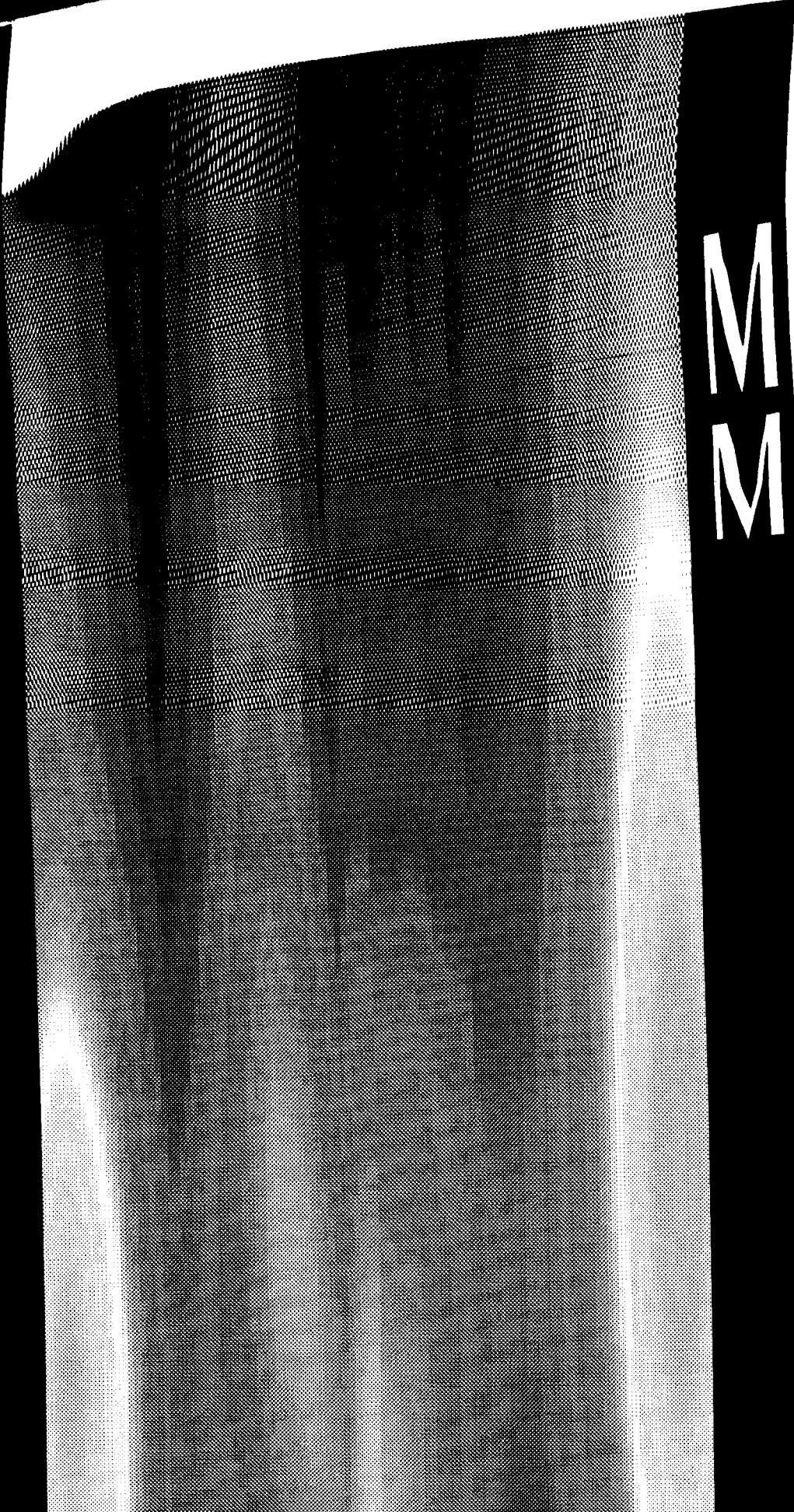


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Melaleuca Management

Plan For Florida

Exotic
Pest
Plant
Council

MELALEUCA MANAGEMENT PLAN
FOR
FLORIDA

RECOMMENDATIONS FROM THE
MELALEUCA TASK FORCE
EXOTIC PEST PLANT COUNCIL

APRIL 1994
Second Edition

François B. Laroche, Editor

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

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. This is the second edition and it should be periodically updated to reflect changes in management philosophy and operational advancements.

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EXECUTIVE SUMMARY

Melaleuca quinquenervia is among the most problematic of 33 major exotic pest plant species that are destroying the biological diversity of Florida's natural wetland and upland areas. Most threatened among these is Florida's Everglades, including Everglades National Park - the crown jewel of America's national park system. The Everglades has been designated a United Nations World Heritage site, and named a UNESCO Man and Biosphere Reserve, because of its exceptional interest and universal value to humankind. Congressionally mandated efforts to establish more natural hydrologic cycles, improve water quality, and preserve unique species (e.g. the Florida panther, the wood stork, the snail kite, and many subtropical orchids, ferns, and palms) will cost millions of dollars over the next decade. *Melaleuca quinquenervia*, already present on over 500,000 acres in southern Florida, threatens these efforts to restore this precious natural resource. *Melaleuca* also occurs in southern California and Hawaii and could survive in most coastal areas along the Gulf Coast.

Melaleuca quinquenervia was introduced into Florida as an ornamental at the beginning of this century. Later, it was purposely introduced into the Everglades in an ill-advised attempt to "turn useless swamps into valuable land". During the last several decades, melaleuca has rapidly expanded its range in wetland habitats as well as urban and rural landscapes. Recent studies, in fact, show that melaleuca infestations have exhibited a fifty-fold increase at many sites over a period of 25 years. *Melaleuca* infests pine flatwoods, hardwood bottomlands, cypress forests, freshwater marshes, sawgrass prairies and mangrove communities as well as improved pasture, natural rangeland, idle farmland, urban areas, and others.

Urban development has pushed housing projects into the midst of vast expanses of *M. quinquenervia* stands. Because *melaleuca* leaves are high in essential oils, intense crown fires quickly develop in these stands. Nearby buildings are at risk when these fires occur. Fires have also caused prolonged power outages. One such outage occurred in 1985 as a result of *M. quinquenervia* fires under major transmission lines. Nearly 2.3 million people lost electrical service. Economic losses associated with this fire and related power outages exceeded \$1 billion. Also as many as 250,000 people in southern Florida may suffer from some sort of melaleuca allergy. A few may even be severely allergic, as suggested by a study in which one patient dermally exposed to *melaleuca* pollen extract suffered a life-threatening reaction. A study commissioned by the Florida Department of Environmental Protection argued that the unbridled spread of *melaleuca* would severely restrict use of south Florida's parks and recreation areas by local

residents and tourists. Potential losses to the south Florida economy were estimated at about \$168.6 million annually.

Melaleuca control efforts within the state of Florida currently cost more than \$2.2 million annually. The South Florida Water Management District (SFWMD) spent nearly \$1.4 million in 1991 to treat about 12 million *melaleuca* trees on 90,000 acres of Everglades wetlands in an area known as Water Conservation Area 3. Nearly half of the Loxahatchee National Wildlife Refuge's 145,000 acres are currently infested with *melaleuca*. Resource managers spent \$600,000 during 1990-93 to treat nearly 0.5 million *melaleuca* trees and saplings on the refuge. The Big Cypress National Preserve spent nearly \$100,000 in 1993 and the Everglades National Parks spent \$260,000 for *melaleuca* control. Various other federal, state and local agencies are actively involved in the control of this invasive pest plant. Following is a summary of *melaleuca* management cost over the past 10 years.

MELALEUCA MANAGEMENT EXPENSES (X \$1,000)								
Agency	FY84-FY88	FY89	FY90	FY91	FY92	FY93	FY94	Agency Totals
USAE	183	80	60	275	65	135	75	873
ENP	210	100	40	68	75	75	90	658
DNR	0	50	50	50	50	0	465	665
DER	0	20	50	159	100	50	100	479
USFWS	80	40	40	60	75	75	75	445
USDA	61	36	50	69	83	107	115	521
BCNP	227	60	100	100	170	100	183	940
Lee Co.	0	10	0	0	100	100	100	310
SFWMD	0	0	0	690	975	1,515	1,200	4,380
Dade Co.	75	75	75	40	60	0	100	425
Annual Total	836	471	465	1,511	1,753	2,157	2503	9,696

A multi-agency task force organized from the Exotic Pest Plant Council by the South Florida Water Management District convened in 1990 to develop a comprehensive plan for controlling *Melaleuca quinquenervia* in Florida. The task force was composed of scientists and natural resource managers representing federal, state, and local agencies

charged with protecting and managing the wetlands that comprise Florida's Everglades. The Task force recommendations were as follows:

1. **Acquire funds that can be used to accelerate current efforts to locate, screen, implement, and evaluate biological control agents for use against *melaleuca*.**
2. **Enhance efforts using mechanical and chemical controls to establish a *melaleuca*-free zone along the boundaries of the Everglades National Park, Big Cypress National Preserve, the Water Conservation Areas, the Holey Land, and Lake Okeechobee.**
3. **Encourage public and private land owners to remove *melaleuca* infestations from within the buffer zone.**
4. **Implement an effective public awareness campaign directed toward encouraging support for *melaleuca* management issues.**

I. INTRODUCTION

Exotic pest plants are introduced either accidentally through shipping materials or deliberately for ornamental or commercial purposes. The aggressiveness common to some of these introduced species is often not recognized immediately. These invasive, exotic species disrupt native ecosystems with such intensity that natural systems can no longer function. The problems associated with foreign aquatic infestations are well documented. Water hyacinth (*Eichhornia crassipes*) is notorious for restricting navigation and reducing water abatement in flood control canals. Navigation has been the primary concern for federal and/or state sponsored nuisance plant control efforts. Unfortunately, wetland exotic plant management has been largely overlooked.

Without an organized forum to address the expanding invasion of exotics into the State's wetlands and other natural areas, early control efforts were spotty at best. In 1982, concerned resource managers organized the Exotic Pest Plant Council (EPPC). 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. The EPPC has identified four exotics that pose an immediate and significant threat to the wetlands of South Florida. They are: melaleuca (*Melaleuca quinquenervia*), Brazilian pepper (*Schinus terebinthifolius*), Australian pine (*Casuarina equisetifolia*) and giant sensitive catsclaw (*Mimosa pilleta*). Of these, melaleuca currently poses the greatest threat.

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. The 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, it is possible to mitigate this threat based on the current knowledge of the infestation and available management techniques.

II. PROBLEM STATEMENT

Melaleuca quinquenervia (Cav.) Blake is native to Australia and was introduced into Florida in the early 1900's as an ornamental tree and possibly as a commercial source of wood. Several of the innate characteristics of melaleuca have facilitated its spread throughout Florida's natural areas. Prolific seed production, fire adaptation and release from natural competition, insect feeding and disease abet its competitive ability. Consequently melaleuca grows more densely in Florida than in Australia and "crowds out" native plants.

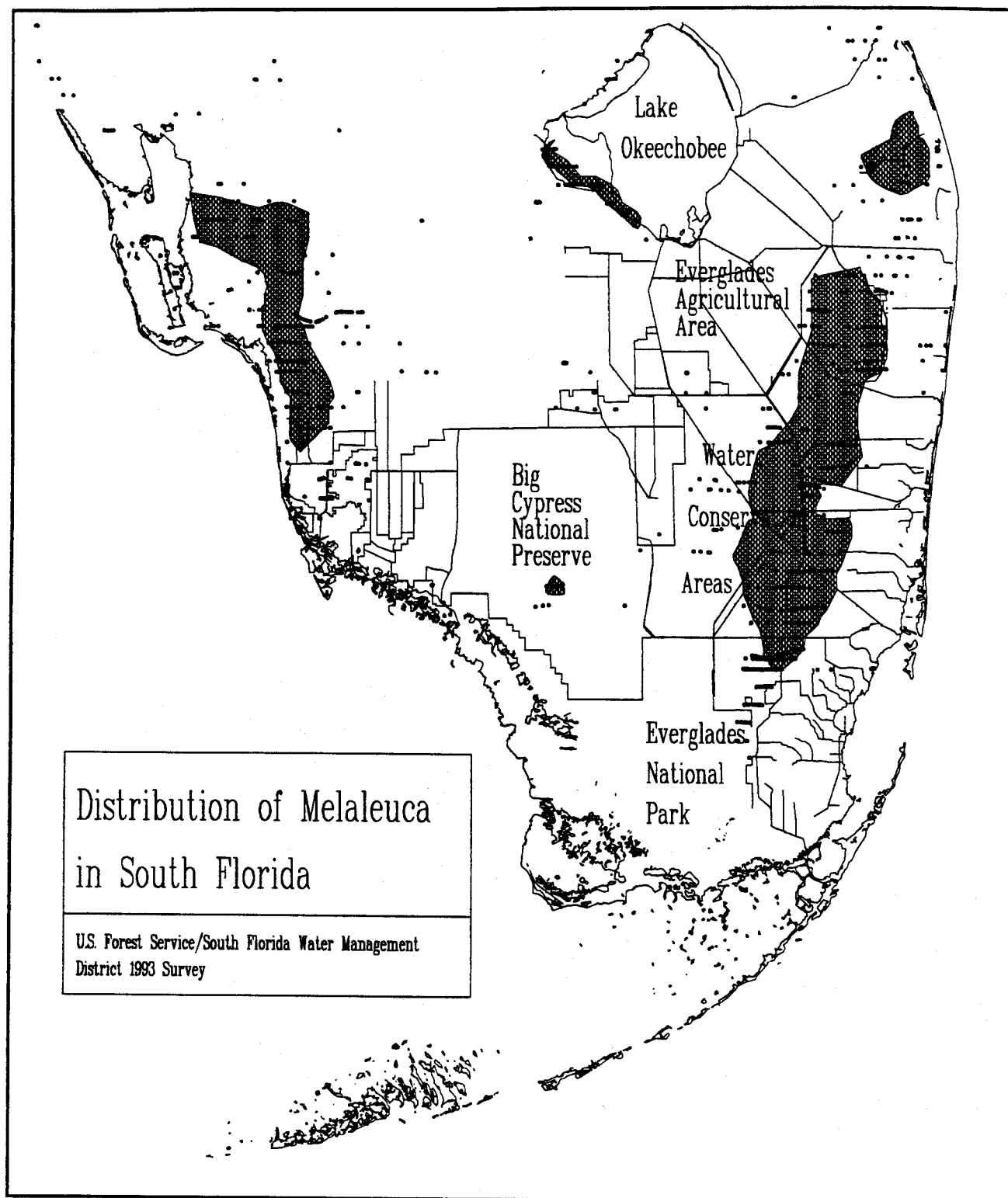
Given the rapid expansion of this species, melaleuca has the potential to alter vast areas of the Everglades by replacing native tree islands, sawgrass marshes, mesic prairies and aquatic sloughs. Mature melaleuca trees commonly form dense monocultures which virtually eliminate all other species. These 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). Stability of an ecosystem is proportional to diversity. When melaleuca invades wet prairie/marsh systems, diversity may increase initially; however, after monocultures form, stability is lost and diversity is decreased 60 - 80% (Woodall, 1988; Austin, 1978).

Melaleuca has fire adaptations that enhance the survival of established trees, promote reproduction and increase fire intensity to the detriment of less fire-resistant competitors (Wade, 1981). The high essential oil content of the tree makes it highly volatile. As a result, crown fires often occur in dense forests of melaleuca. These dense forests pose a serious fire threat to adjacent forests, urban areas and utility structures (Flowers, 1991).

Magnitude of the Problem

Melaleuca was planted from seeds obtained 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 around the areas of original introduction (Figure.1). Its spread was enhanced through its use as wind breaks and fence rows, and its popularity as a fast growing ornamental. Canals have most likely facilitated the spread of the buoyant seeds into the interior of the Everglades where the relatively undisturbed inland wetlands have been invaded. Very few pioneering or "outlier" melaleuca have invaded the Holey Land, Everglades National Park and Water Conservation Area (WCA) 2-A. Light to moderate infestations (widely scattered outlier

Figure 1- Most recent estimate of the present melaleuca distribution in southern Florida. (USDA Forest Service and SFWMD, 1993 unpublished)



and small heads) occur in WCA 3 and the western half of the east Everglades Acquisition Area. 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. Heavy infestations (large heads and solid forest) occur in WCA 2-B and in the marsh of Lake Okeechobee and areas of Broward, Dade, Lee, and Collier Counties, and east and west of the Everglades. In Lee County aerial extent and density appear to have expanded within the last ten years, particularly south of the Caloosahatchee River. These invasions are often associated with forested transitional wetlands with open canopy.

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.**
- 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**

V. RECOMMENDATIONS

The following recommendations reflect changes which have occurred since the previous Melaleuca Management Plan was drafted in 1990 and 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. This past year (1993) the District increased its funding to \$150,000 annually. The U.S. Congress, largely through the efforts of Representative E. Clay Shaw Jr., approved \$2,000,000 for the construction of a quarantine facility in south Florida. Half of these funds were appropriated during FY 1994, the remainder are to be appropriated during FY 1995. 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 1994 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 additional 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 \$2,000,000. 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.** At present, the melaleuca management program in Florida is not truly integrated. Biological control agents are not yet available for the management of seedling trees. Physical control, such as fire and flooding, are not completely understood nor easily managed, and mechanical control has included only the manual removal of seedlings. Consequently, herbicidal control offers the only practical and economically feasible method of eliminating melaleuca. It is essential to eliminate the current infestations. Biological agents, once introduced, will significantly reduce the spread of melaleuca. 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.** Accurate acreage estimates for melaleuca infestations in most areas are not currently available. Where active elimination programs currently exist, cost estimates for continued control are generally based on past control costs. Currently, there are several active melaleuca management programs in the priority areas identified by the Melaleuca Task Force. They are: The Everglades National Park, Big Cypress National Preserve, the Loxahatchee National Wildlife Refuge, the Water Conservation Areas, Lake Okeechobee and Lee County (see Section VIII for detailed summaries).
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 land owners 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 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° 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 plants 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

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, 1980b, 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 wildfire 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. World-wide, 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.

Physical characters of *Melaleuca quinquenervia* are illustrated in Figure 2. 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 inflorescences 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 summer, yet some flowering occurs year-round. 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. Flowers are pollinated by insects and seed fertility is high. 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).

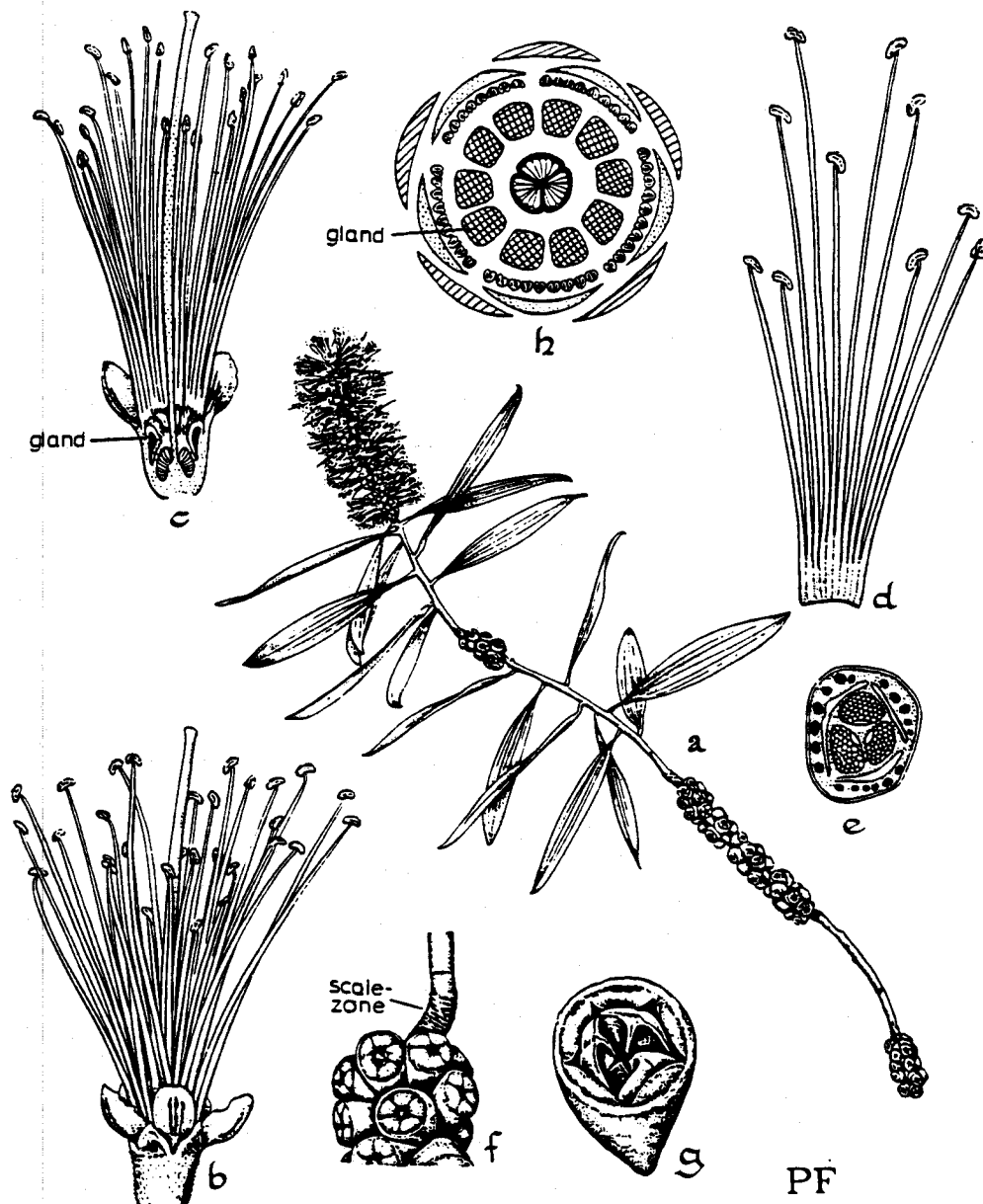


Figure 2- *Melaleuca quinquenervia*: (a) Habit (x1/2); (b) flower (x4); (c) flower in longitudinal section (x4); (d) stamen group (x6); (e) ovary in transverse section (x8); (f) unripe fruits (x2); (g) dehiscent fruit (x4); (h) floral diagram. (Reprinted with permission from P.B. Tomlinson. 1980. *The 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). 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). 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). Therefore, timing of fire, freeze, 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, 1983) 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

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 inhibit 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 optimal 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 (Figure 3). 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

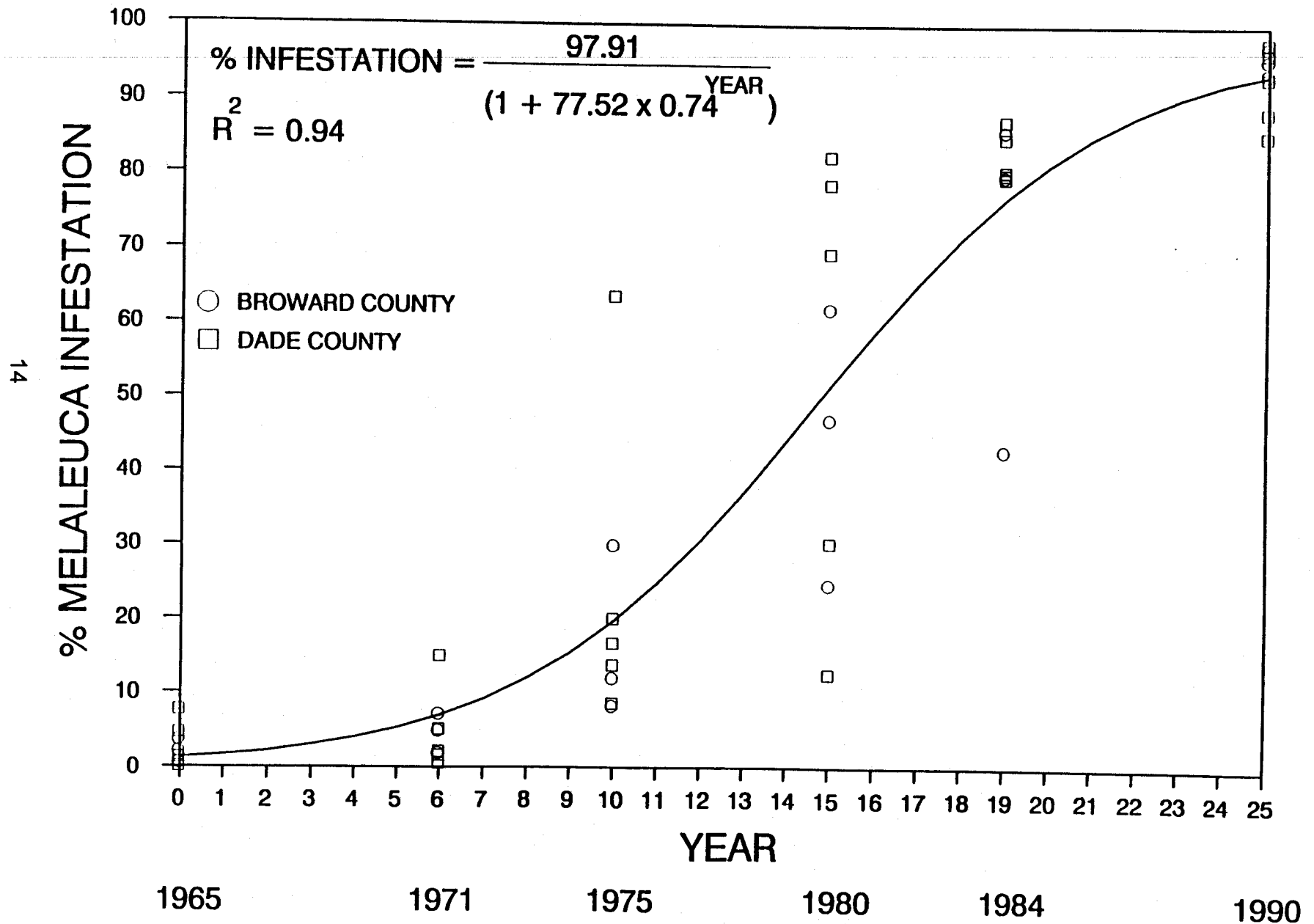
The potential range of melaleuca in Florida is typically noted as the entire peninsula south of Highway 60, excluding the saline zone. This tree is seemingly kept in check by frost although Woodall (1981b) noted that most, if not all mature melaleuca trees had survived severe frost damage during a record-breaking 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 inundations (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.

To date, there has not been a successful inventory survey of melaleuca conducted for the entire region (Hofstetter 1991b, Cost and Carver 1981, Capehart et al., 1977, Arvanitis

Figure 3- Infestation trend of melaleuca within selected sections, each encompassing one square mile, in Broward and Dade County, Florida. (Laroche and Ferriter, 1992)



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) recently 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 infestations 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

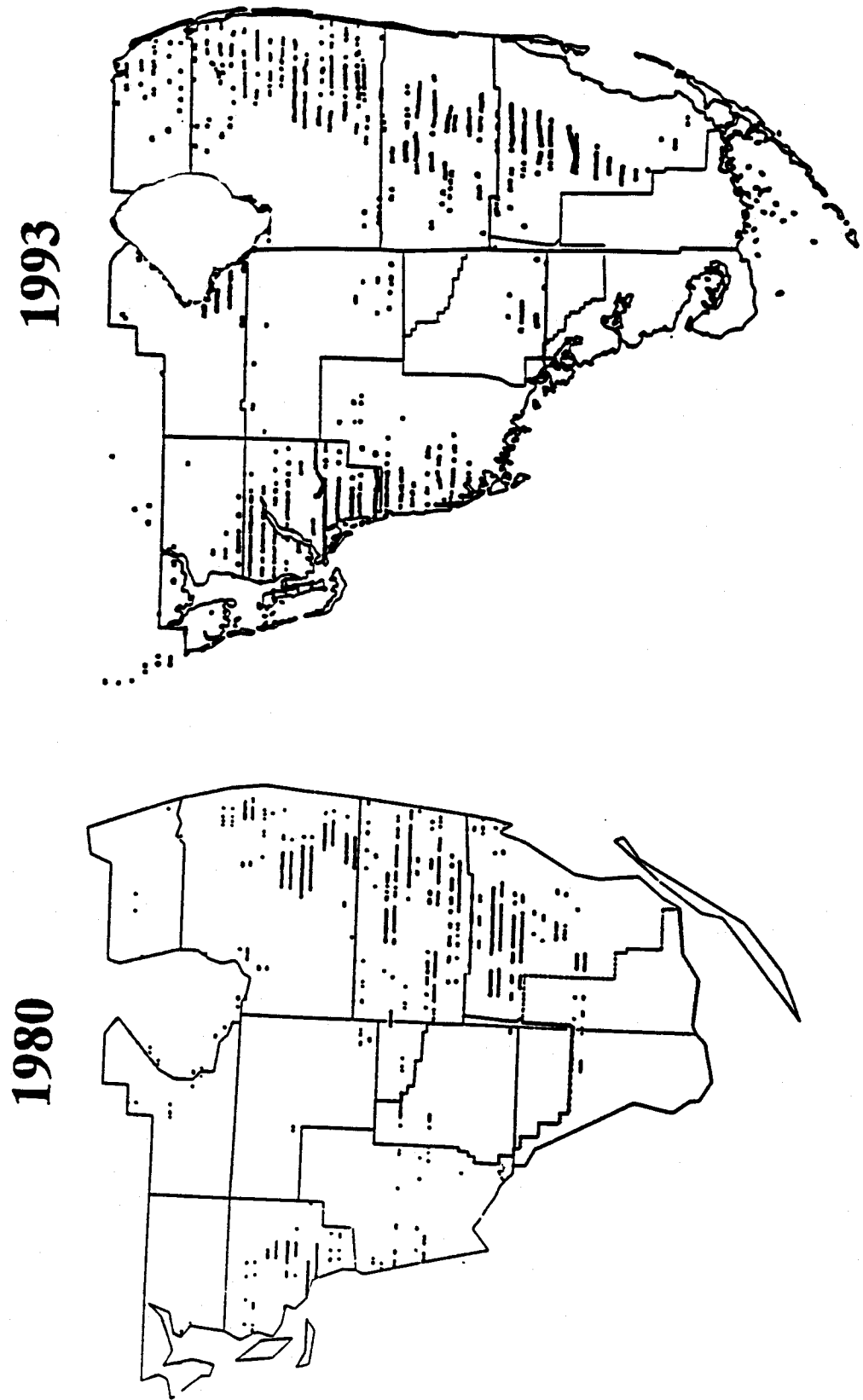
addition to recording the occurrence of the species, relative density information was recorded as well. Results of the 1980 and 1993 surveys are shown in Figure 4.

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) occur 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, 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 have been 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 4- Occurrence of melaleuca throughout South Florida in 1980 and 1993.



C. ENVIRONMENTAL, ECONOMIC AND HUMAN IMPACTS

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 following a fire (Myers, 1983). Second, fuel conditions change significantly as melaleuca displaces sawgrass (Flowers 1991). Compared to fires in 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 ($1.913 \pm 0.578 \text{ ug cm}^{-2}\text{sec}^{-1}$, N=24) and of melaleuca ($2.128 \pm 0.819 \text{ ug cm}^{-2}\text{sec}^{-1}$, 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 m² 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 have 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 individuals 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 a 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

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 feed-back 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 germ plasm 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 germ plasm 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 colonies. However, this presupposes that the criteria are known that define "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

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 regrowth 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

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, 1994) 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 and 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 and 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. 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. Regeneration established from seed released due to herbicide-kill, frost-damage, or hurricane winds, could easily be killed by burning. 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 reburned 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 can 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 resprouting occurs, the trees could then be treated with a foliar application of ARSENAL or GARLON 3A.

4. HERBICIDAL CONTROL

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.

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 5) 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 4); 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.

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
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

Table 2. Continues

HERBICIDE	RATE	METHOD	NOTES
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 of 10-15 Foot Trees After 10 Months

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
2,4-D	1-30 mls/inch DBH	H & 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.

Table 4. 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.

Table 5. 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

More recent SFWMD sponsored cooperative agency herbicide trials are investigating 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. Recent trials (June, 1993) established at the Big Cypress National Preserve indicate that low volume aerial applications of 5-10 total gallons per acre can increase efficacy when compared to conventional total volume applications. 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. Investigations are also underway which evaluate the effectiveness of aerial application with foliar-active herbicides and with soil-active herbicides. These investigations will evaluate herbicide effectiveness on melaleuca, effects on non-target vegetation and environmental fate. Herbicides being evaluated include; VELPAR L, SPIKE 40P, ARSENAL (imazapyr), GARLON 3A (triclopyr), and RODEO (glyphosate). Various application techniques, herbicide combinations and non-herbicidal spray additives are also being evaluated. Until these studies are completed, individual tree application methods - frill (or girdle) and cut/stump - will likely be the control methods of choice. 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. 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. Studies of effects on non-target vegetation are continuing.

To date, the "girdle" application technique of applying herbicide to cambium exposed around a tree's entire circumference has 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. ARSENAL 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. SFWMD costs for controlling melaleuca in FY 1993 averaged \$0.77 per tree in the Everglades Water Conservation Areas, and \$0.40 per tree in Lake Okeechobee. This cost includes labor, equipment and herbicide. In the WCAs, transport of crews to each treatment site, usually by helicopter, has been the largest single cost.

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 small-scale studies with herbicides that are broadcast onto dense melaleuca stands.

Results of these tests may suggest that large-scale broadcast herbicide treatments onto melaleuca forests can be made safely. These labor-conservative methods 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"

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, totalling five treatment units, are 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 Trimble® 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 GIS®/Dbase 4® 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 600-800 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. An air speed of 60-65 knots should typically be maintained in a Cessna 172.
- * 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

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 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. The following counties have ordinances that prohibit the sale or require the removal of melaleuca.

COUNTY	ORDINANCE
Broward	In Draft.
Charlotte**	92-72 County Ordinance.
Collier**	Land Development Code 3.
Dade***	82-68 County Ordinance.
Highlands	County Ordinance.
Hillsborough	Chapter 1-11 Rules of the Environmental Protection Commission.
Indian River	Chapter 929 County Code.

Lake	Chapter IX County Ordinance.
Lee	Section 13 County Ordinance.
Manatee*	719.11 Land Development Code County Comprehensive Plan.
Martin	23.53 County Ordinance County Comprehensive Plan.
Monroe	9.5 County Ordinance.
Palm Beach**	Article 7 Site Development Standards.
Pinellas	90-16 County Ordinance County Comprehensive Plan.
Sarasota	90-01 County Ordinance.
Seminole	Chapter 60 Part I - Arbor permits Chapter 60 Part II - Arbor Ordinance.
St. Lucie	7.90.5 County Ordinance.
Volusia	Article X & XI of Land Development Code.

- * Melaleuca must be removed during construction unless soil erosion can not be prevented without costly and extreme measures.
- ** Permit required to remove melaleuca.
- *** Oldest county ordinance in the state

All these counties have prohibited other plant species along with melaleuca. Also many cities throughout the state have ordinances that prohibit melaleuca and require its removal prior to site development or for mitigation. Notably, the City of Sanibel Island has prohibited melaleuca for over a decade.

VII. RESOURCE MANAGEMENT APPROACH

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 will probably occur in early 1995. 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 currently 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.

VIII. MELALEUCA MANAGEMENT EFFORTS

A. BIOLOGICAL CONTROL RESEARCH

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 of biological controls will be important in reducing the exponential rate of melaleuca expansion now occurring in south Florida wetlands (Laroche and Ferriter, 1992). In Australia, *M. quinquenervia* seedlings are much less common than in the melaleuca-infested areas of Florida. The United States Department of Agriculture (USDA) has been investigating insects which feed on melaleuca seedlings, saplings, and new shoot growth in Australia. The USDA proposes to introduce these insects to south Florida and anticipates a reduction in the rate of spread of these trees. The hope is to reduce the distribution and rate of spread in Florida to that currently seen in Australia.

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 Pterybophorinae (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. which caused severe defoliation and would almost certainly be host-specific. He also noted extensive signs of damage by a mirid bug *Ragewellus suspectus* Distant. Stem-feeding insects found by Habeck (1981) included sap-feeding hemipterous forms 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 are known to feed on the roots. An unidentified Lepidoptera larva bored the stems and killed developing tips.

Surveys conducted by Dr. Joe Balciunas (U.S.D.A. Agricultural Research Service, Office of International Research Programs) from 1986-1989 resulted in the recovery of nearly 600 insect species from *M. quinquenervia* and sibling species. Leaf-feeders were most abundant and included larvae from about 60 species of moths, several dozen chrysomelid beetles, about a dozen weevils, and 5 pergid sawflies. Sap-sucking 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. Nearly 60 species of fruit and flower-feeding insects were also collected.

Unfortunately, the task of determining which insects have potential as biocontrol candidates has never been completed. 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. Further, a complete list of those insects, among the nearly 600 already captured from melaleuca, that have potential as biocontrol agents has not yet been compiled. Clearly not all of the insects associated with melaleuca will be useful or appropriate as biological control agents. So it is vitally important that we know, as quickly as possible, how many potential bioagents are available and the order in which they should be tested.

The two most promising insects collected during the preliminary surveys 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. 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. Laboratory feeding trials implicate three species of Myrtaceae, two *Melaleuca*'s and a *Backhousia*, as food hosts. Oviposition has been confined to *M. quinquenervia*, a few closely related species from the *M. leucadendra* complex, and *Psidium pyriferrum*.

Because the *M. quinquenervia* in Florida is thought to have originated from seeds collected in SQ or NSW, where *L. zonalis* does not occur, there was concern that the U.S. plants would be unacceptable to this sawfly. Consequently, Dr. Gary Buckingham

(U.S.D.A. Agricultural Research Service, Florida Biological Control Laboratory) at the Gainesville quarantine facility was sent a shipment of pre-pupal *L. zonalis* in May 1992. These successfully emerged and subsequently oviposited on Florida *M. quinquenervia*. Further, those egg cases hatched successfully and the larvae readily accepted the Florida plant material. Development was slow and larval mortality high (not unusual when trying to establish a new laboratory colony with an unfamiliar insect), but the surviving larvae pupated and adults emerged this fall (1992). We are now confident that the Florida melaleuca is an acceptable host.

An important question remains to be addressed concerning this biocontrol candidate, aside from its host specificity. The question centers around whether or not *Lophyrotoma zonalis* produces lophyrotomin, an octapeptide found in some pergid sawflies from Australia, South America, and Europe. Consumption of the sawfly *Lophyrotoma interrupta* by Australian cattle is frequently fatal and costs the industry about \$1.1 million annually. Ingestion of larval *Arge pullata* by sheep in Denmark has also proven fatal. In both cases the octapeptide lophyrotomin has been identified as the toxin responsible for the deaths. Several South American pergids that have been implicated in livestock deaths are likely to produce this toxin as well. In light of this evidence, it is extremely critical that we determine whether lophyrotomin is produced by the two *Lophyrotoma* species that are melaleuca biocontrol candidates.

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 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.

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* may 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 pyrifera*) and grumichama (*Eugenia dombeyi*) to melaleuca. It has been dropped from further consideration.

The mirid bug *Eucerochoris suspectus* causes leaf blotching that can distort the growth of young leaves. This insect fed upon 24 plant species and preferred *Melaleuca fluviatilis* to *M. quinquenervia*. Six other species sustained appreciable feeding damage. Thus far, only two nymphs have developed on plants other than *M. quinquenervia*.

Fergusonina sp. is a fly that forms a fleshy tip gall on *M. quinquenervia*. Members of this genus form galls in association with nematodes of the genus *Fergusobia*. Some species have reduced flowering and seed production of *Eucalyptus* trees. About 23% of young tips at one site were affected by galls during 1993.

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. This means 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.

Quarantine research - Nearly 100 plant species and varieties have thus far been offered to *Oxyops vitiosa* during adult feeding trials. Only four species sustained appreciable damage when presented to the weevils along with *M. quinquenervia*. Damage was considered appreciable when leaf surface scarring totalled 25% or more of the scarring on melaleuca. Three additional species sustained appreciable damage during trials in which the insects are offered only a single plant. This type of "starvation" test provides information on the physiological ability of the insect to utilize a test plant for survival. This protocol can generate many false positive responses, however, because it confines the insects in small containers on plants that they would quickly leave in nature. Adults failed to survive for more than 25 days during starvation tests employing species which had sustained appreciable damage during the earlier trials.

Florida field research - Classical biological control programs traditionally include surveys for herbivores already damaging the target weed in its adventive range. The purpose of these surveys is to ensure that time and money are not spent clearing an insect for importation and release, only to find that insect is already (either naturally or through accidental introduction) present in the weed's adventive range. For example, the mite *Orthogalumna terebrantis* was considered a very promising biocontrol candidate when discovered in South America. Surveys later showed that this mite was already present

in Florida, however, so importing this insect would not have been helpful. Similar experiences with the hydrilla moth *Parapoynx diminutalis* and the Eurasian watermilfoil moth *Acentria nivea* reinforce the general usefulness of surveying the adventive range of a weed. Melaleuca insects are less likely to be present in Florida, however, because Australia is not in as close proximity to the U.S. as are Europe and South America (the origins for the plants cited in our examples). Thus, traffic between the U.S. and Australia is reduced relative to the other two regions and there is less opportunity for the accidental introduction of Australian insects.

Pathogen research - Investigations by Dr. Roger Webb and his associate Mr. Min Rayachetty (University of Florida Department of Forestry) of a melaleuca decline at Loxahatchee National Wildlife Refuge in Florida resulted in the discovery that dying trees were infected by *Botryosphaeria ribis*, a fungal pathogen. Further studies have confirmed the lethality of this pathogen, but have also demonstrated that this fungus is non-invasive. That is, the fungus is unable to penetrate the thick protective melaleuca bark on its own and therefore requires that a wound be present to facilitate entry to the cambium.

These researchers have developed simple methods for cloning *Melaleuca quinquenervia* that are being used in studies with *B. ribis*. Eleven single-spored cultures (SPC) have been obtained for six *B. ribis* isolates. SPC's have been characterized, by growth patterns in artificial media, spore dimensions and nuclear conditions, etc. Morphological variations among SPCs are marked. Methods for producing inocula in an effective formulation, and methods for inoculating trees have been developed. Pathogenicity tests show six isolates are pathogenic to *M. quinquenervia*. Leaf bioassays show little difference in pathogenicity among SPCs within isolates. Pathogenicity differed among isolates. Also, *M. quinquenervia* clones differed in susceptibility. Stem treatments produced no canker, discoloration, or callusing of *M. quinquenervia* tissue beyond the inoculation point among controls. Extensive discoloration was associated with depression of the bark on all sides from the point of inoculation for the *B. ribis* isolate. Inoculation with *B. ribis* after 2 to 3 defoliation cycles hastened host mortality. Effects of extreme environmental conditions on disease development, histopathological aspects of disease development, and putative involvement of mycotoxin(s) in disease development remain to be studied.

Biological Control Project Needs

Overseas research needs - The introduction of two candidate species into quarantine for host range testing is an important milestone for the overseas portion of this program. It in no way diminishes the need for further research in Australia, however. Although preliminary host trials suggest these insects specialize on melaleuca, there is no guarantee that either will prove safe for release in Florida. Additionally, control of a woody species like melaleuca will undoubtedly require more than just two insects. In fact, at the outset of this project we estimated that at least 8-12 insects would be required.

Thus, the overseas research program will continue to need funding for the foreseeable future.

Perhaps the most important need of the overseas program is to obtain a single, consistent funding base. Fluctuations in funding levels have provided a constant source of frustration and have severely limited our ability to plan the research. Of course, this need would be eliminated by acquisition of a permanent congressional increase in USDA-ARS base funding for the Aquatic Plant Management Laboratory. Whether or when such an increase will eventuate, however, is uncertain. In the interim, we need supporting agencies to commit to providing continued support at consistent levels.

MELALEUCA BIOCONTROL FUNDING PROFILE (X \$1,000)								
Agency	FY86-FY88	FY89	FY90	FY91	FY92	FY93	FY94	Agency Totals
USAE*	155	77	57	155	50	67	66	627
NPS	90	71						161
DNR		50	50	50	50	30	65	295
DER			50	100	100	50		300
Lee Co.		10		20				30
SFWMD				75	75	125	150	500
Dade Co.				10	10			20
Annual Total	245	208	232	410	285	272	281	1,933
*USAE additional biocontrol in-house expenses amounted to \$61,000 USDA-ARS in-house contributions to this project totaled about \$500,000								

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. Available space in this facility is less than 1000 ft². Space is inadequate for the development of research colonies of the bioagents and for production of the large woody plants used in testing and as food for the insects. As a result, personnel in Gainesville rely on shipments of insects from overseas as a source of test subjects and on shipments of melaleuca cuttings from the USDA-ARS laboratory in south Florida as a 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 perhaps could have been. 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. This meeting was also attended by a congressional aide (Michael Harrington) from the office of Congressman E. Clay Shaw (District 22, FL). 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 is included in the House version of the 1995 budget. However, inflation has already increased the cost of the facility beyond the initial estimate, so certain aspects of the design may have to be downsized to match available funds.

Because of the split appropriation, a portion of the first allotment will be used for planning and design of the building. Construction will not begin until receipt of the second allotment. The anticipated time frame to design and construct the facility is about 3 years after execution of a Memorandum of Understanding between the USDA and the Corps of Engineers. The estimated construction time is about 16 months.

Acquisition of the quarantine building will certainly resolve the existing space problem, but funds to operate the facility will be needed. Congressman Shaw has already begun to lobby Congress to increase to the USDA-ARS Aquatic Plant Control Research Unit's base budget for this purpose. This budget increase was not realized during the FY-1994 budget process, but wording was added to the Agricultural Appropriations Bill that requires USDA to "devote the necessary resources to melaleuca control research at the Aquatic Plant Management Laboratory". Hopefully, funds will be forthcoming in future years that will be commensurate with this mandate. If not, costs of operating the facility will have to be borne by project sponsors.

Florida field research needs - Success of biocontrol programs is generally measured in terms of the reductions that the agent(s) elicit 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 *B. ribis* 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 research.

B. OPERATIONAL EFFORTS

1. ARTHUR R. MARSHALL LOXAHATCHEE NATIONAL WILDLIFE REFUGE

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 impoundments 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 interspersed of four main plant communities: slough, wet prairie, sawgrass and sawgrass-brush, and tree island or bayhead. 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).

Through 1987 and 1988, the testing of herbicides and application techniques for the control of melaleuca continued. 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) crew members 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.

Since the intensive melaleuca control program began in April 1992, over 500,000 trees have been killed (treated and pulled) on the Refuge. The average cost per tree is approximately \$0.43. A grid system has recently been devised which divides the Refuge into cells of 41 hectares each. Crews currently concentrate on systematically treating melaleuca cell by cell. The principal treatment methods are uprooting of seedlings and saplings, and the hack and squirt treatment using ARSENAL. The crews will return a few years after treatment to check each cell and retreat if necessary for sprouting.

2. BIG CYPRESS NATIONAL PRESERVE

In 1974 Congress set aside 570,000 acres of the Big Cypress swamp as a National Preserve. Big Cypress National Preserve is administered by the National Park Service. The National Park Service (NPS) management policies mandate the control of exotic species up to and including total eradication whenever such species threaten protection or interpretation of resources being preserved in NPS lands.

Additionally, Public Law 93-440 which established the Preserve, assures the preservation, conservation and protection of the natural, scenic, hydrologic, floral and faunal and recreational values of the Big Cypress Watershed from biological degradation caused by the invasion of exotic plant species.

Big Cypress National Preserve is considered critical habitat for the following endangered species: the Florida panther (*Felis concolor coryi*), and the Cape Sable Sparrow (*Ammodramus maritima mirabilis*). The spread of exotic plants can alter the habitats needed for the survival of these endangered species. In 1991, the Exotic Species Management Guidelines were established by the National Park Service (NPS-77). These guidelines form the foundation for exotic plant management in Big Cypress National Preserve.

Problem Statement

Meskimen (1962) states that melaleuca was first planted in Big Cypress in 1944 at Monroe Station near the intersection of US 41 and State Road 94. Meskimen surveyed the melaleuca planting when the trees were approximately 20 years old and noted that even though numerous seed crops have been shed no regeneration had taken place. Meskimen attributed the lack of regeneration to the largely alkaline marl soils of the area.

Duever et al. (1979) mapped the distribution of melaleuca in the Preserve and found rapidly expanding populations at Monroe Station, Paolita Station, and one site off Loop Road. Gunderson (1983) in a South Florida Research Center report on Exotic Plants in Big Cypress concluded that 60 square miles of the Preserve were infested to some extent and continued expansion is likely. Systematic reconnaissance flights conducted in 1992, and 1993 reveal that the range of expansion of melaleuca in the Preserve includes over 186 square miles. The spread of melaleuca in the Preserve has been aided by ornamental plantings at homesites and hunting camps, off-road vehicles, and by the increased incidence and severity of fires. Fire regimes in Big Cypress favor the proliferation of melaleuca. Fire promotes seedling establishment, induces coppicing, and high fire intensities lead to the demise of less fire adapted native species.

Integrated Pest Management

In 1984, resource managers identified melaleuca as a serious threat to the natural floral integrity of the Preserve in the Resource Management Plan and initiated a control plan based on the principles of integrated pest management (IPM). The integrated management of exotic plant species requires the combination of biological control, herbicidal, physical and mechanical control. At the present time no biological control agents are available to assist Big Cypress in the control of exotic plant species. In the interim, herbicidal, physical and mechanical methods are required to reduce current infestations in the Preserve and reduce the spread into currently non-infested areas.

Management Strategy

The key elements to a successful control program are a systematic approach, long-term commitment, and consistent follow-up. The widespread invasion of melaleuca in the Preserve has necessitated resource managers to incorporate an incremental approach to

the control of melaleuca. In this approach, the Preserve has been divided into ten treatment units (Figure 5) Melaleuca is identified and eliminated from one treatment unit at a time. Units that pose a potential threat to Everglades National Park and important resource areas have received the highest priority. Once initially treated, units are then monitored and re-treated on a two year cycle. This two year cycle allows seedlings an opportunity to reach a height that will facilitate detection with a minimal chance of these plants producing seed.

Systematic Reconnaissance Flights

Systematic reconnaissance flights (SRF) are utilized to detect and quantify melaleuca population levels (Figure 6). Approximately one-half of the Preserve or five treatment units are flown per year. Flights are conducted in December - March to coincide with the deciduous period of the cypress which facilitates the identification of melaleuca. Flight lines are flown using a Trimble® 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 position of the target is then entered into the GPS as a way-point and the target classified.

Data collected from the flights is then transferred to a PC data base and post-processed using the Trimble® software. Data is then incorporated into a PC based Atlas GIS®/Dbase 4® Geographic Information System (GIS).

Control Methods

The following treatment methods are used to control melaleuca:

The hand pulling of seedlings (under 1 m. in height) and the felling of trees and subsequent stump application with ARSENAL® herbicide (25% dilution/approx. 3-5 ml/tree).

Treated areas (conditions permitting) are then burned approximately two months to one year after the treatment in order to reduce post treatment seedling establishment.

UTM coordinates are obtained from all sites utilizing GPS Trimble® GPS receivers. On larger sites GPS is used to obtain perimeters of the treated areas.

Treatment and SRF data is entered into a *Atlas GIS®/Dbase 4®* system, this system links treatment and SRF information from the database to a map. The database contains treatment and monitoring information since 1984.

National Park Service seasonal crews are hired on an annual basis to treat melaleuca. Approximately 10 employees work from December through May to coincide with the dry

Figure 5- Map of Melaleuca Treatment Areas in The Big Cypress National Preserve (FY 90-94).

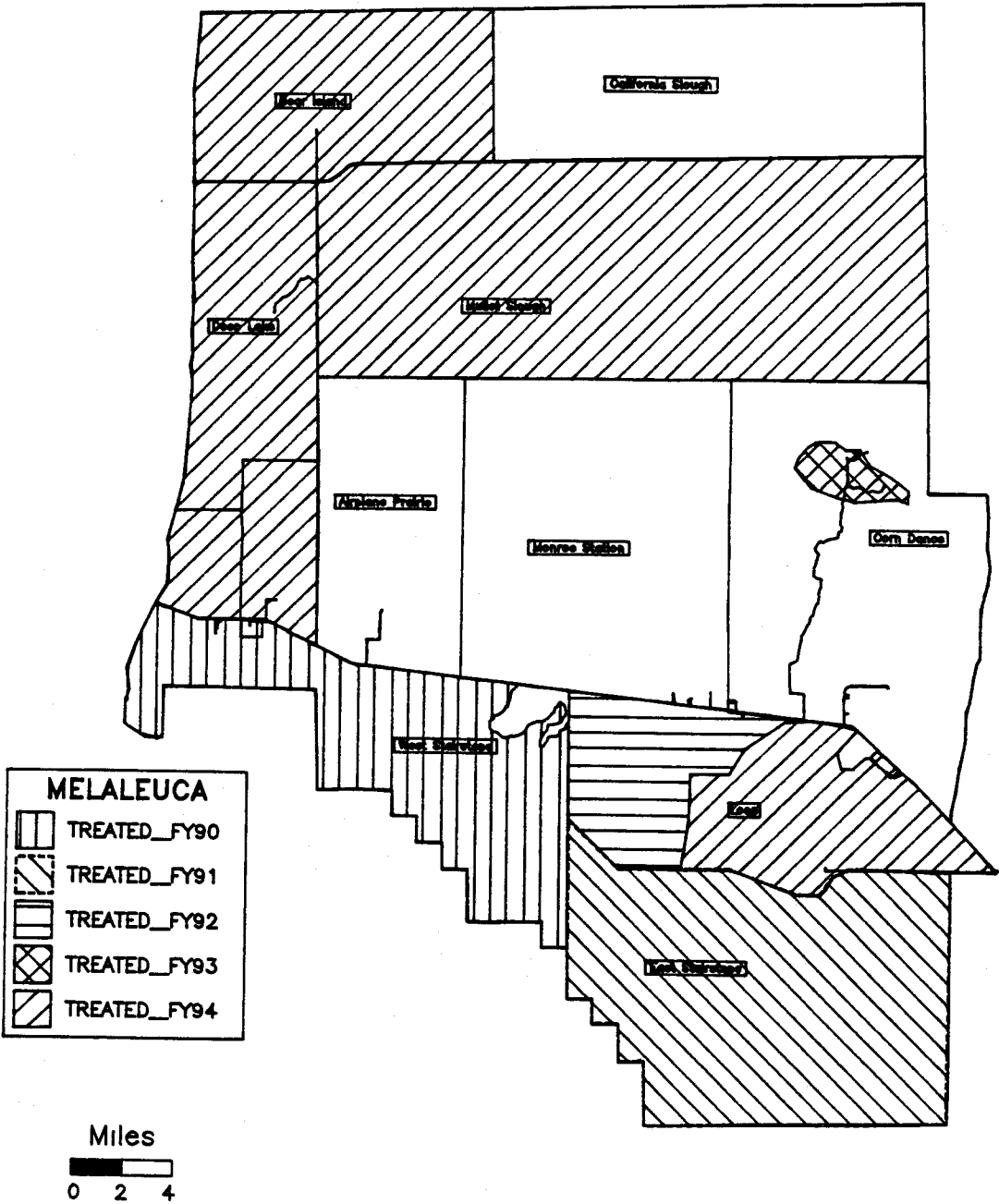
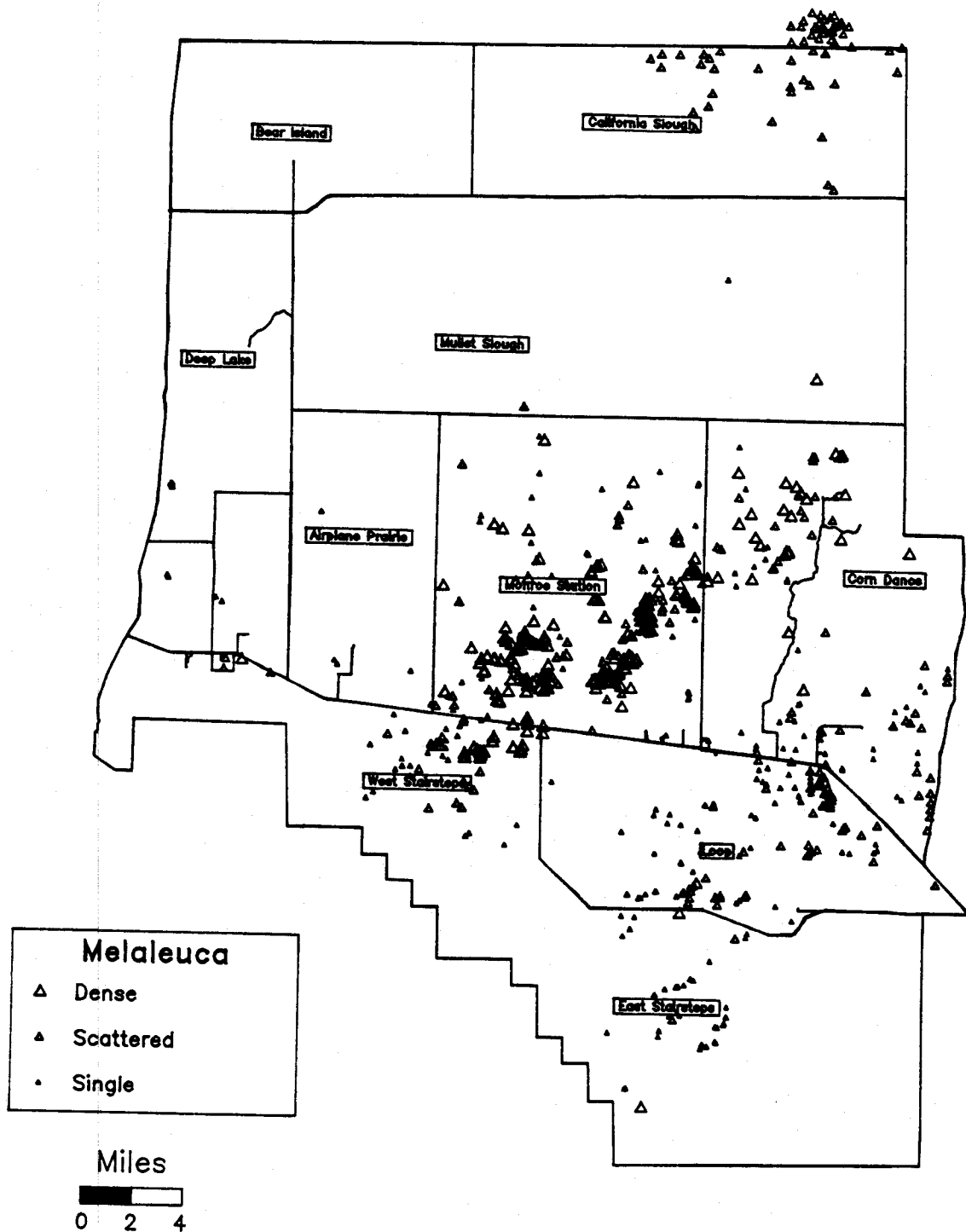


Figure 6- Results of SRF flights conducted at the Big Cypress National Preserve in 1991 and 1993.



season. NPS seasonal crew melaleuca management progress is summarized in Table 6.

Aerial Application

Once an efficacious aerial treatment is developed and approved by the National Park Service, monospecific dense heads will be treated by helicopter. This will significantly reduce the amount of herbicide utilized in the sensitive wetlands of the Preserve. Ground based crews will continue to be utilized for the treatment of outliers and the "mopping up" of aerially treated sites.

Prescribed Burns

In the Preserve, prescribed fire is utilized whenever possible to control seedlings following herbicidal treatment. Myers and Belles (1994) shows that fire can successfully be utilized to kill the majority of seedlings following herbicidal treatment. Treated sites are scheduled for prescribed fire normally within one year of treatment. Occasionally, sites cannot be burned as scheduled due to improper environmental variables such as: insufficient fuel loading, high or low water levels, smoke dispersion etc.

Volunteers

Several south Florida organizations assist Big Cypress in the control of melaleuca. The Tropical Audubon Society, Sierra Club of Miami, Everglades Coordinating Council and Outward Bound have annual melaleuca work days in the Preserve in which volunteer members assist NPS exotic plant control crews.

The Preserve has also established a volunteer program in which back-country users expressing a desire to assist the NPS in melaleuca control are provided with "hit-kits". These "hit-kits" contain herbicide, safety equipment, and data sheets/ maps. In order to participate in this program, volunteers must possess a valid State of Florida Pesticide Applicators License. This program established in 1992, now has over 35 active participants.

Mitigation Projects

Several off-site mitigation projects involving the control of melaleuca are currently being implemented in the Preserve. Off-site mitigation is that which has been approved by state & federal regulatory agencies as appropriate to offset wetland impacts for public works and construction projects outside of the Preserve. These projects provide for eradication and monitoring of melaleuca. In 1993, 55 acres of dense mono-specific melaleuca (over 1,000,000 stems) were treated in the loop unit as a result of off-site mitigation. In 1994, it is anticipated that an off-site mitigation project resulting from the construction of a joint Dade County /Federal Correctional Facility will be initiated that will

Table 6. Summary of NPS seasonal crew melaleuca management efforts in the Big Cypress National Preserve Ochopee, Florida -1993. Number of trees treated with various application methods and cost.

Year	Hand Pulled	Stump/ Garlon 3A	Stump/ Arsenal	H&S Velpar	H&S Arsenal	Labor (hours)	Total Equip. \$	Total Herb. \$	Labor \$	Total \$	Cost /Tree \$
1984	43,615	1	0	10,383	0	1,137	13,628	2,100	34,272	50,000	.53
1985	6,108	1	0	16,676	0	873	11,491	2,500	36,009	50,000	1.56
1986	20,024	368	0	0	0	104	-	-	-	-	-
1987	120,327	23,382	0	0	0	1,281	7,944	2,180	29,876	40,000	.26
1988	419,786	301,507	0	0	1,145	4,305	-	-	-	87,000	.12
1989	11,786	0	196,342	0	21,260	1,930	14,129	4,750	41,120	60,000	.26
1990	2,207	0	110,171	0	7,179	1,882	35,000	15,000	50,000	100,000	.84
1991	15,110	0	97,164	0	15,510	1,825	35,000	20,000	45,000	100,000	.78
1992	3,850	0	428,893	0	0	2,887	65,000	25,000	80,000	170,000	.48
1993	11,424	0	215,419	0	0	4,582	45,700	17,500	36,800	100,000	.44

provide for the eradication and monitoring of melaleuca from over 20,000 acres of mixed prairie and cypress strands in the Monroe Station area of the Preserve.

3. US ARMY CORPS OF ENGINEERS

The U.S. Army Corps of Engineers (The 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 lakeward of the Rim Canal. An Environmental Assessment (EA) of the management plan was conducted by the Corps. 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 CoE 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 funded initial overseas surveys by the U.S. Army Corps Engineers Waterways Experiment Station 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 could 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 continues north along Levee L-50, L-49, L-48 and L-D-4 at Okeechobee. Melaleuca is being mechanically controlled in designated areas of the Federal easement in a manner minimizing disturbance to the Dike system. Felled trees are being windrowed and left in place or being burned. To date, over 600 acres have been cleared.

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 have 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 is scheduled through Fiscal Year (FY) 94. Some cleared sites have been revegetated with species selected for wildlife habitat enhancement.

In 1992, several research projects were undertaken on Lake Okeechobee as part of the U.S. Army Engineer Waterways Experiment Station's Wetlands Research Program. One of these, a melaleuca mapping project, is utilizing the Water Watch remote sensing system. Aerial transects of Lake Okeechobee have been flown targeting all melaleuca within the confines of the Herbert Hoover Dike. At the time of this writing, the product of this effort is still being evaluated.

CORPS OF ENGINEERS MELALEUCA MANAGEMENT FUNDING TO DATE

1987 - Present, Biological Control Research:	\$ 688,000
1990 - Present, Mechanical Removal on Herbert Hoover Dike:	\$ 150,000
1992 - Present, Wetland's Research Program:	\$ 35,000

PROJECTED MELALEUCA MANAGEMENT NEEDS

Removal efforts on Herbert Hoover Dike:	\$ 500,000
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4. DADE COUNTY

The Dade County Department of Solid Waste Management, through a mitigation contribution is providing funds to control melaleuca on 130 acres of M.E. Thompson Park. The Dade County Park and Recreation Department is implementing the melaleuca control efforts. A nine person crew is scheduled to begin control efforts in the spring of 1994.

Treatment methodology includes hand pulling seedlings, and cut-stump treatment of sapling and mature trees with ARSENAL. Aerial applications of ARSENAL/RODEO mix will be utilized in dense melaleuca heads with less than 10% native species. Concentrations will be based upon results of experiments currently underway by the South Florida Water Management District.

The Dade County Department of Environmental Resources Management (DERM) and the Park and Recreation Department are currently negotiating an agreement providing additional funds for melaleuca control at M.E. Thompson Park through mitigation contributions. Control efforts at the Park would be implemented by the Natural Areas Management Section of the Park and Recreation Department. This agreement should be approved by the spring of 1994.

Mitigation contributions arising from permits issued by DERM through the Army Corps of Engineers General Permit no. 59 enabled DERM to provide approximately \$350,000 to the East Everglades Exotic Plant Control Program, and \$20,000 to the USDA's Melaleuca Biocontrol Program.

Dade County and the Big Cypress National Preserve are currently negotiating a Memorandum of Agreement that would provide \$1.6 million dollars for melaleuca control on 20,000 acres of the Preserve. This work is required mitigation for the joint State/County jail facility located in Dade County.

5. Department Of Environmental Protection

The Florida Department of Environmental Protection (The Department) 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 Department's Bureau of Aquatic 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 Department.

The Department 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, the Department 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. Department 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 Aquatic 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 as soon as possible, and in Fiscal Year 1993/94 the Department 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. In FY 1994/95, the Bureau will be spending \$1 million on melaleuca control in response to the legislative mandate.

The Department staff has put together several "work" days to clean up post-treatment areas on Lake Okeechobee. The clean up days have involved people from within the Department, the South Florida Water Management District, and other state and local government agencies. These days have been used to survey already treated areas to insure control and to give participants a close look at the melaleuca problem. During the first "work" day, approximately 12,000 trees were removed from the lake.

6. EVERGLADES NATIONAL PARK

The primary concentration of melaleuca in the park is in the East Everglades Acquisition area, an area characterized by seasonally inundated sawgrass (*Cladium jamaicensis*) and *Muhlenbergia* prairies with scattered tree hammocks and bay and willow heads. Melaleuca occurs in the prairie areas as single plants (outliers), as even-aged stands around a central seed tree, and as monotypic forests of several age classes. It also occurs in the margin of hammocks in various densities. Aerial reconnaissance carried out in 1993 revealed approximately 200 monotypic stands in northeastern Shark Slough alone.

Because the expansion of melaleuca in the East Everglades poses a significant threat to native plant communities existing both within and outside the area - nearly thirty types of natural vegetation communities have been identified in the area, many with rare and endangered species (East Everglades Resources Planning Project, 1980) - concentrated efforts to control its spread have been centered in this area of the park since the mid-1980's.

With the establishment of the East Everglades Exotic Plant Control Project by the multi-agency East Everglades Resource Planning and Management Committee in 1985, and with the assistance of the Exotic Pest Plant Council, the development of and funding for an exotic vegetation control program for the East Everglades, with Everglades National Park as project administrator, reached fruition. The control of both melaleuca and casuarina are managed under this program. Initial funding was provided by the Florida Department of Community Affairs in 1986 through the Areas of Critical Environmental Concern Trust Fund. Project funding by cooperating agencies from 1987 to 1994 is listed in Table 7.

Table 7. Annual project funding by cooperating agencies for exotic pest plant control.

AGENCY	1987-90	1990-91	1991-92	1992-93	1993-94
Dade County Dept. of Environmental Resource Management (DERM)	75,000	40,000	60,000	200,000	200,000
Florida Dept. of Corrections (DOC)		264,000	264,000	264,000	
Florida Dept. of Environmental Protection (DEP)	20,000	20,000			
South Florida Water Management District (SFWMD)			60,000	60,000	60,000
TOTAL	95,000	324,000	384,000	524,000	260,000

Treatment

The melaleuca treatment season for East Everglades runs for 21 weeks, from December to May. The strategy for melaleuca control is based on a "quarantine strategy" described by Woodall (1981a). Because melaleuca advances in a series of sporadic jumps rather than continuously, the biggest benefit is realized by treating the most isolated, distant seed trees and progressing with treatment toward the epicenter of the infestation. Control efficacy is achieved by treating regrowth and recruits at previous sites each year and expanding the control buffer easterly in approximately one-mile per year increments. Surveillance is conducted from a helicopter, using a Global Positioning System (GPS) to navigate along ten-second or twenty-second interval transects running in a north-south direction. Outlier and low to medium densities of melaleuca are treated as found along the transects. High density or monotypic stands are noted for subsequent foliar or broadcast spraying. The data recorded at each treatment site provides information on previously overlooked outliers, resprouts and recruits in previously treated sites, and new sites. New sites are marked with metal tags. Site data includes: latitude/longitude, tag number, seed tree height, hydrological conditions, seedling index, vegetation community type, number of resprouts, and number of stems by treatment method. Field data are entered into Lotus 123 (ver. 3.1). Site location coordinates are converted to Universal Transverse Mercator (UTM) coordinates and entered into Geographic and Resource Analysis Support System (GRASS ver. 3.1) site files to create project maps.

The methods used to control melaleuca include mechanical (pulling seedlings by hand), chemical (cut stump, foliar, broadcast) and physical (prescribed burn, prolonged inundation after cutting). In cut stump treatments, 50% ARSENAL is used. Larger trees are felled with chainsaws and the exposed cambium treated with 50% ARSENAL. Monotypic stands of melaleuca seedlings are either cleared using brush cutters then treated with a broadcast spray solution containing 15% ARSENAL, 1% KINETIC and dye or foliar treated with a 1.5% solution of ARSENAL and 1% adjuvant.

Table 8 summarizes the results of treating melaleuca in East Everglades since 1986. Over 4 million stems have been treated to date. Data for foliar and broadcast treatments are not separated from the cut stump data since they constitute a small fraction of the total. The distribution of Melaleuca treatment sites for the period 1991 to 1993 is shown in Figure 7.

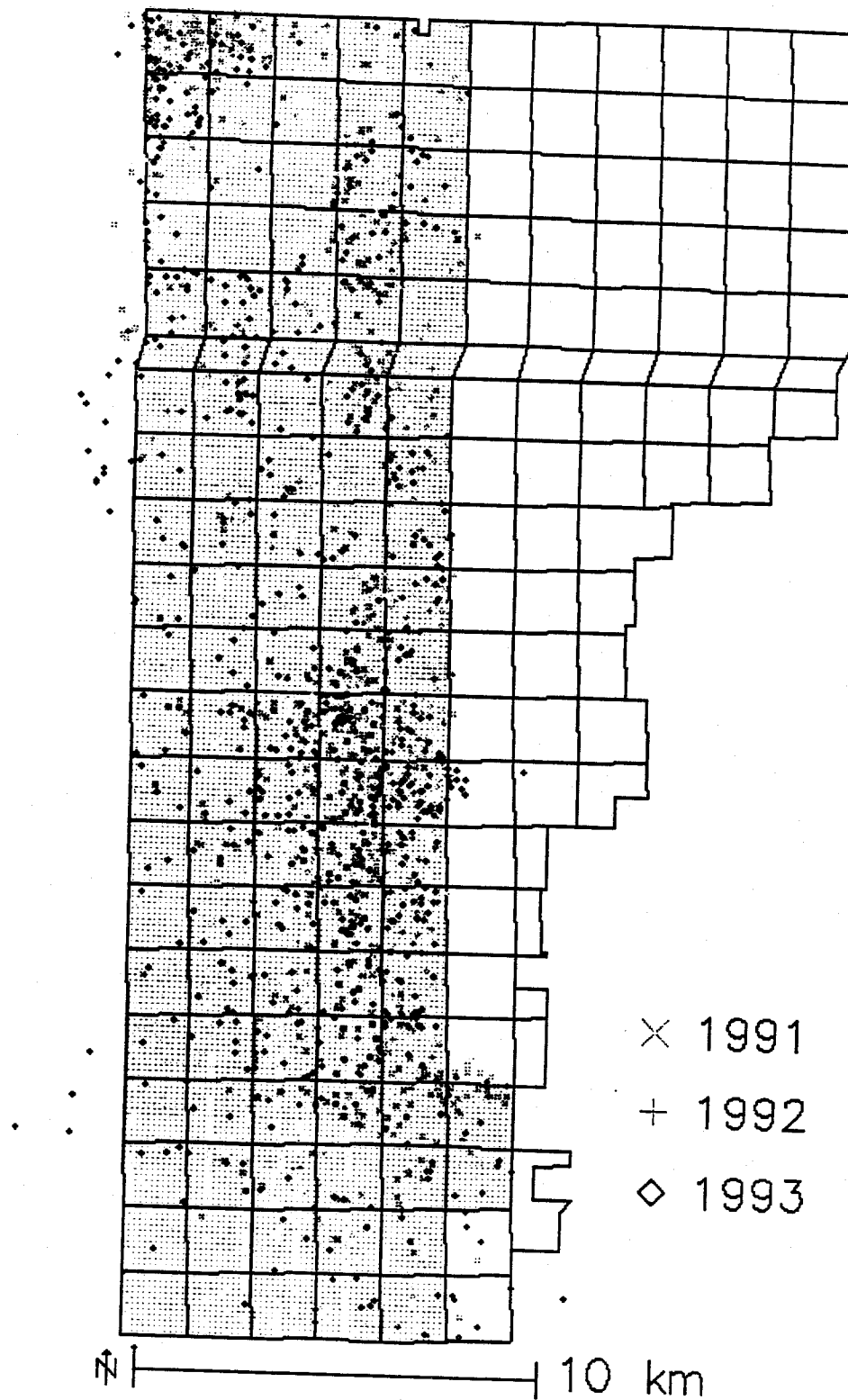
Table 8. Treatment results for Melaleuca in East Everglades (1986-1993).

TREAT.	1986-1988	1989	1990	1991	1992	1993	TOTAL
Hand Pulled	44,041	25,841	11,94	97,833	198,585	33,021	441,117
Stump Treat	17,877	6,737	345	1,495,133	1,845,52	59,267	3,424,880
Frill Girdle	558	1,331	17,007	244	7	0	21,178
TOTAL STEMS	62,476	19,728	29,297	1,595,241	2,044,12	92,279	3,887,145

Aerial surveys and treatment work for 1994 continues into the untreated sixth mile. Surveys in the untreated area indicate a dramatic increase in the number of outlier and low density stands (which require individual cut stump treatments), exceeding treatment capability given current manpower (two three-person crews) and methods. High water levels in certain areas, especially north of Grossman's Ridge, hinder the use of ground and aerial foliar treatments of melaleuca in standing water under current label restrictions. Aerial treatment study plots established in the East Everglades in 1990 to test various herbicide formulations were destroyed by Hurricane Andrew before conclusive data were obtained.

Figure 7-

Map of the Melaleuca treatment areas in the East Everglades Acquisition Area (1991-1993).



Physical Control

The benefits of prolonged hydroperiod in controlling the spread of melaleuca are an important component of an integrated control program. Site alteration may be the most viable alternate method for preventing melaleuca spread. Myers (1975) and Woodall (1981a) recognized the potential of managing seasonal water regimes to control melaleuca establishment. Browder and Schroeder (1980) stated "if somewhat more natural hydrological conditions could be restored so that higher water levels would persist over a larger area melaleuca might not advance." The theory coincides with the observation (Shomer and Drew 1982) that "colonization appears to occur at increasing rates inversely proportional to the length of the effective hydroperiod prevailing at the site." Myers (1975) found that a "favorable window for successful germination exists for only brief periods confined to either the onset of the wet season or after water levels recede in the fall. Prolonged conditions favorable for germination would be found, therefore, only on those sites where the soil surface is exposed but remains wet for long periods of time." Thus a fluctuating or "noisy" hydroperiod is more favorable for melaleuca establishment than a stable one.

In pilot studies at these areas it has been demonstrated that flooding cut melaleuca stumps (without the use of herbicides) results in over 90% mortality (DeVries et al., 1993). The technique is limited, however, to sites that predictably flood for several months (additional research is needed to identify the minimum flooding period to achieve mortality at a given site). The technique would be most effective on sites that are constantly flooded, except for a current lack of mechanized equipment designed to cut trees under water. Reciprocating saws are available for underwater cutting only of seedlings less than 1.5 inches in diameter. If a mechanical tree cutter could be developed to operate in areas just prior to seasonal flooding or even in constantly flooded areas such an approach may be more effective than herbicide treatments.

Treatment Costs

Treatment costs for the project from 1986 to 1993 are summarized in Table 9. From 1986 to 1993 approximately 3,844,000 melaleuca and 90,000 casuarina stems have been treated in the East Everglades at a cost of \$546,241 for helicopter services and herbicides. The total labor over the same period was 14,364 hours or 1795 person-days. The total person hours for 1993 was 2,252. This is a 42% decrease over 1992 as a result of the shortened season and use of only one seasonal crew due to Hurricane Andrew. The total helicopter flight time for 1993 was 216 hours at a cost of \$93,553. We exceeded the guarantee flight hours (150) by 66 hours. This was due to the increase in daily flight survey lines and additional flight time to transport a three-man Student Conservation Association (SCA) crew for ten weeks.

Table 9. Treatment costs and labor hours for melaleuca and casuarina treatment in the east Everglades by year 1986-1993.

YEAR	FLIGHT COST \$	HERBICIDE COST \$	COST/YR.	LABOR NPS-HRS	LABOR NON-NPS	TOTAL HRS/YR.
1986	2,261	3	2624	32	32	64
1987	12,965	187	13,152	224	336	560
1988	25,495	556	26,051	708	48	756
1989	55,198	442	55,640	926	442	1,368
1990	70,451	788	71,239	1,419	112	1,531
1991	111,053	7,744	118,797	2,755	72	2,827
1992	146,295	7,400	153,695	4,942	64	5,006
1993	93,553	11,540	105,093	2,252	1160	2,252
TOT.	517,631	28,660	546,291	12,258	2,266	14,364

7. LEE COUNTY

The Lee County Board of County Commissioners has supported the USDA biocontrol program financially. The County has an eight person land management division which was funded from operating funds. This division was eliminated due to changes in priorities and budget cuts. The County now has 2 staff who spend a significant portion of their time on exotic plant control on County preserves and parks.

Capital funding for specific projects has been allocated in the past, and staff will continue to pursue funding of this type. Specifically, \$250,000 is allocated for the contract Lee County has with the Florida Division of Forestry for exotic control and reforestation in one area and an additional \$70,000 will be used for exotic control to be done by a private contractor in other areas

8. PALM BEACH COUNTY

The City of West Palm Beach in conjunction with the Northern Palm Beach County Water District has been involved in mitigation due to the widening of Lake Park Road. Part of the mitigation has been the eradication of 138.5 acres of melaleuca monocultures in the City of West Palm Beach Water Catchment Area (WCA). The project was awarded to a contractor and commenced in the WCA on December 14, 1992 and was completed March 3, 1994.

The contractor used the herbicide ARSENAL (EPA experimental use permit No. 464-EUP-87). The primary methods of application was the frill or girdle on mature trees and cut stump treatment method was used when frill and girdle was not possible. Hand pulling of small trees and seedling was also used. It was found that if the target tree did not have the chemical applied within approximately one hour after the frill and girdle or cut stump method, it's effectiveness was greatly reduced with regrowth appearing within sixty days.

Upon completion of this contract our estimates indicate that a total of approximately 970,000 trees in the 138.5 acres will be eliminated. Also we have eliminated approximately 900,000 outlier being described as singular or groups of less than fifty trees outside the monoculture areas.

The contractor has the obligation of maintaining this 138.5 acres for a period of one year after the completion date of the contract. The Northern Palm Beach County Water District has the obligation to maintain the 138.5 acres for an additional four years under a maintenance contract. The City of West Palm Beach will have the responsibility to monitor these ongoing maintenance agreements and to eradicate the remainder of the melaleuca trees in the WCA, using the approved treatment and application methods described above.

9. SOUTH FLORIDA WATER MANAGEMENT DISTRICT

The approach for managing melaleuca throughout the South Florida Water Management District was originally recommended by the Melaleuca Task Force in January of 1990. Melaleuca management strategies developed by the MTF were first implemented by the District in WCA-3B in November of 1990. These strategies involve the integration of all available methods: biological, herbicidal, mechanical and physical.

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.

Management Strategy

At present the District's melaleuca program is not truly integrated. Biological control agents are not yet available, consequently, the initial efforts in developing melaleuca control methods have been concentrated around herbicidal control, and limited use of physical and mechanical control methodologies. Melaleuca management strategies are based on the quarantine strategy described by Woodall (1980). The least infested areas are addressed first, in order to stop the progression of the current infestations. The District's control operations consist of three phases:

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

Phase II In this phase, previously treated sites are revisited for follow up treatment to remove seedlings previously missed or which may have resulted from control activities of the preceding year.

Phase III This phase entails the long term management of melaleuca with the eventual introduction of biological control agents. It also involves the surveillance and inspection of previously treated sites to monitor the effectiveness of the melaleuca control program.

The girdle application method with the herbicide ARSENAL is the primary tool used on mature trees. Based on previous experience, herbicide applied with the hack and squirt method does not completely kill the tree. The bark around the circumference of each tree is completely removed, with a machete, to expose the cambium for squirt application of the herbicide. Other herbicides and methods of application are also used for melaleuca control. The use of a particular combination of herbicide and application method depends on the condition of the site (wet or dry) and density of melaleuca trees being treated. Herbicides such as VELPAR L and SPIKE 40P are very effective, although, they can only be used when a site is completely dry. Aerial application of pellet formulation of these two herbicides are more cost effective however, effects on non target vegetation must be considered. Aerial applications of SPIKE 40P, VELPAR L, GARLON 3A, ARSENAL, and combinations of ARSENAL and RODEO have been used on an experimental basis only. As more information is generated from these experimental trials, this type of application will be used essentially in large areas of melaleuca monoculture. The Cut/Stump application of ARSENAL or RODEO is also very effective, but remaining stumps may create a navigation hazard for airboat traffic when the march is wet. This type of application is used only on trees with base stem diameter of less than two 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 possibility of regrowth. Back-pack application of ARSENAL or VELPAR L is sometimes used to control melaleuca seedlings in dense monoculture.

Whatever control methods are used, whether it is biological, mechanical, herbicidal, or physical, a comprehensive data collection and evaluation plan is essential for the success of melaleuca management in south Florida. Record keeping is invaluable for making future management decisions. Data collection in the District's melaleuca control 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 acres treated at each site and, labor and equipment hours. Since the creation of the melaleuca task force, the District has initiated several melaleuca control projects, primarily in the WCAs and Lake Okeechobee.

WCAs Control Operations

Preliminary recommendations for melaleuca management in the WCAs were made by the WCA Melaleuca Interagency Steering Committee (WCAMISC) which was formed in October of 1990, to address the problems encountered during the onset of the project. The WCAMISC was composed of a group of professionals, knowledgeable in melaleuca management, from the Game and Fresh Water Fish Commission, the Department of Environmental Protection, the Florida Division of Forestry, the District and Florida Power and Light. However, the District oversees all aspects of melaleuca control operations. Melaleuca occurs throughout all the WCAs with degrees of infestation ranging from ten to greater than five thousand trees per acre. WCA-2B is densely infested, while WCA-3A and 3B are moderately infested and WCA-2A is the least infested area (Figure 8). The melaleuca control project began at the south-east corner of WCA-3B in November of 1990. The work proceeded northward through WCA-3B and 3A south (Figure 8).

Depending on accessibility and remoteness of control sites, a helicopter, and/or airboats, and/or all terrain vehicles are used to transport crews and supplies. Once on the ground, these crews perform melaleuca treatments with the use of the appropriate method of herbicide application as described above. Crews may consist of three to eight people, depending on the density of melaleuca infestation at the site being treated.

From November 1990 to January 1994 approximately 2,240,063 trees and 17,027,37 seedlings have been eliminated within WCA-3A south and 3B (Table 10). Melaleuca control is also performed along all canal bank and levees of the WCAs. Aerial treatment applications in the WCAs are performed only for experimental purposes. The district in cooperation with various other agencies has been investigating the use of several herbicides (ARSENAL/RODEO, ARSENAL/GARLON A, GARLON 3A, SPIKE 40P and VELPAR L) for future use on large monoculture of melaleuca. Total expenditures for melaleuca control in the WCAs are listed in Table 11. Control efforts are continuing in WCA-2A and phase I work will begin in WCA-3A north during fiscal year 94 (Figure 8).

Figure 8- Melaleuca infestation and control efforts to date in the Water Conservation Areas and Lake Okeechobee.

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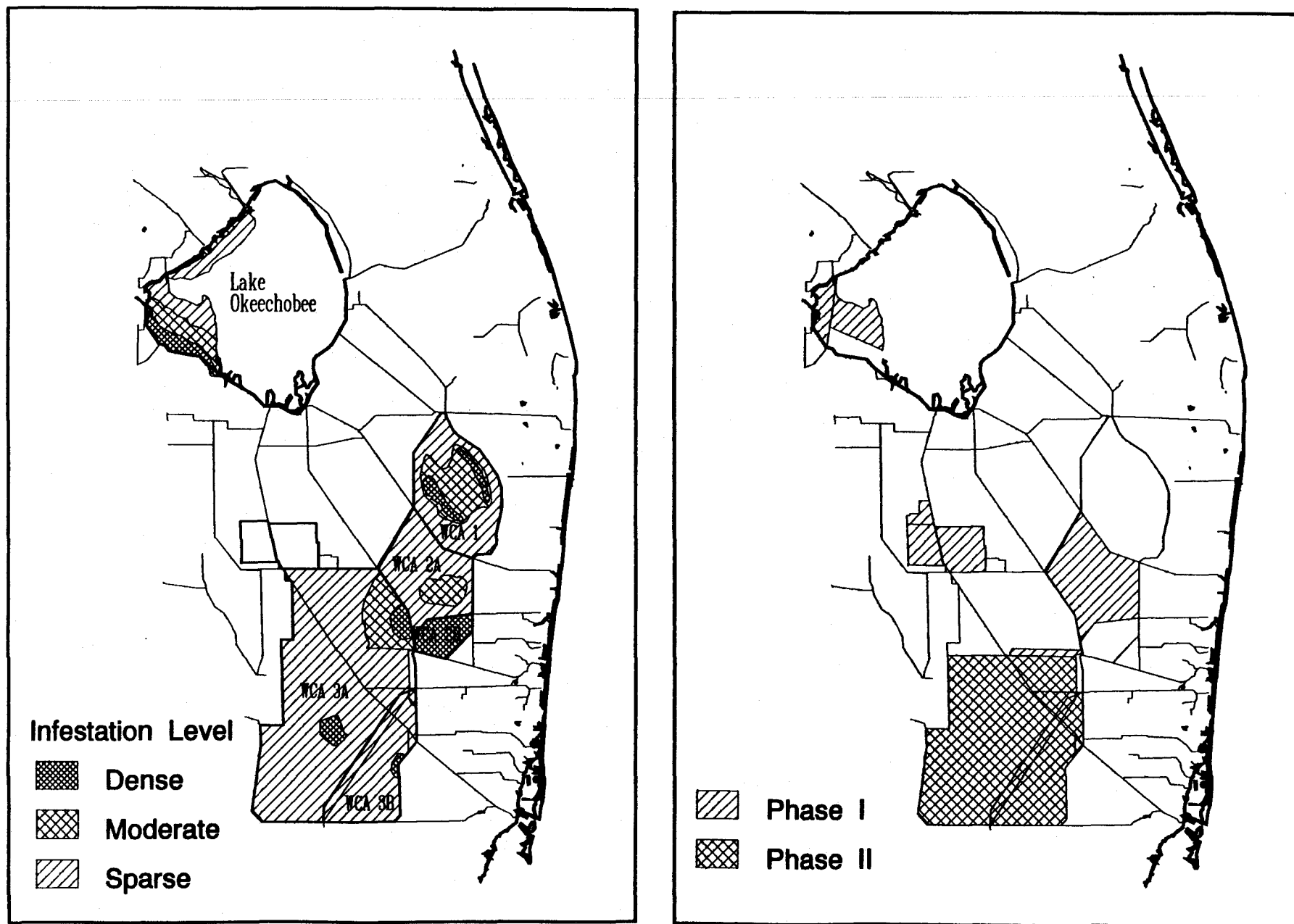


Table 10. Melaleuca control summary in the Water Conservation Areas and Lake Okeechobee.

FY	TREES	SEEDLINGS	LABOR	COST/PLANT	TOTAL COST
WATER CONSERVATION AREAS					
91	156,001	1,103,073	3,970 h ¹	\$3.33 - \$0.41 ²	\$519,885
92	388,324	547,448	8,775 h	\$1.75 - \$0.73	\$678,661
93	1,391,095	12,142,900	26,241 h	\$0.65 - \$0.07	\$899,690
94 ³	304,643	3,233,956	10,579 h	\$0.77 - \$0.07	\$234,316
LAKE OKEECHOBEE					
93	523,461	1,134,468	9,292 h	\$0.40 - \$0.07	\$211,159
94 ³	420,713	689,769	7,119 h	\$0.39 - \$0.15	\$162,132

1 labor hours 2 cost per mature trees - cost per trees and seedlings
3 as of January 1994

Table 11. South Florida Water Management District melaleuca management expenditures.

PROJECT	FY91	FY92	FY93	FY94 ¹
WCAs	\$614,437	\$823,552	\$1,044,457	\$234,316
Lake Okeechobee	---	---	\$211,159	\$162,132
Biocontrol	\$75,000	\$75,000	\$125,000	\$195,000
Program Support ²	---	<u>\$75,000</u>	<u>\$135,000</u>	<u>\$135,000</u>
TOTAL	\$689,437	\$973,552	\$1,515,616	\$726,448

1 as of January 1994

2 support to Loxahatchee Wildlife Refuge and Everglades National Park

Funding for melaleuca control in the Water Conservation Areas are derived from all the sources listed in Table 12, except SWIM funds. SWIM funds are used in Lake Okeechobee only.

Table 12. South Florida Water Management District melaleuca management funding sources.

SOURCE	FY91	FY92	FY93	FY94
DEP ¹	---	---	---	\$400,000
SWIM	---	---	\$200,000	\$200,000
SWIM contingency	\$300,000	---	---	---
FP&L	\$500,000	\$500,000	\$500,000	---
District ad valorem	<u>\$155,000</u>	<u>\$295,000</u>	<u>\$855,000</u>	<u>\$885,000</u>
TOTAL	\$955,000	\$785,000	\$1,555,000	\$1,485,000

1 Department of Environmental Protection

Lake Okeechobee Control Operations

Melaleuca was originally introduced on Lake Okeechobee by the U.S. Army Corps of Engineers in the late 1930s. These fast growing, fire and flood tolerant 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 has now spread into many thousands of acres of marsh in the lake.

There are 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 main area of infestation includes the shallow marsh region of the lake where trees have spread lakeward. Melaleuca infestations in the outer marsh typically consist of outliers and small heads of varying ages.

Melaleuca control operations on Lake Okeechobee began in early August 1993. Preliminary recommendations for the control of melaleuca at Lake Okeechobee were made by the Lake Okeechobee Melaleuca Advisory Committee (LOMAC). This group

includes representatives from the South Florida Water Management District, Florida Department of Environmental Protection, U.S. Army Corps of Engineers, U.S. Fish and Wildlife, Florida Division of Forestry, and the Florida Game and Fresh Water Fish Commission.

The goal of the melaleuca management program on Lake Okeechobee is to effectively manage the tree by first containing, then progressively reducing populations within the littoral zone. To date, significant headway has been made on the outlier trees west of the Moore Haven cut; 523,461 trees and 1,134,468 seedlings have been treated in the area. Crews have now moved east of the cut, controlling outlier trees and heads in the outer marsh; 420,713 trees and 689,769 seedlings have been controlled in this area to date. This program is primarily a 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 1,300 acres of mature melaleuca has been treated aerially at Lake Okeechobee.

Other Projects

The District provides financial support to the USDA Melaleuca Biocontrol project and to other melaleuca management project at the Everglades National Park and the Loxahatchee Wildlife Refuge (Table 11). In an effort to educate the public, the District, in cooperation with other agencies, organizes volunteer days for melaleuca elimination.

The strategy for managing melaleuca is modified as control methodologies are developed which improve efficacy and cost effectiveness. The District has been actively involved in the investigation of control methods for mature and seedling trees. This investigative research needs to continue to improve control methods and reduce control cost.

CONCLUSION

The ultimate control of melaleuca in Florida will probably depend on the success of biological control agents introduced from Australia. 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 cost 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 general control method.

Work progresses to control melaleuca throughout south Florida, especially on state and federal lands. In the past 20 years, many scientists and informal coalitions of concerned citizens have highlighted the severe threat by the uncontrollable spread of melaleuca. 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 to form a state and federal interagency Melaleuca Task Force to draw upon the experience of the area's scientists, resource managers, the Exotic Pest Plant Council, and others to develop a regional melaleuca management plan. This Task Force brought much needed coordination to melaleuca management and focused attention on funding, public awareness, and legislative needs. This coordination of effort must continue if there is to be long-term control of melaleuca in south Florida.

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 preparation requirements for successful recruitment of indigenous or planted vegetation 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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