land within the Pennsuco mitigation area

The use of prescribed burning will facilitate seedling control and hopefully reduce the need for phase II control and help maintain a mosaic of vegetation types within the enhanced sawgrass community.

Save Our Rivers. The Save Our Rivers (SOR) program was created in 1981 for the Water management districts to acquire and manage environmentally sensitive lands for the benefit of the public. This is funded through the Water Management Lands Trust Fund, which receives revenues from the documentary stamp tax. Preservation 2000, enacted in 1990, also adds land acquisition funds to the SOR program.

One of the primary management efforts for these lands is the control and eradication of invasive exotic plants, primarily upland species. These species include melaleuca, Australian pine, Brazilian Pepper, Tropical Soda Apple, Cogongrass, Chinese tallow, Downy rose myrtle, Lygodium, and others. This is accomplished through the use of primarily ground-based contractual application services. There is also a limited amount of contractual aerial application for dense monocultures.

There are four areas in which the contract crews are expending the majority of this programs funds: CREW lands near Ft. Myers, Dupuis Reserve near Indiantown, Garner-Cobb property in the Upper Kissimmee Chain-of-Lakes region, and Modellands near Florida City.

Future plans include ongoing control of species as seedlings appear and initial treatments of infestations of new exotics. Other land management practices such as prescribed burning will facilitate seedling control and hopefully reduce the need for phase II measures and help maintain a mosaic of vegetation within the enhanced communities.

Conclusion - The operational and experimental work accomplished to date, demonstrates that melaleuca can be effectively and consistently controlled using an integrated management approach. The ultimate control of melaleuca throughout the District will probably depend primarily on the future availability of funds. The magnitude of the threat of melaleuca and the cost of current control efforts are enormous. However, at the current rate of treatment, melaleuca should be under maintenance control in the Water Conservation Areas and in Lake Okeechobee within the next ten years.

The elimination of melaleuca from the Everglades, Lake Okeechobee and other District's managed lands may cause a temporary disruption of the native flora and fauna. However, any sign of disturbance caused by control treatments usually vanish within one to two years. This temporary adversity is an acceptable event in ridding these natural areas of an invasive exotic pest plant. Only through Melaleuca eradication can we insure the sustainability of these treasured wild land.

9. U. S. ARMY CORPS OF ENGINEERS

Charles E. Ashton and William C. Zattau

The U.S. Army Corps of Engineers (Corps), Jacksonville District has the responsibility for jointly managing the Central and Southern Florida Flood Control Project and the Okeechobee Waterway Project with SFWMD. Both projects are impacted by melaleuca, which was planted in the 1930's on the lake-side of the Herbert Hoover levee system to buffer the levee from the erosive force of storm driven waves.

Melaleuca on the Herbert Hoover Dike and associated federal rights-of-way negatively impacts authorized project purposes; including flood control, navigation and the preservation of natural resources including fish and wildlife. Additionally, melaleuca growing in these areas threatens the integrity of the levee system.

In 1979, the Corps contracted the U.S. Army Engineer Waterways Experiment Station to investigate methods for controlling the growth and spread of melaleuca in Lake Okeechobee. This research focused on determining the extent of melaleuca infestation in the lake, evaluating various control methods, and development of a control program.

Herbicide efficacy trials were established on mature trees and on seedlings along the Herbert Hoover Dike near the towns of Okeechobee and Clewiston, respectively. Prior to treatment, randomly selected melaleuca in each plot were tagged with identification numbers. At each evaluation, vitality (live versus dead) was determined for each tagged individual.

For mechanical control, the Corps employed a John Deere Tree Harvester (JD 693-B Feller/Buncher) equipped with a Rome cutting head. The harvester cut the trees at about one foot above the ground, gathered and stacked them. In 1985, the Corps developed a management plan for 1,200 acres of melaleuca in areas along the south and southwest shore of Lake Okeechobee, predominantly Lakewood of the Rim Canal. The Corps conducted an Environmental Assessment (EA) of the management plan. The plan, which utilized the herbicide VELPAR-L, was coordinated with the U.S. Fish and Wildlife Service (USFWS) in accordance with Section 7 of the Endangered Species Act of 1973, as amended. The USFWS recommended alternatives to the plan, due mainly to concerns regarding the Everglades snail kite. Based upon review of the EA, the CEO District Engineer issued a FONSI (Finding of No Significant Impact) on 25 June 1986.

In 1986, an agreement was reached between the South Florida Water Management District and the Corps for control of these 1,200 acres of melaleuca. These planned management operations did not occur because modifications in the VELPAR-L herbicide label made after the agreement was signed prevented use in the areas intended for control.

In 1987, the Corps began funding the initial overseas surveys by the U.S. Army Corps Engineers Waterways Experiment Station (WES) scientists and the United States Department of Agriculture/Agricultural Research Service scientists to inventory the natural enemies of melaleuca. Corps support and funding for this project continues.

In 1989, representatives from the Lake Okeechobee Interagency Group conducted an evaluation of GARLON 3A for use in the control of melaleuca. On March 20, 1989, two 15-acre plots of mature melaleuca forest were aerially treated in the southwestern marsh of Lake Okeechobee. One plot was treated with a 2 gallon per acre (GPA) rate of GARLON 3A and the other plot was treated with a 3 GPA rate of GARLON 3A. Water samples were taken to monitor herbicide residue and dissipation from the treatment site by the Department of Natural Resources (Nall, 1989). Water samples were taken from the margin of the 3 GPA plot and at 100m and 400m intervals away from the plot in three directions to determine dissipation. Petri dishes were placed within the plot and at 10m and 100m intervals away from the plot in the three directions to sample drift. Control samples were taken at two locations prior to treatment. Herbicide residue samples were taken one hour, 24 hours and 4 days after treatment. Because of low water in the treatment area, samples were not be taken at all planned locations and the sampling was suspended after 4 days.

No GARLON was detected 100m from the application site in the petri dishes and amounts were very low at 10m and within the plot (underneath the canopy), indicating that little herbicide drifted beyond the plot and that little penetrated beneath the canopy. Water samples showed the same trend with the maximum concentration of 0.10 ppm detected immediately post treatment. Only one detection (0.04 ppm at 100m) was made on day four. The highest concentrations found were on the edge of the plot: 3.45 ppm immediately post treatment and 3.97 ppm 24 hours post treatment. No GARLON was detected in the plot 4 days post treatment.

Four month post treatment efficacy evaluations revealed only 15% - 20% control of melaleuca in the 3 GPA plot and 10% - 15% control in the 2 GPA plot. The Lake Okeechobee Interagency Group recommended that another treatment should be conducted to evaluate seasonal differences in efficacy. On August 3, 1989, a second application of GARLON at 3 GPA was aerially applied to 15 acres of melaleuca. The plot intersected the previous 3 GPA plot such that 7.5 acres of treated melaleuca could be evaluated as a second application. Once again, 80%- 85% of the treated melaleuca survived. There did not appear to be a difference between the area treated once and the area that had been treated twice.

In 1990, the Corps finalized a Herbert Hoover Dike Melaleuca Management Plan and initiated a mechanical removal program targeting melaleuca along selected portions of the Dike. The mechanical removal program has targeted melaleuca stands beginning at Moore Haven on Levee L-D-3 and north along Levee L-50, L-49, L-48 and L-D-4 at Okeechobee. Melaleuca is mechanically controlled in designated areas of the Federal easement in a manner minimizing disturbance to the levee system. Felled trees were windrowed and left in place or burned. To date, over 600 acres have been cleared. Starting in 1997 to early 1999 approximately 22 miles of the Herbert Hoover Dike from Clewiston to Pahokee were mechanically cleared of exotics including melaleuca at cost of $250,000. As part of the Corps management plan, portions of the Corps removal project are being completed through the use of volunteers. Beginning in early 1993, volunteers have been harvesting the trees for mulch and treating the stumps with herbicide in an effort to prevent regrowth.

Reforestation demonstration sites were been established on 100 acres of federal right-of-way cleared in the above referenced efforts. Monitoring of selected follow-up chemical and mechanical control strategies for control of any melaleuca regrowth was initiated. Some cleared sites have been revegetated with species selected for wildlife habitat enhancement.

As part of the biological control efforts to control melaleuca, the Corps has funded approximately $70,000 per year from1992 to the present, on overseas biological control research conducted by the USDA/ARS. As part of the biocontrol efforts, the Corps also is working on Water Resources Development Act Critical Projects to increase the effectiveness of land managers to utilize biological control technologies to manage melaleuca. The Critical Projects are the construction, by the U.S. Army Corps of Engineers, of a quarantine facility to enable testing of candidate organisms for biological control on the University of Florida campus in Davie or Fort Pierce. Upon completion, the facility will be turned over to the USDA/ARS for operation. The second project is an upgrade and retrofit the current quarantine facility in Gainesville, Florida. The third project is large-scale rearing of approved biological control organisms for release at multiple sites within the South Florida Ecosystem area.

Biological control agents are an important component (chemical, mechanical removal, and water manipulation) of a successful integrated plant management strategy for melaleuca control. Engineering and design of the new quarantine facility is complete and the Corps awaits local sponsor funding. The upgrade of the Gainesville facility and mass rearing projects are awaiting funding.

COST: 1) New facility-$ 4.6 million
2) Upgrade $1.8 million
3) Large scale rearing, release, and monitoring $ 4.0 million.

In 1996, an Environmental Assessment on the "Integrative Approach to Melaleuca Management in the State of Florida was completed".

On Lake Okeechobee in 1997 and 1998, the Corps funded $664,000 for management of approximately 320 acres by chemical treatment of melaleuca through a cooperative agreement with the South Florida Water Management District. Some melaleuca was removed by mechanical means along the Herbert Hoover Dike.

In 1999, as part of "Take Pride in Lake Okeechobee", the Corps cleared a small spoil island near Clewiston of melaleuca and planted the island with native trees and plants including cypress and pond apple.

U.S.A.C.E. **Melaleuca Management Funding to Date:**

1987 - Present, Biological Control Research:	$ 1,108,000
1990 - Present, Mechanical Removal on Herbert Hoover Dike:	$ 400,000
1997- Present, Chemical Control:	$ 664,000
1992 - Present, Wetland's Research Program:	$ 35,000

Projected Melaleuca Management Needs:

Removal efforts on Herbert Hoover Dike:	$ 650,000
Fund Biological Control Research through WES:	$70,000/year

CONCLUSION

Robert F. Doren

The control of melaleuca in Florida will depend on a complimentary implementation of chemical, mechanical, cultural and biological technologies. If biological control agents introduced from Australia are successful as expected, they will provide the best and cheapest long-term solution to the overall problem. They will also allow the other technologies to be redirected toward the myriad of other invading plant species. However, until then integrated approaches will be mandatory if we are to continue to be successful.

The magnitude of the threat of melaleuca and the cost of current control efforts are enormous. No control technology should be dismissed. However, a collective approach will be required to mitigate the melaleuca threat. Fire, water level manipulation, herbicides, biological and mechanical control methods need to be integrated into the management scheme. In the short run, the primary tool may be chemical herbicides. They are presently the most effective technique available, and large acreage may be treated at a reasonable expense. Fire and water level manipulation can be useful in areas where physical circumstances are favorable. Mechanical clearing is effective where land is being cleared for other purposes (development, road building, etc.), but it is not feasible (economically or technically) in wetland and natural areas. However, no one method should be relied upon as a panacea.

Great progress to control melaleuca has been made on state and federal lands, and on some local government sites. Much work still needs to be done on those natural lands in state and federal ownership where resources have been insufficient to achieve a maintenance control phase. Resources that were used to bring some areas under maintenance control should now be partially refocused to support control in these other areas while maintaining sufficient resources to support the maintenance control of melaleuca in areas from which it has been removed.

In the past 20 years, many scientists and informal coalitions of concerned citizens have highlighted the severe threat by the uncontrollable spread of melaleuca and other invasive species. During the 1980s, members of the newly formed Exotic Pest Plant Council worked to assist with invasive plant problems. In 1990, the South Florida Water Management District helped the Exotic Pest Plant Council form a multi-organizational Melaleuca Task Force to draw upon the experience of the area's scientists, resource managers, and others to develop a regional melaleuca management plan. This Task Force brought much needed coordination to melaleuca management and focused attention on resources needed to implement such a broad program, priorities for funding and control actions, public awareness, and legislative needs. This coordination of effort must continue if there is to be long-term control of melaleuca in south Florida.

With the development of a statewide strategic plan for Florida, and the implementation of President Clinton's executive order on invasive species, invasive species issues are finally becoming an important focus. Species-based tactical plans like the Melaleuca Management Plan are essential elements of a state strategy for managing invasive species, as much as a state strategy will be essential to support a national strategy mandated by the presidential executive order. It is vital that we continue to build the partnerships needed to effectively manage invasive species like melaleuca and that these partnerships extend to include all the agencies and organizations involved with invasive species management in Florida. One major area that will be needed as part of any strategic plan for Florida, and one that includes melaleuca, will be the need for some comparability and consistency among agencies in the ways they assess species distributions, program priorities, program success, implement control actions, and track funding and progress of programs.

The following are areas of research identified by task force members as essential to the successful control of melaleuca in Florida.

* Factors affecting seed germination and seed survivability.
* Factors affecting seed distribution.
* Factors affecting herbicide penetration and translocation in mature trees and seedlings.
* Post-release monitoring and establishment criteria for biological control agents.
* Site restoration following major large-scale melaleuca removal.
* Continued investigation into alternative control methods.
* Develop improved methods of surveying and mapping melaleuca populations.

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Pennsuco Wetland Mitigation Area
Melaleuca Control

Before Treatment

April 1998

After Treatment

February 1999