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TECHNICAL MEMORANDUM

THE FUNCTIONALITY OF MELALEUCA-DOMINATED WETLANDS IN SOUTH FLORIDA:

A CRITICAL REVIEW OF SCIENTIFIC LITERATURE

by

Douglas T. Shaw
and
Kimberly J. Jacobs

April 1996

Resource Assessment Division
Water Resources Evaluation Department
South Florida Water Management District
West Palm Beach, Florida

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EXECUTIVE SUMMARY

A critical review of published scientific studies of environmental and water resources functions of melaleuca-dominated wetlands was conducted to support District rulemaking and provide background for upcoming legislative action. The scientific information on melaleuca-dominated wetlands is sketchy and has been confined mostly to portions of the South Florida Water Management District's (District) lower east coast region. Nevertheless, the literature indicates that even wetlands heavily infested with melaleuca continue to provide important residual functions that must be considered when determining mitigation requirements. No evidence could be found to support assertions that a wetland's functional capacity drops to zero or that the ecosystem "crashes" when melaleuca coverage exceeds 75 percent. Melaleuca invasion does lead to decreased plant community diversity and obvious changes in the physical structure of the habitat. However, understory plants associated with melaleuca typically include a variety of wetland obligates and some protected species. Studies in Dade County suggest that while the quality of wildlife habitat for native, wetland-dependent animals may decline with increasing melaleuca coverage, utilization of melaleuca by other types of wildlife increases or remains constant. Mature melaleuca often provides nesting and feeding sites for native wading birds, raptors, winter-resident song birds, and breeding populations of small mammals and reptiles, including many listed species, especially when suitable native habitat is limited. Wildlife utilization of melaleuca appears to be strongly influenced by the surrounding land use, suggesting that site-specific information may be needed to make a final assessment of wetland functionality to determine mitigation requirements. Information on melaleuca impacts to hydrologic functions of wetlands is inconclusive. Conventional wisdom suggests that where melaleuca invades marsh or wet prairie, water losses due to transpiration and interception may increase. However, previous studies have failed to confirm this in the field, and no information could be found that relates potential changes in hydrology to changes in the water resources functions of wetlands. Additional information on understory vegetation and hydrology in melaleuca-dominated wetlands, and wildlife utilization of melaleuca in pine-cypress settings is considered a critical prerequisite to District rule development.

INTRODUCTION

This document is the product of a request by the Natural Resources Management Division of the Regulation Department for a critical review of scientific literature pertaining to the functionality of wetlands in south Florida invaded by the exotic tree *Melaleuca quinquenervia* (Cav.) Blake ("melaleuca"). The request was in response to a bill, referred to as the Melaleuca Control Act, which was considered during the 1995 state legislative session, that would have waived mitigation requirements for alteration of wetlands containing greater than 75% melaleuca cover. Although this bill failed to pass during the 1995 legislative session, a revised version is currently in committee and is expected to be introduced during the 1996 session. In anticipation of the bill's passing, the District Governing Board in January, 1996, authorized the Regulation Department to initiate rulemaking to provide incentives for removing melaleuca on private land and to establish "...mitigation ratios based on percent coverage of melaleuca in wetlands." (SFWMD, 1996). It is anticipated that criteria for determining mitigation ratios will need to be based on easily-estimated indices of melaleuca impact such as percent cover, tree density, or degree of canopy closure, and will also depend on the type of wetland impacted and the nature of surrounding landscape.

Despite the millions of dollars spent on melaleuca control since the mid-1980's, melaleuca has now become a prominent, and perhaps permanent, feature of wetlands in many parts of the District. It is estimated that melaleuca is now present on over 500,000 acres of wetlands in south Florida and that from 25,000 to 50,000 acres of this total are considered to be monospecific stands of the tree (Ferriter, 1994). Most of the scientific effort to date has appropriately focused on documenting the spread of melaleuca in south Florida and methods for controlling melaleuca invasion. By comparison, little formal effort has been directed at a thorough documentation of the effects of melaleuca on wetland functions and values such as wildlife habitat, flood storage, aquifer recharge, and water quality improvement. The intent of this review is not to refute past observations of detrimental impacts to wetlands caused by melaleuca infestation, but rather to shed light on those functions and values still remaining after melaleuca becomes dominant and to identify needs for additional study to support District rulemaking. It is the position of the District that, although a wetland may be heavily infested with melaleuca, it still provides some residual value to wildlife and water resources that must be considered when assigning mitigation ratios. In addition to its relevance to District rulemaking, information presented in this review will also likely have some bearing on planning for the Northwest Dade County Lake Belt project, on wetland mitigation banking, and on the status of private lands in state and local environmentally-sensitive lands inventories.

METHODS

Initial lists of publications relevant to this project were obtained from a computer bibliographic search conducted by the SFWMD Reference Center using the Dialog software system. Information on literature databases searched and keywords used can be found in Appendix 1. The articles and reports identified in the search were obtained for review either from the shelves or reprint files of the Reference Center, through inter-library loan, or directly from the author or agency responsible for the publication. Additional relevant publications cited in the bibliographies of the articles found in the computer search were also obtained where possible. By repeating this process for all articles obtained, we feel that virtually all of the available published matter relevant to the functionality of melaleuca-dominated wetlands was obtained and reviewed.

For the most part, the review was confined only to those results, data, and conclusions reported by the author(s) of a given publication. Summaries of this information for each article reviewed are contained in Appendix 2. However, in some cases, data reported in publications were re-analyzed to obtain additional statistics or results were re-interpreted in light of additional information obtained for the review. Visits by the authors of this review to study sites referred to in publications and follow-up conversations with publication authors and project managers were used to clarify certain details reported in some of the publications and to obtain updates of work completed since the date of publication.

Of the many articles in print on melaleuca in south Florida wetlands, most focused on control practices and needs or projections of spread and potential impacts of melaleuca invasion. Only a very few articles document controlled scientific studies of the functionality of melaleuca wetlands, and even fewer directly relate functionality to cover or density of melaleuca stands. Most articles with relevant information are cited and discussed in the review that follows, and all relevant publications are summarized in Appendix 1. The majority of the relevant citations were derived from four major research programs conducted since the late 1970's. Much of the early information (late 1970's and early 80's) on wildlife use and hydrologic processes in melaleuca wetlands was conducted as part of the U.S. Forest Service/Florida Division of Forestry Melaleuca Research Program based in Lehigh Acres, the wildlife research program at the University of Florida-IFAS research center in Broward County, and wildlife assessments of tree islands in the Everglades Wildlife Management Area conducted by the Florida Game and Freshwater Fish Commission. Additional studies were conducted during this period by researchers at the University of Florida-Gainesville and the University of Miami, though many of these were never published in the open literature. The most recent and comprehensive information on wildlife functions in melaleuca wetlands was obtained through several interrelated research efforts conducted as part of the Dade County Lake Belt planning effort for Metro-Dade Department of Environmental Management. As of this writing, the initial two-year studies for this project have just been completed, and a final report synthesizing the results of all of the field studies is pending. This review utilized cumulative information contained in the most recent quarterly reports for the separate field projects. Additional studies involving the hydrologic functions of melaleuca wetlands in the Lake Belt planning area are expected to be initiated during the coming year.

LITERATURE REVIEW

Geographic Scope of Melaleuca in South Florida Wetlands

In south Florida, melaleuca has invaded many wetland and transitional habitats, but is most prevalent where soils remain moist to saturated, but rarely submerged, during the summer wet season (Myers, 1983). Natural wetland habitats satisfying these conditions include seasonally wet prairies and sloughs, shallow depressional wetlands in pine flatwoods, tree islands or hydric hammocks, wet flatwoods, the transitional ecotone between pine forest and cypress swamps, and other wetlands that have been artificially drained. Scattered individuals or stands may occur on many other kinds of wetlands (long-hydroperiod marshes, mangrove swamps) when favorable conditions occur, but the tree will rarely become dominant on such sub-optimal sites (Myers, 1983).

The latest estimates indicate that melaleuca is concentrated in five major areas of south Florida (See Fig. 1; from Thayer, *et.al.,*1994):

1. The eastern portions of the Water Conservation Areas and the relict wet prairies between the coastal ridge and the historic Everglades in Dade, Broward, and Palm Beach Counties;

2. Wet flatwoods in the northern portion of the Loxahatchee Slough and the Pal-Mar region of northern Palm Beach and southern Martin Counties;

3. The southwest shore of Lake Okeechobee in Palm Beach and Hendry Counties;

4. Wet prairies in the Big Cypress National Preserve along the Tamiami Trail in eastern Collier County;

5. Wet flatwoods and the periphery of cypress swamps in a band extending from north of Fort Myers in northern Lee County to Naples in northern Collier County.

A substantial portion of this total acreage is on public lands, relatively free from development pressure. However, three areas comprising two different ecosystem types are particularly vulnerable to development, and are therefore highly relevant to this review. These areas consist of:

1. The lands between the Conservation Areas and the urban core of the southeast coast, referred to in this review as the "East Everglades." Development pressure in this region is primarily from limestone rock mining in Dade County and suburban encroachment from the east;

2. The pine flatwoods and cypress lands in the upper east and lower west coast regions, comprising (2) and (5) above. Though these two distinct areas of flatwoods and swamp are not contiguous with each other, they are structurally and ecologically similar, and can be treated as a single landscape type for discussion purposes. Development pressure in both areas is largely from suburban expansion.

Each of these areas contains a characteristic assemblage of natural wetlands and associated wildlife and landscape features. Most of the literature reviewed below has concentrated on the East Everglades in Dade County, along with a few additional studies of melaleuca-dominated wetlands in the Water Conservation Areas and in the pine-cypress landscape of Lee County.

Invasion of melaleuca into one of these native wetland habitats is said to decrease the ability of the affected wetland to perform functions beneficial to the environment. It has been observed that as melaleuca invades a wetland, the structural characteristics of the habitat may change and native vegetation may be displaced or eliminated, thereby decreasing the utility of the site for native wildlife (Pritchard, 1976; Austin, 1978; Hofstetter, 1991; Schmitz and Hofstetter, 1994). This assertion has been demonstrated for certain categories of wildlife only in the East Everglades. It has also been asserted that as a melaleuca stand becomes established on a site, the hydroperiod and the magnitudes of components of the water budget may change, potentially affecting the hydrologic or water resources functions of the wetland (e.g., Schmitz and Hofstetter, 1994). Evidence in support of this conventional wisdom is largely anecdotal and of limited value to District rulemaking.

Wetland Functions

An assessment of the value of wetlands containing melaleuca must focus on the residual functions provided by such wetlands relative to those of unaffected natural wetlands. **wetland functions** are "the actions that are naturally performed by wetland ecosystems, or simply the things that wetlands do" (Trott, *et al.*, 1996). Wetland functions are a net result of the interaction between landscape position, ecological processes, and biota and may include both "services" that contribute to the quality of human life and functions that sustain a characteristic flora and fauna. State and federal regulations specifically list habitat for fish and wildlife resources, biological productivity, nutrient exchange, water quality improvement, aquifer recharge, flood storage, flow stabilization, production of agricultural products and timber, recreation, scientific and aesthetic resources as wetland functions of the highest value (40CFR, 230.41(b); Executive Order 11990, FS 403.918(2)). Many of these functions are the inherent result of a characteristic wetland hydrology and biota. Instead of focusing directly on the "external" services provided *by* wetlands, the U.S. Army Corps of Engineers propose a list of "internal" processes sustained *in* wetlands that enable them to provide functions of value to the environment. The Corps' list for south Florida wetlands includes: (1) maintenance of typical wetland hydrology; (2) nutrient, element, and compound cycling; (3) maintenance of a characteristic plant community; (4) maintenance of the distribution and abundance of vertebrates and invertebrates; (5) maintenance of the spatial structure of the habitat; and (6) maintenance of the interspersion and connectivity for faunal species (Trott *et al.*, 1996).

Trees in wetlands are strongly linked to important ecological functions, including habitat functions and nutrient and carbon cycling through uptake, litterfall, and production of detritus. Important habitat functions of wetland trees include providing wet season refugia for terrestrial animals; providing cover, nesting, and roosting sites for wetland and wintering forest birds, and providing increased structural diversity within the landscape.

In this review, only those functions related to the environmental protection and water resources missions of the District are considered. Accordingly, the remainder of the literature review is organized into sections reviewing published studies of *vegetation community composition, structure, and Succession* (including Corps functions 3 and 5 listed above), *wildlife functions* (including Corps functions 4 and 6), and *hydrologic functions* (including Corps functions 1 and 2) of melaleuca infested wetlands. Additional information on economic and aesthetic functions of wetlands can be found in Schmitz and Hofstetter (1994), Flowers (1991), Huffman (1981), Geary, *et al.* (1981), and Robinson (1981).

Vegetation Community Composition, Structure, and Succession

Despite the wholesale changes that can occur in plant community structure when melaleuca invades wetland communities, there have been few published studies of plant succession in affected wetlands. The structural change that occurs as a prairie of one-meter tall sawgrass and other herbaceous species succeeds to a 10 to 20-meter tall forest of dense melaleuca trees is obvious. Many observers have remarked on the change in structure in terms of its affects on human mobility, but few have specifically investigated the link between structural changes and changes in food webs or cues used by wildlife to select among habitats. Myers (1986) and Duever, *et al.* (1979) observe that the seasonally wet pine-cypress ecotone often invaded by melaleuca in the lower west coast may be undersaturated with native plant species and may have no distinct native plant community to begin with. Myers (1986) postulates that in the absence of competition from well-adapted native vegetation, pond cypress (*Taxodium ascendens*) has historically spread from more optimal sites into the sub-optimal wet prairie zones surrounding baldcypress (*Taxodium distichum*) swamps. Invasion of melaleuca into these same zones has had the effect of compressing pond cypress back into the wetter side of its habitat, to which it appears better adapted (Myers, 1986).

Austin (1978) asserted, based on an unpublished student project, that plant diversity decreased 60-80% in wet prairie systems following invasion by melaleuca. It is presumed that Austin's observations were made in mature melaleuca stands, as others have observed that during the early stages of invasion, plant community diversity increases above that of native wet prairies and marshes (Ostrenko, *et al.*, 1979; Dalrymple and Dalrymple, 1996). Richardson (1977) combined intensive field inventories with comparisons of historical and recent aerial photography to reconstruct pre-drainage plant communities and document community changes in coastal Palm Beach County. He noted that in areas where melaleuca had become established in wet prairie communities, native species of the genera *Sagittaria*, *Hypericum*, and *Stillingia* were completely eliminated. This decrease in diversity is presumably due to a combination of the superior reproductive and growth characteristics of melaleuca versus native plants, shading of herbaceous species by dense melaleuca canopy, and possible allelopathic effects of melaleuca on other species.

DiStefano (1981) noted that melaleuca stands were often associated with a reduced or absent understory and hypothesized that melaleuca may have an allelopathic effect on other plants. Results of greenhouse studies to investigate this potential were inconclusive, though DiStefano asserted that allelopathic suppression of some species, notably pines, is possible. DiStefano's own field inventories of melaleuca stands in the lower west coast indicated that while species such as cypress (*Taxodium spp.)*, laurel oak (*Quercus laurifolia*), cabbage palm

(*Sabal palmetto*), wire grass (*Aristida spp.*), *Panicum* species, and saw palmetto (*Serenoa repens)* appeared to be suppressed, possibly due to competition with melaleuca, mature stands are often associated with the wetland saw fern *Blechnum serrulatum*, cabbage palm, air plants of the genus *Tillandsia*, and as many as twenty-two other native species, many of them wetland plants.

Similarly, Alexander and Hofstetter (unpublished data, cited in Schmitz and Hofstetter, 1994) observed complete displacement of native species in the genera *Andropogon, Eragrostis, Eupatorium, Rhynchospora, Cladium, Panicum, Pluchea, Erianthus*, and *Setaria* in some melaleuca-dominated wetlands, but also noted that as the melaleuca stands matured they tended to thin from around 100,000 trees per acre to about 5000 trees per acre. A similar self-thinning process has been observed to occur in both temperate and tropical forest stands throughout the world. The authors noted that there is as yet "no clear successional trend to indicate replacement of melaleuca," but as the canopy thins and more sunlight penetrates, a sparse understory of saw fern, royal fern (*Osmunda regalis*), maiden fern (*Thelypteris spp.*), giant leather fern (*Acrostichum spp.*), sawgrass (*Cladium jamaicense*), wild coco (*Eulophia alta*), buttonbush (*Cephalanthus occidentalis*), and pond apple (*Annona glabra*) appears. Most of these are obligate wetland species, and all are considered facultative wetland species or wetter. Observations by District staff (Shaw and Mortellaro, 1996) confirm that mature melaleuca stands often have a native understory of ferns, saw palmetto, cabbage palm, and sawgrass, as well as epiphytes growing directly on melaleuca trunks.

The changes in vegetation structure and composition observed as melaleuca invades wetlands are often cited as being detrimental to native wildlife dependent on the wetland (e.g., Pritchard, 1976). Several of the studies reviewed in the next section give evidence that as wet prairie communities are succeeded by melaleuca forests, the composition of bird species changes from a community dominated by birds adapted to open shallow-water environments to a community with a large proportion of woodland songbirds (e.g., Dalrymple and Dalrymple, 1995b; 1996). Wetland birds and some raptors will use adjacent trees of any type as perches to spot prey, as cover, or as resting areas. Similar changes might be expected when, for example, a marsh succeeds to a willow swamp or a wet prairie is invaded by native pond cypress. However, in studies of small mammals in melaleuca stands, Mazzotti, *et al.* (1981) concluded that low understory species richness alone does not determine rodent distribution and abundance, and Sowder and Woodall (1985) concluded that "utilization of a particular melaleuca habitat by small animals may depend more on the ecosystem within which it is located than on the vegetation characteristics within the habitat." These and other studies of wildlife utilization of wetlands at different stages of invasion by melaleuca are reviewed in the next section.

<u>Gaps in Research and Implications for Rulemaking.</u>

The few published surveys of melaleuca-infested wetlands in south Florida suggest that while many species of native plants may be displaced or eliminated, some native wetland vegetation persists in the understory of melaleuca stands, even in areas with mature trees and a high degree of canopy closure. Most of the studies cited above provided species lists only.

These published species lists could be supplemented with additional information from District permit application files and environmental assessments of sites containing melaleuca. However, no systematic surveys of understory vegetation in melaleuca stands has been conducted to date, and quantitative data on understory diversity and abundance as a function of melaleuca cover are scarce (Dalrymple and Dalrymple, 1995a). Because many of the plants noted as occurring in association with melaleuca are either wetland obligates or are protected under state law (e.g., air plants and some ferns), it is crucial that such surveys be conducted prior to developing mitigation rules for melaleuca-dominated wetlands.

The successional patterns of plant community change in wetlands invaded by melaleuca are not well known. Although canopy thinning has been observed to occur in mature melaleuca stands that allows for a more dense understory, it is not known whether these changes are short-lived or permanent. As yet, there is little evidence to indicate that melaleuca are being replaced by other vegetation in the oldest stands, but whether the canopy thins to the point that native vegetation begins to achieve a measure of co-dominance remains to be seen. Some observers have noted that successional processes in melaleuca stands may change topographic and hydrologic conditions of the original wetlands (Schmitz and Hofstetter, 1994), but there has been no systematic long-term tracking of succession in melaleuca stands to verify this observation.

Wildlife Functions

Early and well-founded fears over the rapid spread of melaleuca into south Florida wetlands led to the commonly heard assertion that melaleuca creates a "biological desert, hostile to all but a few of the most adaptable of Florida's creatures" (Pritchard, 1976). Bancroft *et al.* (1992) also speculate that spread of melaleuca could limit important habitat for native wildlife, including threatened and endangered species. However, subsequent study has demonstrated that although utilization of wetlands by some kinds of wildlife decreases after melaleuca becomes established, melaleuca-dominated wetlands can hardly be considered a "biological desert," and melaleuca value to wildlife depends strongly on the nature and condition of surrounding lands.

Schortemeyer *et al.* (1982) in a two-year study of melaleuca-infested tree islands in the Everglades Wildlife Management Area (Water Conservation Areas 2 and 3) documented species and numbers of individuals observed during general wildlife surveys, nesting surveys, small mammal trapping, and fish sampling. Nearly all of the 19,726 individuals and 45 species observed during wildlife surveys were birds. All birds observed were species common to the Everglades, and the top 90% of sightings (in terms of frequency of observation) consisted of: tree swallows, cattle egrets, anhingas, black vultures, turkey vultures, Everglades kites, American coots, red-winged blackbirds, great blue herons, boat-tailed grackles, and double-crested cormorants. Observations included ten species listed as threatened, endangered, or species of special concern by the Florida Game and Fresh Water Fish Commission (FGFWC, 1990), including American alligator, little blue heron, Everglades kite, tri-colored heron, limpkin, northern harrier, snowy egret, American kestral, and wood stork. Most of the listed species were observed in low numbers, with the exception of the endangered Everglades kite, with 812 observations reported.

Over 75% of observations by Schortemeyer *et al.* (1982) were of incidental uses of melaleuca heads, typically involving wildlife either traveling by or entering and leaving the head. Roosting or perching was the most common "contact" activity reported, with about 15% of all observations. Of the eleven most frequently observed species listed above, only one, the American coot, made *more* direct use than incidental use of melaleuca. However, four of the five most frequently observed species did make *some* direct use of melaleuca, usually as a resting or loafing site. Surveys also identified ten species as nesting in melaleuca habitat, including anhingas, great blue herons, great egret, cattle egret, black-crowned night heron, green-backed heron, wood stork, cormorant, and Everglades kite. Mammal trapping was largely unsuccessful. Fish sampling yielded nine species in melaleuca, compared with an average of over 12 species in adjacent non-melaleuca habitat. Total fish biomass and densities were considerably higher in non-melaleuca habitats than in melaleuca, but this may be attributable to differences in water depth.

Unfortunately, the study of Schortemeyer *et al.* (1982) offers little in the way of comparison with uninfested tree islands or other native habitats. The sites chosen for this study were, for the most part, tree islands where native vegetation had been virtually destroyed by high water levels in the 1960's and 70's, leaving melaleuca the dominant surviving woody vegetation. Many of these sites were chosen because of previous observations of high wildlife usage. The authors speculated that melaleuca heads offered a suitable alternative in an area where native tree island habitat was limited. They also suggest that the wildlife value of melaleuca at a given site may be largely derived from that of adjacent native cover types. They note that though the tree islands themselves were heavily infested with melaleuca, the percentage of melaleuca in the landscape as a whole was very low.

Mazzotti and colleagues (Mazzotti *et al.*, 1981; Ostrenko and Mazzotti, 1980; Ostrenko *et al.*, 1979) studied small mammal occurrence in a variety of melaleuca habitats ranging from mature forest-like melaleuca heads to native graminoid communities with minimal occurrence of melaleuca. All sites were located in the northern portion of Everglades National Park, just south of the Tamiami Trail in Dade County. The researchers documented resident breeding populations of the native cotton mouse, *Peromyscus gossypinus,* in mature melaleuca heads, and the rice rat, *Oryzomys palustris,* was observed in both mature stands and mixed melaleuca-graminoid habitats. The cotton rat, *Sigmodon hispidus*, was also trapped in mixed habitats, but was primarily associated with the graminoid portion of the habitat. One of the papers (Ostrenko *et al.*, 1979) reported that *Peromyscus* and *Sigmodon* apparently went locally extinct or moved to other locations during the wet season, suggesting that the proximity of melaleuca to wet season refugia may be important. However, this observation was not reported in the later papers and may have been simply a reflection of the difficulty in trapping during the wet season. A total of 21 animal species (16 vertebrates and 5 invertebrates), including the "rare" short-tailed shrew, *Blarina carolinensis*, were found in association with mature melaleuca forest (Ostrenko *et al.*, 1979). The authors also cite some indirect evidence that rodents were being taken by predators in melaleuca habitats (Ostrenko and Mazzotti, 1980). The authors noted that rodent densities were low in melaleuca, compared with published accounts for native hammocks, but others (e.g., Sowder and Woodall, 1985) have noted that this difference could be due to differences in hydrology or availability of wet season refugia. In any case, Mazzotti *et al.* (1981) concluded that melaleuca habitat cannot be "intuitively classified as biological deserts."

Sowder and Woodall (1985) attempted to repeat Mazzotti's work in the pine-cypress landscape of Lee County, but abandoned their efforts after only one week when trapping yielded extremely low numbers of rodents. These authors concluded that rodent usage is low in both melaleuca and native cypress (at least at their study sites) and that utilization of a melaleuca habitat may depend more on the ecosystem within which it is located than on the structural characteristics within the habitat itself. The Sowder and Woodall study, despite its obvious limitations, was the only publication extant that dealt with wildlife use of melaleuca-dominated wetlands in pine-cypress settings.

Only one study to date has directly investigated relationships between wildlife and areal coverage of melaleuca. Dalrymple and Dalrymple (1995b, 1996) recently completed a two-year survey of birds, amphibians, reptiles, mammals, fishes, and selected invertebrates at 50 sites in northwest Dade County, within the area proposed for the Northwest Dade County Lake Belt. Sampling sites were classified according to the following cover categories, with 10 sites from each category: (1) 0-10% melaleuca coverage, (2) 10-50% melaleuca coverage, (3) 50-75% melaleuca coverage, (4) 75-100% dense sapling melaleuca coverage, (5) 75-100% dense mature melaleuca. Curves of total number of individuals ("abundance") and total number of species ("richness") as a function of cover category derived from the final quarterly report are shown in Figs. 2 and 3, respectively. The figures indicate that both abundance and species richness are lowest in areas with either very sparse or very dense coverage of melaleuca, and highest for moderate melaleuca coverage. It should be noted that fishes accounted for nearly 65% of all individuals observed and birds accounted for 22% of individuals and nearly 50% of species observed, so results may be somewhat biased toward these classes of animals. Results such as those shown in the figures are fairly typical in ecology, where very low and very high levels of disturbance result in low diversity, while intermediate levels of disturbance often result in maximum diversity; this pattern is often cited as evidence for the so-called intermediate disturbance hypothesis (Connell, 1978). Dalrymple and Dalrymple (1996) note about these results that while areas with high melaleuca cover have a similar number of species as sites with low melaleuca cover, many of the species using melaleuca are not typical of natural graminoid wetlands.

The authors classified each animal observed as native or non-native and either "wetland dependent," "seasonally dependent," or "wetland independent" based on known life history information and habitat requirements. (Reviewers note: many of the birds classified by the Dalrymples' as wetland-independent are commonly observed in the canopy of forested wetlands and in shrubby vegetation near herbaceous wetlands in natural settings throughout south Florida). Based on this classification their data indicate that as melaleuca cover increases, the percent of wetland dependent species (excluding fishes, which are all considered wetland dependent) using the habitat decreases and the percent of non-native species increases. These trends are shown in Figs. 4 and 5. In Fig. 4, the percent non-native individuals may be skewed toward the extremely large numbers of non-native fishes, mostly cichlids, collected at the study sites. Note in Fig. 5 that usage by animals which are seasonally dependent on wetlands appears to be unaffected by melaleuca coverage.

Figures 2-5 show trends which may be of use in assessing wildlife value of melaleuca for the purposes of rulemaking. Several possible measures of habitat value, including percent natives versus non-natives and percent wetland dependent animals, show steady declining trends with increasing melaleuca coverage. Despite these trends, the graphs do not reveal the existence of any clear threshold level of melaleuca coverage for which wildlife functions appear to decline precipitously. Certainly, there is little basis for the choice of 75% coverage as such a threshold.

It should be emphasized again that the work of Dalrymple and Dalrymple (1996) was confined exclusively to the Lake Belt region of northwest Dade County and is therefore not necessarily applicable to melaleuca habitats in other parts of the District. Like other researchers cited above, they conclude that melaleuca "draws its wildlife habitat value from the surrounding lands." For example, a dense stand of mature melaleuca surrounded by unnatural habitats such as parking lots or housing developments may have little or no environmental value. However, a mature dense melaleuca stand in a mosaic of natural wetlands and areas with low melaleuca coverages can be seasonally used by native wetland animals. The authors note that "while [melaleuca] may not provide habitat of the same quality as natural surrounding areas, it does provide an alternative habitat that is acceptable for some species uses." In light of these observations regarding the importance of adjacent lands, it is surprising that so little information is provided on the site selection process used in the Dalrymple study, particularly since it appears that sampling sites were not selected randomly. It is not known the extent to which factors such as hydrology, proximity to breeding and refuge areas, the existence of corridors for movement between these areas and the study sites, and adjacency to other habitat types might have played a role in the wildlife utilization of particular sites. Presumably, the effects of such factors were relatively uniform for all sampling sites used in the study. Also, it is not clear whether percent coverage of melaleuca for the purposes of site selection was estimated from the ground, from aerial photos, or by some other means, nor is it clear what unit area was used in estimating percent coverage. These are important issues that will need to be addressed in the District rulemaking process as well.

Few studies have compared wildlife utilization of melaleuca habitats with the full range of relevant alternatives. For example, the Dalrymples' work provides little insight as to whether melaleuca-dominated wetlands regain natural levels of wildlife abundance and diversity when melaleuca is removed or whether replacement habitat created as a result of mitigation has higher wildlife value than melaleuca. Two studies relevant to this review have attempted to assess the wildlife value of created littoral edges on former rock mine lakes relative to adjacent habitats in the northwest Dade County Lake Belt region.

Repenning (1986) compared wildlife utilization of mitigated and unmitigated mine edges with adjacent "control" areas. Only one of the sites surveyed by Repenning, the Rinker Krome Ave. mine, is relevant to this review. Here mitigated edges consist of recently constructed littoral marsh with melaleuca seedlings present. Unmitigated edges are largely dense melaleuca and Australian pine, and control areas consist of a mixed sawgrass/melaleuca marsh with scattered dense melaleuca heads. This study focused primarily on birds. Winter bird diversity and species richness was highest on the unmitigated edge because the dense melaleuca there apparently attracted many forest birds; diversity and richness were lowest in the control areas. Although this latter result apparently contradicts the findings of Dalrymple and Dalrymple (1996), it should be noted that Repenning's work is based on a small number of sample sites, compared with 50 sites sampled by Dalrymple and Dalrymple. Species making use of the melaleuca forest were belted kingfisher, little blue heron, red-winged blackbird, common yellowthroat, American robin, American goldfinch, yellow-rumped warbler, blue-gray gnatcatcher, palm warbler, boat-tailed grackle, and prairie warbler. The majority of these species commonly inhabit vegetation in close proximity to wetlands. For breeding birds, species richness was low in all habitats. The scarcity of wading bird observations in the melaleuca may stem from the fact that the unmitigated mine edge was rarely if ever flooded (Repenning, 1986).

A recently completed wildlife study by Nova Southeastern University (Nova Southeastern, 1995) compared created littoral zones, canals, and adjacent melaleuca forested areas at six sites in northwest Dade County, including the Krome Ave. mine site studied by Repenning (1986). Although a wide variety of animals were surveyed in lakes and littoral zones, birds were the only class of animal surveyed in melaleuca. Apparently observers did not actually venture into the interior of melaleuca forests, recording bird observations from the edge only, where diversity is typically considered highest. Nevertheless, of 51 total bird species observed at all sites, 36 of those (70%) were observed in association with melaleuca; of those 36 species, 17, or nearly half, are noted by Dalrymple and Dalrymple (1996) as being wetland-dependent or seasonally dependent, and 8 are listed by the Game and Fish Commission as threatened, endangered, or species of special concern (FGFWFC, 1990). Abundance of birds in melaleuca was always greater than in lakes and canals and often (3 of 6 sites) substantially greater than in littoral zones at the same site. Species richness in melaleuca was comparable to and often greater than littoral zones; 14-15 species were recorded in all but one of the melaleuca areas. Using data presented in the report, we calculated the Shannon-Weaver diversity index for each habitat in each site. This index incorporates both number of species and number of individuals in each species (Hayek, 1994). Based on this index, diversity was highest in melaleuca at four of the six study sites and was higher than lakes and canals at all sites. Though little information is given in the report on the comparability of study sites, the authors do note that one of the sites, Florida Rock Lake, "continues to be a good bird site due to the proximity of a marsh and wooded area" (Nova Southeastern, 1995). This observation echoes those of others that wildlife value is dependent on the nature of the surrounding landscape.

<u>Gaps in Research and Implications for Rulemaking</u>

The articles reviewed in this section give evidence that melaleuca provides important residual habitat functions for native wildlife, including listed species, though the quality of habitat may be less than that of native communities. Although research indicates that utilization of melaleuca by some species decreases with increasing melaleuca coverage, there is no evidence to support claims that the ecosystem "crashes" when melaleuca cover reaches a certain level nor is there evidence to suggest that declines in habitat value are irreversible.

Figs. 2-5 provide some quantitative guidance that can be used to assess melaleuca impact on wildlife functions for wetlands in the East Everglades region. Dalrymple and Dalrymple (1996) point out that the kinds of species using a habitat are a more relevant indicator of habitat quality than is species richness by itself. Two possible indicators based on *kinds* of species, the percent non-native animals and the percent of species considered wetland dependent, seasonally dependent, and independent using the wetland are depicted in Figs. 4-5. However, existing wetland protection policy, including federal and state legislation and regulations, makes no distinction between different *types* of wildlife using a wetland (Want, 1995), so directly incorporating these results into rules for mitigation is not recommended.

Dalrymple's work was confined to the Dade County Lake Belt area and can be considered representative of other East Everglades settings. However, this region is just one of several distinct wetland settings in the District, each with its own characteristic flora and fauna, where melaleuca infestation has become serious. Similar studies in pine-cypress settings should be considered essential pre-requisites to rulemaking.

A surprisingly consistent conclusion of all the studies reviewed is that the wildlife value of melaleuca seems to be dependent on the nature of the surrounding landscape, *perhaps more so than on the level of melaleuca coverage.* The Dalrymples' research suggests that melaleuca dominated wetlands may in some cases still provide important wildlife functions, particularly when the surrounding landscape is largely in natural condition or when suitable alternative habitat is limited. Thus criteria for mitigation must not only address the different wetland settings in which melaleuca occurs, but also the condition of the surrounding landscape. Also, more comparison is needed between melaleuca-dominated wetlands and the full range of relevant alternatives, including undisturbed natural wetlands, filled or drained wetlands with and without onsite mitigation, and wetlands where melaleuca-dominated wetlands have been restored to natural conditions.

Almost all of the studies relating wildlife functions to melaleuca cover employ a "space-for-time substitution," which assumes that studying many sites (in "space") with different degrees of melaleuca infestation is equivalent to tracking individual wetlands over many years of succession (in "time") as melaleuca cover increases. The space-for-time approach is most frequently chosen where results are needed in a relatively short period of time and where long-term studies are either impractical or are cost prohibitive. However, given that wildlife use seems to be dependent on the surrounding landscape, the space-for-time approach has serious drawbacks. For this approach to be valid, all study sites must either be chosen from the same landscape setting or otherwise controlled for the effects of adjacent landscape features, or else a very large number of sites must be selected *randomly* so as to statistically dampen the effects of surrounding landscape. This further points to the need for long-term tracking of wildlife in individual wetlands through the different stages of melaleuca succession to verify that wildlife functions at a single site actually decline as melaleuca cover increases over time and that the results reported above are not simply artifacts of the sites that were chosen for study.

Hydrologic Functions

Much speculation has centered on the hydrologic impacts of melaleuca invasion and its implications on regional water resources (e.g., Pritchard, 1976). Melaleuca is commonly said to be capable of drying wetlands or reducing hydroperiods through increased transpiration and rainfall interception, and through changes in topography that may occur as a melaleuca swamp succeeds to a more mesic "melaleuca hammock" (e.g., Hofstetter and Schmitz, 1994). However, none of these effects has been convincingly demonstrated in the field.

Evapotranspiration (ET) is composed of the *evaporation* of rain water intercepted by the vegetation canopy and from the ground and *transpiration* through the leaves of water drawn from below the ground surface. Woodall (1980), citing earlier research by Olmsted (1978), notes that stomatal resistance of melaleuca is greater than for vegetation commonly used to estimate potential ET (typically agronomic crops), suggesting that ET in melaleuca may be less than ET by those plants. He also notes that melaleuca may transpire no more than a closed stand of pine or cypress, but that melaleuca is capable of establishing dense stands on sites which do not normally support dense stands of native trees.

While several authors have conducted greenhouse studies of melaleuca ET, little of the resulting information can be readily extrapolated to field conditions. Meador (1976), following up on an earlier two-week experiment, measured water loss in pots containing seedlings of pond cypress and melaleuca in a greenhouse. The results showed that the melaleuca seedlings consistently returned about 20% more water to the atmosphere than did the cypress, but expressed as a rate per unit leaf area, cypress transpires 50% more than melaleuca. The water loss measurements were corrected for soil evaporation by comparing results with control pots containing no plants, and field humidity was simulated by placing all pots over a tank of water. However, extrapolating the results to real-world wetlands depends on a highly uncertain field measurement of leaf area index, which the author admitted may be in error, particularly for cypress (Meador, 1976). A similar study by Hofstetter (unpublished data, reported in Schmitz and Hofstetter, 1994) comparing sawgrass and melaleuca found no significant difference between transpiration rates per unit leaf area for both plants. However, extrapolating to total leaf area of plants in the field, Hofstetter concluded that melaleuca may transpire more than four times the amount of water than does the sawgrass it replaces.

Recent advances in forest hydrology indicate that ET may be strongly influenced by soil moisture content, heat flux between the ground and the canopy, and microclimatic effects including local variations in wind, humidity, and temperature produced and maintained by the canopy. Despite this, the effects of differences in these factors between greenhouse and field conditions were not considered in Meador's nor in Hofstetter's experiments. Woodall (1979) cautions against extrapolating from the results of seedling lysimeters of the type used by Meador and recommends the use of diurnal fluctuations of groundwater in observation wells to estimate ET from entire melaleuca stands. In response to such weaknesses in previous studies, Chin (1996) has proposed a field study approach based on measurement of heat flux, micrometeorological parameters, and sap flow to gain a better understanding of melaleuca ET under field conditions. However, this proposed study has yet to be initiated.

Woodall (1984) studied rainfall interception losses in melaleuca canopy and determined that total losses during a three month wet season study period were about 19% of precipitation. While this figure is high, it is not atypical of wet season interception losses in native woody vegetation such as slash and longleaf pine and was derived from a stand "expected to give a particularly high value." Woodall notes that even grassy vegetation can intercept and evaporate more than ten percent of precipitation. Thus when melaleuca replaces native graminoid communities such as a sawgrass prairie, additional interception losses may amount to as much as 10% of precipitation; however, when melaleuca invades sites dominated by pond cypress or slash pine there may be little additional loss to interception. Woodall's comparisons, however, should be accepted with a measure of caution. No comparably designed studies of interception losses in native vegetation of south Florida were available, so the results of his field experiment with melaleuca were compared only with published interception estimates for trees commonly used in silviculture, mostly from other parts of the country. The field study was conducted only during the wet season, making extrapolations over the entire year somewhat questionable. Also, difficulty in measuring the depth of equivalent stemflow in Woodall's experiment lends a high degree of uncertainty to his results.

Chin (1996) estimated *theoretical* ET for melaleuca, native short herbaceous vegetation, and lakes to support hydrologic modeling for the Northwest Dade County Lake Belt project. Theoretical transpiration estimates were calculated using the Penman-Monteith formula with a combination of published values, educated guesses, and regional average values of climate variables as inputs. An empirical relationship derived by Woodall (1984) was used to estimate the interception component of the ET. These calculations indicate that melaleuca and lakes theoretically lose about the same amount of water annually, approximately 1600 mm, while native short vegetation theoretically loses about 1200 mm annually. While these results appear to support claims that ET in melaleuca ET is greater than ET in emergent wetland vegetation, the high level of guesswork and uncertainty inherent in the calculations makes them unreliable for drawing inferences about impacts on wetland functions. Chin notes that these calculations provide the "best estimates based only on climatic data," but proposes detailed field measurements to yield "more definitive values of melaleuca ET."

Thus, while it may seem reasonable that melaleuca may remove more water than native herbaceous wetland plants through ET and interception, the evidence needed to support this hypothesis is far from conclusive. The studies cited above each focused on a single component of the wetland water budget, and while the results suggest that the magnitudes of these components may be higher in melaleuca-dominated wetlands, studies of the effects on the entire water budget have not been conducted. More sophisticated study designs that recognize the effects of microclimate on ET and that incorporate additional components of the water budget will be required to shed additional light on melaleuca ET and its impacts on wetland hydrology.

Literature searches were conducted in an attempt to locate additional articles related to flood storage, water quality, groundwater recharge, hydroperiod maintenance, and other water resources functions of melaleuca-dominated wetlands. These searches indicate that no assessments of hydrologic functions or water budgets have been conducted in melaleuca wetlands in Florida. Many authors (e.g., Mitsch and Gosselink, 1993; Nixon and Lee, 1986) have observed that trees in wetlands may play an important role in modifying water quality through the cycling of nutrients and metals. However, this function has apparently not been studied in melaleuca-dominated wetlands.

Hofstetter and Schmitz (1994) suggest that as melaleuca stands mature, the closed canopy and resulting decreased ground surface temperatures and decomposition, combined with high rates of leaf litter production, tend to raise the ground surface in the interior of the stand. This land building process is said to produce a kind of hammock with a slightly higher elevation, and possibly shorter hydroperiod, than the surrounding wetland. While changes of this type seem plausible, no scientific documentation of these effects can be found in the published literature.

Gaps in Research and Implications for Rulemaking

There is clearly not enough information available from the literature to make a determination as to what extent the hydrologic and water resources functions of wetlands are affected by melaleuca infestation. A conservative position for rulemaking in the absence of any further study would be to say that *no convincing evidence exists* to suggest that water resources of wetlands are compromised at all by melaleuca. However, a proactive approach would involve further studies of wetland water budgets to provide additional information on impacts to water resources functions.

Available research suggests melaleuca invasion of native wetland communities may increase water losses from ET and interception, but in the absence of comprehensive water budget studies, there is no indication how those losses may affect the overall hydrologic functioning of the affected wetlands. Likewise, long-term tracking of successional processes in melaleuca stands will be needed before assessments can be made of the impacts of "hammock" creation on wetland hydroperiods. While research on hydrologic *processes* (e.g., ET, interception) may be useful in gaining insight into the design of field studies, the difficulty in extrapolating from single trees grown in the greenhouse to real-world wetlands severely limits the direct use of the results for criteria development. The District has recently commissioned a study of ET in melaleuca wetlands as part of the Dade County Lake Belt planning effort (NW Dade Co. Freshwater Lake Plan Implementation Committee, 1995). The first part of the study was the development of a research plan describing in detail a proposed approach and methodology for field measurements of melaleuca ET (Chin, 1996). Because this study is still in the planning stage, it may be possible to modify the design of the research to provide information that would be useful to District rulemaking.

A comprehensive water budget study of wetlands in different landscapes of south Florida is essential to assessing the water resources functions of melaleuca-dominated wetlands versus unimpacted wet prairies and swamps. Opportunities for hydrologic and water quality monitoring to provide this type of information at melaleuca-impacted and unimpacted reference sites around the District have been identified by Resource Assessment staff (Shaw and Mortellaro, 1996). Monitoring by Resource Assessment at reference sites is scheduled to begin in mid-1996. However, it is likely that additional wetlands with varying degrees of melaleuca infestation will need to be added to this program to provide the kind of information most useful to District rulemaking.

FINDINGS AND DISCUSSION

Wetland Functions Versus Melaleuca Coverage

The Melaleuca Control Act proposes rules that would eliminate or greatly reduce mitigation requirements for wetlands that exceed a specified threshold of melaleuca cover, presuming that melaleuca-dominated wetlands provide little or no beneficial functions to the environment. This review finds that there is insufficient scientific information to define such a threshold and additional study will be needed to provide solid scientific justification for District rulemaking. The literature indicates that melaleuca-dominated wetlands do indeed provide important residual functions in some areas, while the effects of melaleuca on other functions are largely unknown.

None of the articles reviewed above refutes the generally negative effects of melaleuca on south Florida wetlands. Indeed, increased melaleuca coverage apparently leads to decreased plant community diversity and obvious changes in the physical structure of the habitat. There is also evidence that, in at least one type of wetland setting in south Florida, the quality of wildlife habitat decreases, particularly for native wetland-dependent animals. Studies in the East Everglades indicate that as melaleuca cover increases, the proportion of non-native and wetland-independent wildlife using the habitat increases, with attendant decreases in the proportions of native and wetland-dependent animals. Utilization by seasonally dependent native wildlife appears unaffected by percent melaleuca cover. Measures such as these could potentially be useful indicators of habitat quality. However, such indicators should be used with caution since state and federal legislation makes no distinction between wetland-dependent and wetland-independent wildlife in providing legal protection to wetland habitat (Want, 1995).

We can find no scientific basis in the literature for eliminating mitigation requirements completely when melaleuca coverage exceeds 75% of the wetland area. The information presented in this review indicates that even wetlands heavily infested with melaleuca provide important residual functions. Understory plants associated with mature melaleuca, though generally sparse, often include a variety of wetland obligates and some protected species. Wildlife observed in association with melaleuca includes many native wading birds, raptors, other birds considered seasonally dependent on wetlands, small mammals, and reptiles. This list too includes more than a few rare, threatened, and endangered species. There is no hard evidence that wildlife support or any other functions suddenly crash when melaleuca cover reaches a certain level, nor is there evidence to suggest that observed declines in habitat value are irreversible. While reduced mitigation requirements may be appropriate for heavily infested wetlands in some locations, we do not recommend eliminating mitigation entirely.

Information on the impacts of melaleuca to the hydrologic functions of wetlands is inconclusive. Conventional wisdom suggests that where melaleuca invades marsh or wet prairie, water losses due to ET and interception may increase. Likewise, where succession in melaleuca stands causes local raising of the land surface, it is reasonable to expect the hydroperiod in that part of the wetland to become shorter. However, none of these assertions have been convincingly demonstrated in the field, and it is not clear how such changes would be different from those which occur when, for instance, a marsh succeeds to a willow swamp or a wet prairie is invaded by native pond cypress. In any event, no studies could be found that relate such changes to changes in the hydrologic functions of wetlands, nor were any studies found that document impacts of melaleuca on other water resources functions such flood storage, aquifer recharge, or water quality improvement.

Regional Setting and Effects of Surrounding Landscape

No studies of wildlife functions of melaleuca stands have been conducted in wetland settings other than the east Everglades, though the tree is now common in pine-cypress landscapes in the lower west and upper east coast regions. The pine-cypress landscape is distinctly different from the wet prairies of the east Everglades, and sustains its own characteristic wetland types, plant communities, and wildlife. It would be highly inappropriate to rely on research results from only one portion of south Florida (east Everglades) to develop rules which will have District-wide applicability.

Almost all studies of wildlife in melaleuca indicate that wildlife usage is at least partly a function of the surrounding landscape. Factors such as the landscape setting, adjacency to natural areas, levels of landscape disturbance, and the availability of alternative habitats appear to be mitigating factors that can substantially influence wildlife values at a given site. A melaleuca wetland surrounded by a parking lot may have considerably less value to wildlife than melaleuca surrounded by or in close proximity to large expanses of Everglades marsh. Because of this, it is likely that site-specific information will be needed to make a final assessment of wetland functions for determining mitigation requirements. Recently proposed methods for rating wetland functions in the field are described below.

Functional Assessment Methods

Several methods are currently under development that allow the quality of wetland functions to be rated in the field based on site-specific information. The District has participated in the development of two of these rating systems, the HGM Functional Assessment method and the Wetland Rapid Assessment Procedure (WRAP).

The HGM is under development by the U.S. Army Corps of Engineers and is intended for use in the Corps' Section 404 regulatory program for permitting dredge and fill activities in wetlands. The method is based on a system developed by Brinson (1993) that classifies wetlands for the purposes of functional assessment according their hydrologic, geomorphic, and regional settings. Five basic hydrogeomorphic classes are recognized, each of which sustains a characteristic set of functions. Regional sub-classes are also recognized, including the East Everglades Flats and others in Florida (Trott, 1995; Trott *et al.*, 1996).

The HGM methodology rates the "functional capacity" of wetlands relative to those of reference wetlands from the same region. When rating a wetland in the field, a functional capacity index (FCI) score from zero to one is estimated for each function based on pre-determined field indicators. An FCI of 1.0 corresponds to maximum level of functional capacity that can be attained by a particular sub-class of wetlands, suggesting that the wetland is performing at the same level as reference wetlands belonging to this sub-class; an FCI score of 0.0 indicates that the wetland is not capable of sustaining the function (Trott *et al.*, 1996). Trott *et al* (1996) note that functional capacity units (FCU) can be computed by multiplying the FCI for a particular function by the size of the wetland area. Presumably, when a permit is sought for dredge and fill activities in a wetland, the FCU values could be calculated for each of the wetland's functions and then combined to calculate the acreage of compensatory mitigation required.

The WRAP system, under development by the District's Regulation Department, is similar to the HGM system, but is more specifically tailored to wetlands in the District and is intended for rapid post-permit assessment of wetland mitigation projects (Natural Resources Management Division, 1996). The WRAP system, like HGM, rates wetland functions relative to those provided by relatively undisturbed wetlands of the same type and region. However, the WRAP methodology is simpler to use in the field, relying more on experience of the evaluator than on specified measurements or pre-selected indicators to assign a numerical rating to each function. The WRAP procedure also places more emphasis on habitat functions and values than does the HGM method.

The HGM and WRAP systems are tools for use by regulatory agencies to ensure consistency and accuracy when evaluating wetlands (Natural Resources Management Division, 1996). Both methods are designed to incorporate the best available scientific information for assessing wetland functions in the field. Regardless of the method used, however, it will be necessary to translate the results of scientific research into appropriate rating values and criteria. To date this has not been done. Consequently, <u>neither method should be considered a substitute for scientific research, nor should documents describing the methods be considered reports of scientific findings.</u>

The September 1995 draft of the HGM East Everglades Flats Regional Guidebook (Trott, 1995) contains proposed FCI values for several important wetland functions that are based, among other things, on *percent coverage of melaleuca*. For example, sites with greater than 75% melaleuca cover are given an FCI value of 0.1 out of a possible 1.0 for "species diversity/abundance." While this value may simply be a proposed value for discussion purposes, it is not labeled as such. It should be strongly emphasized that this value <u>does not correspond with the results of the published research</u> reviewed above and <u>should not be considered a statement of scientific finding</u>. Likewise, the January 1996 draft of the WRAP documentation report (Natural Resources Management Division, 1996) gives wetlands a rating of zero out of a possible three points in the "exotic and nuisance plant species and long term viability" category when there is "greater than 75% exotic and nuisance plant infestation." While this category is not exclusively aimed at melaleuca, it does not appear to be justified by the research reviewed here.

Success in using the HGM, WRAP, or similar methods to determine mitigation requirements will depend strongly on the quality of data and observations of the reference wetlands used for comparison. The Corps of Engineers plans to establish wetland monitoring sites throughout south and central Florida as reference wetlands for the HGM method. Presently, funding for this work is uncertain, and in any case full-scale monitoring at reference wetlands would not be initiated for several years. Alternatively, the network of reference wetlands established by the District's Resource Assessment Division could be expanded to include additional sites required for implementing either HGM or WRAP. Hydrologic instrument and monitoring well installation is presently underway at sites identified by Shaw and Mortellaro (1996), many of which were also identified by the Corps as potential reference sites for HGM. Regular hydrobiological monitoring will be initiated at the District sites in May, 1996 and is expected to continue over the long term.

INFORMATION NEEDS AND RECOMMENDED ACTIONS

This review has identified several major gaps in scientific knowledge regarding the functionality of melaleuca-dominated wetlands. Some of these have important implications on the development of mitigation rules. Information needs and recommended actions that should be considered a pre-requisite to rule development are summarized below and in Table 1.

1. **Need:** Better *quantitative* information is needed on understory vegetation in melaleuca stands. Presently, only species lists are available and only at a few locations on the southeast coast and in Lee County. Quantitative rules for determining mitigation ratios will need to be justified by quantitative comparisons of understory composition, diversity, and abundance in wetlands with varying degrees of melaleuca coverage.

   Action: Recommend conducting a survey of understory vegetation in melaleuca wetlands, including an assessment of community composition, abundance, and diversity. A study of this kind was recently proposed by Dalrymple and Dalrymple (1995a). This survey could either be contracted or conducted by District staff from RAD or NRM. A survey of this type would not require repeated sampling and could therefore be completed relatively quickly within a few months.

2. **Need:** Better information is needed on the effects of melaleuca on hydrologic and water resources functions. Improving knowledge of individual hydrologic processes (e.g., ET) may be useful for designing studies to support rulemaking. However, approaches that attempt to extrapolate the results of greenhouse studies to the field appear to have little merit and in the end provide only limited insight on the effects on hydrologic functions of wetlands. An approach which focuses on the water budgets or hydroperiods of melaleuca-dominated wetlands relative to those of reference wetlands of the same type would appear to be more fruitful. Only through analysis of *all* the components of the wetland water budget can assessments be made of the impacts of melaleuca on aquifer recharge, flood storage, and water quality.

   Action: Recommend NRM and/or RAD staff participation in developing the final work plan for the District-commissioned study of melaleuca ET to be conducted by Dr. David Chin of the University of Miami as part of the Northwest Dade County Lake Belt planning effort. This project is presently in the planning stages, and a proposed research plan has been completed. NRM and RAD oversight is recommended to ensure the study results in information that can be used to support District rulemaking without the need for additional followup studies. Possible areas where the project scope could be expanded include: (a) the addition of study sites outside the Dade County Lake Belt region, (b) use of diurnal water table fluctuations to estimate ET rates from wetlands with different degrees of melaleuca coverage, and (c) water budget analysis to assess the impacts of melaleuca ET on wetland water resources functions.

3. **Need:** Information is needed on wildlife utilization of melaleuca-dominated wetlands in pine-cypress settings. Melaleuca infestation has become a serious problem in several areas of the District that may be affected by the proposed Melaleuca Control Act and District rulemaking. The most important locations for additional wildlife surveys are the pine-cypress landscapes of Lee, Collier, Palm Beach, and Martin Counties where melaleuca readily invades the herbaceous ecotone between pine flatwoods and cypress swamps.

   Action: Recommend initiating studies of wildlife utilization of melaleuca-dominated wetlands in pine-cypress landscapes similar to the two-year study in the East Everglades recently completed by Dalrymple and Dalrymple (1996). These studies could either be contracted or conducted by District staff from RAD and NRM.

4. **Need**: Direct comparisons are needed of residual functions provided by melaleuca-dominated wetlands versus those provided by replacement habitat established through mitigation. No published studies to date have directly compared the functions of melaleuca wetlands with those provided by wetland habitats created or restored as a result of mitigation. It is not clear that the functionality lost as a result of melaleuca infestation cannot be restored if melaleuca is removed. Nor Is it clear from the literature that mitigation, particularly onsite mitigation, provides functions and values that equal or exceed those of melaleuca-dominated wetlands. A previous study commissioned by the District concluded that typical onsite mitigation has not insured long-term maintenance of desired wetland functions and values (Erwin, 1991).

   Action: Recommend conducting scientific comparisons of functions of melaleuca dominated wetlands with those of unimpacted native wetlands and wetlands established as a result of compensatory mitigation. These comparisons could be incorporated into the scopes of work of other recommended studies or conducted separately. Note that mitigation bank sites being established by the District in Palm Beach and Lee Counties provide opportunities to monitor wetland functions before and after removal of melaleuca.

5. **Need**: Information is needed on the effects of adjacent land use and cover on the utilization of melaleuca habitats by wildlife. Based on the conclusions of the research reviewed, it is unlikely that the wildlife functions and values provided by melaleuca-dominated wetlands will be solely a function of onsite melaleuca cover. Dense melaleuca stands adjacent to large protected areas of high natural quality will likely provide greater benefits to wildlife than dense melaleuca surrounded by residential development. Procedures will need to be developed to be able to evaluate the quality of the landscape and to quantify its positive or negative effects on wildlife utilization of melaleuca.

Action: Recommend an assessment of wildlife utilization of melaleuca habitat as a function of adjacent land use or the degree of melaleuca interspersion in the landscape. This assessment could be implemented as a separate study as suggested by Dalrymple and Dalrymple (1995a) or incorporated into the scope of the wildlife study recommended above. If it is determined that adjacent land use or other site-specific factors are indeed a strong influence on wildlife utilization, then methods such as HGM or WRAP will need to be refined so that the residual functions of melaleuca-dominated wetlands can be consistently and accurately assessed in the field.

6. **Need**: Documentation is needed of long-term successional processes in melaleuca-dominated wetlands. One of the outstanding questions regarding melaleuca impacts on wetlands is the degree to which a melaleuca stand over time becomes a type of "hammock," perhaps intermediate between the original wetland habitat and a true upland. Anecdotal evidence suggests that a land building process may take place in the interior of mature stands that could potentially lead to reduced hydroperiods and changes in wildlife and plant community composition. However, these processes have never been documented in the field.

   Action: Implement monitoring of individual melaleuca stands to document long-term successional processes. Such monitoring should include routine monitoring of water levels and hydroperiods and periodic assessments of plant community composition and soils. Because of the long-term commitment inherent to such an approach, it is recommended that monitoring be conducted by District staff rather than by a contractor. However, to keep costs to a minimum, a low-intensity monitoring strategy utilizing photographic documentation and limited hydrologic monitoring is recommended. Long-term monitoring can be used to identify and document adverse changes in wetland hydrology, hydric soils, and topography, to determine the extent to which native vegetation regains a foothold, if at all, and to verify the results of wildlife studies that employ the space-for-time approach.

7. **Need:** Simple, practical methods are needed for estimating the degree of melaleuca coverage for the purpose of determining mitigation requirements. Few of the studies reviewed provided clear information on how percent melaleuca was defined or over what land area it was calculated. It is critical that methods proposed for inclusion in District rules be consistent with those used in the research on which those rules are based.

   Action: Recommend critical scientific review of numerical criteria and methods for calculating melaleuca coverage proposed for District wetland mitigation rules. External peer review of proposed rules and criteria could be coordinated by the Resource Assessment Division through the expert assistance program or through an expert workshop forum. Internal review could be provided by RAD staff.

Table 1 -- Summary of Recommended Studies

Recommended Study or Review		Proposed Implementation
1.	Survey of understory vegetation	Field survey conducted by RAD staff (3-4 months)
2.	Assessment of hydrologic functions	Expansion of District-commissioned ET study to include comprehensive water budget analysis (1-2 years)
3.	Survey of wildlife use of melaleuca in pine-cypress settings	Contracted study managed by RAD staff (1-2 years)
4.	Comparison of melaleuca wetlands with wetland habitat established through mitigation	Incorporate into scope of study 3 above
5.	Assessment of wildlife use of melaleuca as a function of adjacent land use	Incorporate into scope of study 3 above
6.	Long-term monitoring of successional processes	Implement low-level monitoring by RAD staff at selected sites (10+ yrs)
7.	Review of numerical criteria and methods	Combination of internal and external scientific review coordinated by RAD. (2 months)

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Appendix 1 -- Literature Databases and Keywords used in the Computer Bibliographic Search.

1. Dialog files searched:

   Environmental Bibliographies 1974-1995
   Water Resources Abstracts 1968-1994
   Dissertation Abstracts Online 1861-1995
   Biosis Previews 1969-1995
   Aquatic Science and Fish Abstracts 1978-1995
   NTIS 1964-1995
   SciSearch 1974-1995
   AGRICOLA 1979-1995

2. Keywords used:

   MELALEUCA
   TRANSPIRATION AND MELALEUCA
   UNDERSTORY AND MELALEUCA
   HYDROLOGY AND MELALEUCA
   MELALEUCA AND FISH
   WETLAND? AND MELALEUCA
   FLORIDA AND MELALEUCA
   EVAPOTRANSPIRATION AND MELALEUCA
   MELALEUCA AND MAMMALS
   MELALEUCA AND WILDLIFE
   MELALEUCA AND BIRDS
   MELALEUCA AND WATER QUALITY
   MELALEUCA AND WATER RESOURCES

Appendix 2 -- Summaries of Publications Reviewed

Author: Schortemeyer, et.al. (1982)
Title: Final report on wildlife occurrence in melaleuca heads in the Everglades Wildlife Management Area
Affiliation: Florida Game and Fresh Water Fish Commission
Document: Agency report (draft final)

Summary: Study date & duration: Sept 1979-Nov 1981 (26 months); general wildlife surveys Jun 1979-Dec 1980; nesting surveys Mar-June 1981; mammal trapping Aug-Nov 1981 (152 trap nights); fish sampling Mar-Apr 1981; plant nutrient March 17 and April 21, 1980, and January 19 and 20, 1981.

Study location(s): WCA's 2 & 3 (Dade, Broward Co.)

Melaleuca forest type: 17 selected melaleuca heads (0.25-1 ha with trees ranging from 2 to 10m); 8 heads in WCA-2A, 8 heads in WCA-3A, 1 head in WCA-3B; 8 selected because of prior observations of significant wildlife utilization, 8 selected randomly, 1 selected because of prior observations of no wildlife use but heavy use in adjacent willow head.

Sampling design/methods: Different methods & sampling at different sites, no one method used at all 17 sites. General wildlife surveys at 12 heads + willow head; biased toward birds; number of surveys per site ranged from 12 to 27. Methods: flush survey w/ airboat (day & night; 50.4% of all surveys), blind survey (2 hrs., 50 m; 40.2% of surveys), casual survey (unscheduled; 1.6% of surveys), walk-thru survey (45 mins, all habitats, sight/sign; 7.8% of surveys). Recorded animal activities: feeding, nesting, perching/resting, roosting, incidental. Aerial and ground nesting surveys were performed bi-monthly during nesting season, in 20 heads, 8 of which were selected for prior utilization. Small mammal trapping, was performed in 8 heads (melaleuca areas only) using three sizes of traps; only presence/absence was recorded and some sampling problems occurred with wet sites. Fish sampling used Rotenone in 2 heads and nearby habitats (five locations); size classes and biomass were determined. Plant nutrient analysis compared forage quality of melaleuca with known south Florida deer forage plants (3 woody, 5 herbaceous), 2 sites only; chemical analysis for protein, crude fat, crude fiber, ash, nitrogen free extract, Ca, P, Mg, K, Na.

Results/Conclusions:

General wildlife surveys: Water depths -10cm to +125 cm. 19726 animals or their sign observed. 45 species, inc. 43 species of birds (99.83% of all animals). 97.77% of observations were live animals. 75.7% of all sightings were, in order, tree swallows, cattle egrets, anhingas, black vultures, and turkey vultures. 90.75% of sightings were these birds plus, in order, Everglades kites, American coots, red-winged blackbirds, great blue herons, boat-tailed grackles, and double-crested cormorants. Species observations include 10 listed species, mostly in low numbers: American alligator (22), little blue heron (24), Everglades kite (812), tri-color heron (59), limpkin (7), northern harrier (7), snowy egret (41), American kestral (45), and wood stork (10). 76.64% of observations were classified as "incidental," either traveling by or entering and leaving the head. Roosting/perching was the most common "contact" activity comprising 15% of all observations. The only one of the top 11 species with more observations in direct association rather than incidental (indirect) was the American coot. However, 4 of 5 top species did make some direct use of melaleucas, usually as a resting/loafing site. Seasonal variation appears related to hydrologic conditions and is different for different species. Observations at the site adjacent to a willow head suggest most usage was in willows rather than melaleuca. Animal usage of "randomly" selected heads was low.

Nesting surveys: Species found nesting were anhinga, great blue heron, great egret, cattle egret, snowy egret, black-crowned night heron, green-backed heron, wood stork, cormorant, and Everglades kite. Wood stork, kite, and snowy egret are listed. Other heron nests are important because communal with other, possibly listed, species.

Mammals: Only rice rats captured (overall capture rate 0.086); largely unsuccessful; one deer seen, sign of raccoon observed.

Fish: 3900 individuals, 20 species + 3 amphibians, none listed; average of 9 species collected (4 abundant overall) in each melaleuca site, 12.7 avg. (10 abundant overall) for non-Melaleuca sites; biomass and density were substantially higher in non-Melaleuca. 84% of all fish were bluefin-killifish, golden topminnow, mosquitofish, and blue-spotted sunfish.

Forage quality analyses: Incomplete, but analysis indicates that melaleuca not easily digestible and low in nutrition. Birds make greatest use of melaleuca heads because they are a substitute for natural tree island habitat and because percentage of melaleuca cover in landscape as a whole is very low (they attribute most usage to adjacent cover types).

Reviewer's comments/ weaknesses of study: biased site selection; seasonal bias, conditions not representative of developing areas; not enough statistical validity to comparisons of melaleuca and native habitats, ad hoc study design. Study locations were in areas of WCA's where high water levels had killed or damaged native trees, making melaleuca heads the only dominant woody vegetation.

Author: Meador (1976)
Title: Transpiration of Melaleuca and Taxodium seedlings
Affiliation: University of Florida-Gainesville, Dept. of Botany
Document: Conference proceedings

Summary: Study date & duration: July 14-Aug 17, 1976; following up on a two-week experiment in March 1976.

Study location(s): greenhouse study at Gainesville; melaleuca seedlings obtained from Dade Co. site west of Turnpike near South Miami; leaf index parameters measured in the field from melaleuca in a ditch along SR 82 near Lehigh Acres in Collier Co.

Melaleuca forest type: seedlings in pots.

Sampling design/methods: Objective was to compare transpiration by melaleuca seedlings with 3-yr old pond cypress seedlings to verify hypothesis that transpiration is higher in melaleuca because of 40% greater stomate density of leaves. Cypress seedlings averaged 90.5 cm and 98.5 leaves/plant; melaleuca averaged 123 cm and 88 leaves/plant. Each was planted in 2.8 liter pots. Each week the height and number of leaves on each plant were measured. At the end of the study all leaves were harvested and the leaf area was determined for each seedling using an Automatic Area Meter. Leaf area each week was estimated from the number of leaves and the leaf area at the end of the study. 15 seedlings of each species and 10 control pots (no plants) were placed above a tank of water to simulate field humidity. Water loss was determined by saturating the soil with water and weighing at the same hour every day, then subtracting the evaporation from control pots. Relative humidity and temperature were monitored continuously. Stomate density was determined from subsampling and counting under a microscope. Leaf area index was obtained in the field in Collier Co. from roadside melaleuca and nearby cypress domes.

Results/Conclusions: Melaleuca consistently returned more water to the atmosphere than did cypress, by about 20%. Expressed as rate per unit leaf area, cypress transpires 50% more than melaleuca. Identical correlation (86%) between transpiration and vapor pressure deficit for both species. Leaf area index for melaleuca was 4.9 and for cypress 4.1.

Reviewer's comments/ weaknesses of study: Difficult to extrapolate from greenhouse to field conditions; of particular importance would be the effects of wind and microclimate. Field measurements for leaf area index were probably in error and this parameter has a large influence in the transpiration per leaf area. Basically inconclusive.

Author: R.W. Repenning (1986)

Title: Mitigation of Fish and Wildlife Values in Rock-mined Areas of South Florida, Part II: Wildlife

Affiliation: School of Forest Resources and Conservation, IFAS, University of Florida-Gainesville

Document: Final project report to U.S. Fish & Wildlife Service Region 4

Summary: Study date & duration: vegetation sampling dates not given; bird counts: Jan 23-Feb 26, 1984 (10 counts) and Apr 15-May 25, 1984 (12 counts); wildlife observations were made from November 1983 to July 1984.

Study location(s): rock mines in Dade County; only the Krome Ave. Mine site (Site 2) contained melaleuca. Site is adjacent to the Krome North Processing (Detention) Center.

Melaleuca forest type: Habitats were: sawgrass/melaleuca mixed marsh with scattered melaleuca "domes" (control), dense forest of melaleuca and casuarina (unmitigated edge), and marsh with melaleuca seedlings (mitigated edge). Mine is 20 yrs old; mitigation area is recent, but no age is given.

Sampling design/methods: Considered adjacent wetlands to be control; compared with mitigated and unmitigated mine edges. Vegetation: six nested plots (largest 10 m square) for tree density, shrubs, and ground cover; canopy cover measured as present or absent. Birds: strip transects with non-statistical similarity indices for comparisons. Other wildlife observation noted and species lists generated.

Results/Conclusions: Vegetation: tree density (inc. mature melaleuca) was higher in adjacent control areas than in the mitigated or un-mitigated mine edges; trees on unmitigated berm larger and higher canopy cover; shrub density (inc. seedling melaleuca) highest in mitigated area and lowest in control area. Winter bird diversity and species richness highest on unmitigated edge because this area attracted many upland or forest birds (60% of species observed there) and lowest in control wetlands. Similarity indices between unmitigated edge and the other two habitats were very low. Species making use of the unmitigated edge were: belted kingfisher, little blue heron (listed), red-winged blackbird, common yellowthroat, American robin, American goldfinch, yellow-rumped warbler, blue-gray gnatcatcher, palm warbler, boat-tailed grackle, and prairie warbler. In this list the robin through the prairie warbler were not found in the mitigated edge. For breeding birds, richness was low at all habitats; mitigated edge density was higher than the other habitats. In the unmitigated area the following birds were observed: red-winged blackbird, common nighthawk, northern mockingbird, and rufous-sided towhee. Non-breeding migrants also included belted kingfisher. General observations included 51 species of birds, 9 species of reptiles, and 4 species of mammals (inc. house cat) in and around the mine site. Lists of these were provided. Cuban anole were observed in the unmitigated area. Little blue heron, tricolored heron, American kestral, osprey, and loggerhead shrike were the listed species observed. Little in the way of replacement wetland habitat is offered by unmitigated mines.

Reviewer's comments/ weaknesses of study: low statistical significance; comparability of control, mitigated edge, and unmitigated edge complicated because of different topography and hydrologic conditions; poor documentation.

Author: Mazzotti, F.J., W. Ostrenko, and A.T. Smith (1981)
Title: Effects of the exotic plants *Melaleuca quinquenervia* and *Casuarina equisetifolia* on small mammal populations in the eastern Florida Everglades.
Affiliation: Everglades National Park, South Florida Research Center
Document: article in *Florida Scientist*

Summary: Study date & duration: May 1976-Apr 1977; seven rotations, 2 successive trap nights per rotation.

Study location(s): Everglades National Park, Tamiami site 27 km west of Miami and south of Tamiami Trail containing all phases of Melaleuca invasion into wet prairies.

Melaleuca forest type: 2-ha mature melaleuca head (monoculture) at least 30 yrs old with no understory and 6-7 yr. old saplings on periphery and 0.03-ha mixed melaleuca/graminoid prairie (partially drained) with clumps of melaleuca surrounding the large head.

Sampling design/methods: Focused on three sympatric rodents of the Everglades. Used 40 Sherman live traps in grid configurations, either rectangular or the shape of the tree island, for the mixed habitat. On the large head two perpendicular lines of traps were used with 40 traps each. Inter-trap spacing was 3-4 m in both habitats. Animals were weighed, sexed, classified as adult or juvenile, identified by toe clipping, and examined for reproductive condition.

Results/Conclusions: *Peromyscus* (cotton mouse) was found primarily in the interior of mature melaleuca heads; *Oryzomys* (rice rat) occurred primarily and *Sigmodon* (cotton rat) exclusively in the mixed melaleuca-graminoid habitat. Frequency of recaptures of *Peromyscus* and *Sigmodon* indicated they were in their preferred habitat. Compared with depauperate fauna of *Casuarina* heads, the rodents were common in melaleuca habitats. No reproductive animals were caught in *Casuarina*, but reproductive animals and juveniles were caught in melaleuca. Low understory species richness alone does not determine rodent distribution and abundance. Rodent densities were low in melaleuca habitats compared with native hammocks, but melaleuca habitat cannot be "intuitively classified as biological deserts."

Reviewer's comments/ weaknesses of study: Interpretation of results complicated by differences in availability of wet season refugia between habitats sampled. It is unknown the extent to which melaleuca habitats are accessible to higher members of the food web that would normally utilize Everglades rodents. Low number of site replicates (1).

Author: Ostrenko, W., B. Rothstein, and F. Mazzotti (1979)
Title: The utilization of *Melaleuca quinquenervia* hammocks by native south Florida small mammals and description of their population dynamics.
Affiliation: Miami Museum of Science
Document: Abstract of conference presentation published in *Florida Scientist*

Summary: Study date & duration: Not given.

Study location(s): Not given, but presumed to be the same site(s) as in Mazzotti, *et.al.* (1981) above.

Melaleuca forest type: (1) mature forest-like melaleuca stand, (2) denser, younger trees, (3) dense saplings, (4) open-canopy mixed graminoid community, (5) graminoid community.

Sampling design/methods: Studied same three rodent species as in Mazzotti, *et al.* (1981), presumably again by live trapping. In addition, apparently looked at invertebrates as well as vertebrates. Also looked at food selection of Sigmodon and Peromyscus.

Results/Conclusions: *Peromyscus* occurred most often in mature melaleuca forest and never in dense saplings. *Oryzomys* found in small numbers in each of the habitats, and was most active in the wet season. *Sigmodon hispidus* was found only in the open canopy and graminoid community. *Sigmodon* and *Peromyscus* apparently went "regionally extinct" during the wet season and "reappeared during the dry season." A total of 21 animal species (16 vertebrates and 5 invertebrates) were found in association with mature melaleuca forest.

Reviewer's comments/ weaknesses of study: No documentation; published abstract only. Proper use of terms "regionally extinct" is questionable. Low number of site replicates (1).

Author: W. Ostrenko and F. Mazzotti (1980)
Title: Small mammal populations in *Melaleuca quinquenervia* communities in the eastern Florida Everglades.
Affiliation: Historical Museum of Southern Florida
Document: Proceedings paper for Melaleuca symposium, Florida Division of Forestry

Summary: Study date & duration: Oct 1978-Dec 1979 (apparently follows up on Mazzotti, *et. al.,* 1981 study cited above); 15 monthly trap rotations (1040 trap nights).

Study location(s): Tamiami Trail site of Mazzotti, *et al.* (1981); entire area somewhat disturbed from partial burning.

Melaleuca forest type: (1) mature forest-like melaleuca head, (2) dense, young trees, (3) mixed melaleuca-graminoid head, (4) sawgrass prairie 1 km east of other sites; burned during study period but recovered rapidly, (5) roadside ditch and spoil bank covered with Brazilian pepper.

Sampling design/methods: mark-recapture trapping (Sherman live traps) on the three rodent species studied in Mazzotti, *et al.* (1981).

Results/Conclusions: *Peromyscus* found in all habitats, but most abundantly in forest type (1), where the population was permanent and contained 90% of all breeding females captured in the entire study area; abundance was lowest in the mixed head and sawgrass prairie. Clearly mature melaleuca is a suitable breeding habitat for *Peromyscus*. *Oryzomys* were most abundant in sawgrass prairie, but 17% of captures were in Melaleuca habitats, where it is considered transient. Melaleuca habitats did not apparently support *Sigmodon*; it was found most abundantly in the roadside habitat and also in mixed melaleuca and sawgrass prairie (however all individuals caught in these latter habitats were in association with native graminoid plants rather than melaleuca). All *Sigmodon* appeared to be permanent, reproducing populations. All of these occupancy patterns were non-random. The rare short-tailed shrew was also captured in mature melaleuca, roadside, and sawgrass prairie. No exotic rodents were trapped. Some circumstantial evidence to suggest that rodent predators are taking the rodents in the mature melaleuca head: remains in barn owl hairballs, presence of a large indigo snake (listed animal). Melaleuca heads support fewer individuals of rodents than native hammocks, but differences in hydrology may account for this difference.

Reviewer's comments/ weaknesses of study: Did not account for wet season refugia in trees for *Peromyscus*, especially. No comparison with structurally and hydrologically similar cypress heads. Low number of site replicates (1).

Author: A. Sowder and S. Woodall (1985)
Title: Small mammals of melaleuca stands and adjacent environments in southwestern Florida.
Affiliation: School of Forest Resources, University of Georgia-Athens
Document: Note in *Florida Scientist*

Summary: Study date & duration: May 1982 (end of dry season); traps checked each morning; 7 days of trapping at Daniels site, 5 days of trapping at Alico site.

Study location(s): Six-Mile Cypress Strand south of Daniels' Rd. (Lee Co.) and just north and east of old US 41 and Alico Rd. (Lee Co.).

Melaleuca forest type: Daniels Site: cypress strand and 30-yr old, 25m+ tall, melaleuca stand (with only a sparse saw fern understory); Alico Site: similar mature melaleuca stand and power line corridor (with a complete understory of ruderal graminoids and forbs); all habitats reportedly had similar hydroperiods.

Sampling design/methods: Melaleuca stands were compared to stands of adjacent native vegetation. Single trapline in interior of each habitat, parallel to habitat boundary, 20 stations at 8-m intervals on each line, 3 traps per station + 20 Sherman traps placed in trees to check for arboreal activity. Trapped animals not released.

Results/Conclusions: Very low numbers of *Sigmodon* and *Peromyscus* in Daniels cypress, a single *Sigmodon* in melaleuca. Trapping discontinued at Alico site after 5 days without a single capture. No evidence of resident breeding populations. Concluded that utilization of a particular melaleuca habitat by small animals may depend more on the ecosystem within which it is located than on vegetation characteristics within the habitat.

Reviewer's comments/ weaknesses of study: Extremely short study period and small sample size.

Author: S.L. Woodall (1984)
Title: Rainfall interception losses from Melaleuca forest in Florida.
Affiliation: USDA Forest Service, Southeastern Forest Experiment Station
Document: USFS Research Note

Summary: Study date & duration: May 24-Aug 26, 1982 (wet season)

Study location(s): Six-Mile Cypress Strand (Lee Co.)

Melaleuca forest type: mature, stand of pure melaleuca, near maximum stand density and foliage, 30-yr old trees, approx. 30 m tall for dominant trees; chosen for maximum potential interception losses.

Sampling design/methods: Leaf area index measured at end of study by injecting all trees in the plot plus adjacent with a herbicide and capturing leaf fall in six 84x84 cm traps. Two precipitation gages 275 m apart in unobstructed locations on east-west transect with interception plot between; paired weighing bucket and standard USWB gages installed 1.5 km from plot for storm timing information. Representativeness of gages was verified after the study. Throughfall caught in plastic 5-liter buckets with evaporation baffles; one bucket in each of the 36 sub-plots; placed randomly; on wooden platforms above the ground surface. Each sub-plot was a 6 by 6 grid with 4-m spacing. Stemflow collars installed on 6 dominant trees with DBH 30-40 cm; nailed to tree and caulked; draining to 19-liter reservoir. The reservoir overflowed on larger storm events, so large storm data were mostly rejected. Depth of equivalent stemflow was calculated from each tree's stemflow volume and its estimated crown projection area, than extrapolated to stand basis assuming each tree was an unbiased sample of a closed single-layer canopy. Collections typically made the morning following afternoon storms. Throughfall gages corrected for evaporation between time of storm and time of collection. Sampling error was calculated. Interception losses calculated by water balance.

Results/Conclusions: LAI = 5.9; verified from additional data. Linear divergent relationship between throughfall and precipitation. Presumption that characteristics of melaleuca would minimize stemflow were not supported by the study; high hydrophobicity of bark inhibits absorption and detention storage. Interception losses for entire study period were estimated to be 19% of precipitation. While this value is high, it is not atypical for woody vegetation; even grasses can intercept as much as 9% of precipitation. Thus replacement of native graminoid communities may result in as much as 10% of precipitation additional loss, and replacement of native forest types may result in no additional losses. Melaleuca losses similar to those reported for slash pine and longleaf pine. Replacement of cypress by melaleuca probably results in little increase in losses even though melaleuca is evergreen; period when cypress leaves are off has much less rainfall and cypress mid- and understory plants remain evergreen.

Reviewer's comments/ weaknesses of study: High uncertainty in estimating depth of equivalent stemflow for entire stand. Lack of comparable studies for south Florida native vegetation; comparisons were made against vegetation outside the region. Studies of interception by native graminoid communities would be extremely difficult.

Author: D.F. Austin (1978)
Title: Exotic plants and their effects in southeastern Florida
Affiliation: Dept. of Biological Sciences, Florida Atlantic University
Document: Review article in *Environmental Conservation*

Summary: Study date & duration: mostly a review of literature and personal observations to date

Study location(s): article focuses on southeast Florida: Dade, Broward, Palm Beach, Martin, and St. Lucie Counties.

Melaleuca forest type: no distinction

Sampling design/methods: none

Results/Conclusions: Plant diversity of decreases 60-80% in marsh/wet prairie systems following invasion by Melaleuca based on a student class project.

Reviewer's comments/ weaknesses of study: mostly undocumented supposition; not a controlled study, but just a review of history.

Author: Hall, J.M. (1977)
Title: Observations and analysis of *Melaleuca quinquenervia* in Florida
Affiliation: Eckerd College, St. Petersburg, FL
Document: Conference abstract published in *Florida Scientist*; based on an undergraduate class project; author was undergraduate in biology at the time; college has no information on author's whereabouts.

Summary: Study date & duration: not reported

Study location(s): not reported

Melaleuca forest type: disturbed and undisturbed mangrove ecosystems with melaleuca infestation

Sampling design/methods: not reported. Considered anoles, ants, beetles, and spiders inhabiting melaleuca.

Results/Conclusions: not reported.

Reviewer's comments/ weaknesses of study: not enough published information to review; contacted Eckerd College: author was an undergraduate at the time of the presentation, no current contact information on author.

Author: Alexander, Hofstetter, and Parsons (1977)
Title: Comparison of transpiration of cajeput (*Melaleuca quinquenervia*) and sawgrass (*Cladium jamaicense*)
Affiliation: University of Miami, Dept. of Biology
Document: Conference abstract published in *Florida Scientist*

Summary: Study date & duration: not reported

Study location(s): not reported

Melaleuca forest type: Not reported; water weight losses were measured on well-established potted plants.

Sampling design/methods: Compare water loss from native and exotic species in the Everglades. Data presented on transpiration amounts and rates under several environmental conditions. Weight losses measured from potted plants.

Results/Conclusions: not reported.

Reviewer's comments/ weaknesses of study: not enough published information to review.

Author: Woodall (1979)
Title: Analytical techniques for estimating evapo-transpiration from *Melaleuca quinquenervia* stands
Affiliation: U.S. Forest Service, Forest Resources Lab, Lehigh Acres
Document: Conference abstract published in *Florida Scientist*

Summary: Study date & duration: not reported

Study location(s): not reported; probably Six-Mile Cypress Strand, Lee Co.

Melaleuca forest type: Not reported

Sampling design/methods: used diurnal fluctuations in groundwater observation well method to estimate ET of entire melaleuca stands. Compared results with other vegetation types.

Results/Conclusions: Apparently results were site-specific, no definitive conclusions.

Reviewer's comments/ weaknesses of study: not enough published information

Author: Dalrymple and Dalrymple (1995,1996)
Title: Dade County Lake Belt Plan -- Wildlife Studies (4th & 8th quarterly reports)
Affiliation: Everglades Research Group, Inc., consultants for Dade Co. DERM
Document: quarterly reports

Summary: Study date & duration: Jan. 1, 1994 - Dec. 31, 1995 (2 yrs.)

Study location(s): 50 sites located within the Lake Belt study area of Dade County, roughly defined as the area bounded by U.S. 27, Florida's Turnpike, the Tamiami Trail, and Krome Ave.

Melaleuca forest type: stratified according to percent melaleuca coverage: 0-10%, 10-50%, 50-75%, 75-100% saplings, and 75-100% mature trees; 10 sites in each category.

Sampling design/methods: Wildlife defined as: selected macroinvertebrates, fishes, amphibians, reptiles, birds, and mammals. Methods include: (1) dip net sampling for fishes, invertebrates, and amphibians, (2) minnow trap sampling, 15 traps/site, some submerged, some floating, (3) drift fence sampling for aquatic and semi-aquatic macroinvertebrates and vertebrates, (4) faunal transects for presence/absence of mammals, herps, (5) bird strip transects, (6) road surveys on the wellfield canal levee, Krome Ave., FP&L right-of-way for mammals, herps, wading birds, (7) surveys of RIFA mounds in three 1/10 ha circular sample plots to estimate density, (8) live trapping for small mammals in one site per cover type, (9) scent and bait stations (one per cover type) for medium and large mammals. Methods 1 through 6 were performed monthly and methods 7 through 9 were performed quarterly.

Results/Conclusions: (1) Species richness highest in areas with moderate melaleuca coverage, typical of sites in an early stage of disturbance; this is mostly a result of bird usage; (2) areas with low coverage have more species that are fully dependent or seasonally dependent on wetlands; areas with moderate coverage retain high numbers of wetland associated species, but also have additional species not typically associated with wetlands; areas with high coverage have similar species richness to areas with low coverage, but *many* of these species not typical of natural *graminoid* wetlands, such as migratory upland birds (but abundances of such birds are lower in melaleuca than in good quality native habitats such as cypress swamps, tropical hammocks, pine rockland; (3) cumulative numbers of individuals highest in areas with low to moderate coverage, mostly the result of higher numbers of macroinvertebrates and fishes during the wet season; (4) non-native species and individuals highest in dense coverage; cichlid fishes most abundant group of non-natives; (5) 10 species observed are listed species, 7 of which are listed species; (6) wildlife value of melaleuca habitat appears to be related to surrounding habitat; melaleuca by itself appears to have little intrinsic value to wildlife; it may not provide habitat of the same quality as surrounding natural habitat, but provides alternative habitat acceptable for some species use.; (7) as succession goes from 50-75% melaleuca to 75-100% melaleuca, the number of wetland associated species decreases, the number of non-native animals increases, and the species *abundance* decreases -- note it does not conclude that the value to wildlife is zero. Note that species richness ranged from 94 in 0-10% cover and 98 in 75-100% mature trees to 115 in 50-75% cover; abundance ranged from 7421 individuals in 25-50% cover to 2492 individuals in 75-100% mature trees (vertebrate species and individuals mirrored this trend). There were a total of 92 bird species, compared with 16-30 species of other animals; there were 10,737 fish individuals and 3678 bird individuals, compared with 272-942 individuals of other animals. Numbers of herps similar across all cover types, but dropped in dense melaleuca, possibly due to decreased sunlight and subsequent formation of periphyton and associated grazers upon which herps depend.

Reviewer's comments/ weaknesses of study: Best controlled and most relevant study to date; good statistical validity on most results. No reporting of understory vegetation. High water levels during many quarters limited some sampling activities. It is not clear whether individual study sites changed in terms of melaleuca coverage during the course of the study; such change might be needed to substantiate the conclusion that abundance and richness drops significantly when coverage increases to 75-100%. Some sites seem to have changed location between earlier and later quarterly reports. Study does not consider how melaleuca changes the hydrologic character of the landscape. Possibly some differential scaling effects as percent melaleuca cover is defined on the basis of different unit areas -- this may be important to investigate (particularly in Dade Co.) because of the conclusion that the value of melaleuca is related to the quality of the surrounding landscape.

Author: Nova Southern University (1995)

Title: Dade County Lake Belt Plan -- Lakes and Littoral Studies (7th quarterly report)

Affiliation: Nova Southeastern University, Oceanographic Center, consultants for Dade Co. DERM

Document: quarterly report

Summary: Study date & duration: Jan. 1, 1994 - Dec. 31, 1995 (2 yrs.); this report summarizes activities through Oct. 1995

Study location(s): six canal and mine lake sites in Dade County: Rinker Lake North (Rinker FEC quarry), Tarmac Lake, Rinker Lake South (Krome Ave.), Florida Rock Lake, Dade-Broward Canal north end, Dade-Broward Canal south end.

Melaleuca forest type: sampling sites were stratified as lake/canal open water, littoral zone, or wooded area adjacent to littoral shelf or levee. Personal observation by the reviewer indicates that these wooded areas were almost exclusively dense mature melaleuca.

Sampling design/methods: Wildlife defined as: mammals, birds, herps, macroinvertebrates, fishes, zooplankton, and phytoplankton. Most sampling was done in lakes and littoral zones only. Only birds were "sampled" in melaleuca areas, using a transect method. Angle and distance were recorded and sightings were denoted as to whether the bird was seen flying overhead or perching/standing. It does not appear that bird transects actually entered the interior of melaleuca forests. Sampling frequency was monthly.

Results/Conclusions: Results were not summarized for melaleuca areas compared with other habitats. It was noted that the Florida Rock site is a good site for birds "due to the proximity of a marsh and wooded area." The wooded area is presumably melaleuca. This observation is consistent with other investigators who note that an increased number of distinct habitats (such as is often found in disturbed areas) leads to a greater diversity of birds, and that the utility of melaleuca habitats appears related to the nature and quality of surrounding habitat.

Reviewer's comments/ weaknesses of study: This reviewer analyzed the 7-quarter cumulative bird observations list and found that: (1) of 51 total species observed at all sites, 36 of those were found in melaleuca woods, (2) of these 36 species, 8 of those are state or federal listed species, (3) of those 36 species observed, 15 are listed by Dalrymple as being wetland dependent, 2 are noted as seasonally dependent, and 2 others are known by this reviewer to be commonly found in wetland edge vegetation, (4) abundance in wooded areas generally greater than open water and often greater than littoral areas; number of species in wooded areas comparable to, often greater than, littoral zone, all but one site had 14-15 species in wooded areas; (5) reviewer-calculated Shannon-Weaver Index was highest for wooded areas in 4 of 6 sites, comparable to littoral zone at 1 of 6 sites, and significantly less than littoral zone but much greater than open water for 1 of 6 sites. Author's knowledge of birds seems somewhat weak -- many common names out of date, some sightings questionable. No information on site selection -- are habitats within a site comparable hydrologically, are all littoral sites approx. the same age, can information from the same habitat be compared from site to site? Or does surrounding habitat influence the results?

Author: D.R. Richardson (1977)
Title: Vegetation of the Atlantic Coastal Ridge of Palm Beach County, Florida
Affiliation: Dept. Biological Sciences, Florida Atlantic University, Boca Raton
Document: Article published in *Florida Scientist*; based on author's M.S. thesis

Summary: Study date & duration: utilized historical surveys from 1845-1870, 1940 and 1973 aerial photos, 1913-1973 soil surveys, and 1974-75 ground truthing studies.

Study location(s): All of coastal Palm Beach County west to Loxahatchee Slough and Conservation Area 1.

Melaleuca forest type: not specified

Sampling design/methods: Used historical information to reconstruct pre-drainage vegetation patterns and current information to map current vegetation patterns in study area. Developed possible successional scenarios to explain changes in vegetation from pre-drainage conditions. Inventoried plants at selected ground truthing locations, including areas invaded by melaleuca.

Results/Conclusions: Observed that many formerly wet prairie sites have been changed into pure stands of melaleuca or secondary pine forests over the past 40-70 yrs. Observed that the effect of melaleuca has been to eliminate many wet prairie species, including *Sagittaria, Hypericum,* and *Stillingia*, by "forming almost impenetrable stands. Also observed that severe and frequent fires may have played a role in eliminating these species. Observation at one site showed that most pure stands of melaleuca were devoid of all ground cover plants.

Reviewer's comments/ weaknesses of study: Species lists for entire sites only. No species information nor information on richness or abundance specifically for melaleuca stands.

Author: DiStefano (1982)
Title: The role of allelopathy in the invasion patterns of Melaleuca quniquenervia in southern Florida
Affiliation: University of Florida -- Gainesville
Document: Master's thesis

Summary: Study date & duration: 1980-81

Study location(s): Greenhouse studies conducted in Gainesville; some field inventories conducted in Lee County.

Melaleuca forest type: Melaleuca seedlings were used in the greenhouse study. Dense melaleuca stands were inventoried in the field.

Sampling design/methods: Experiments were conducted to identify allelopathic effects of melaleuca on native vegetation. Field inventories were conducted of melaleuca stands to provide indirect evidence of suppression of native species by melaleuca.

Results/Conclusions: Inconclusive. Possible allelopathic effects on slash pine were noted. Good information on species present in understory of melaleuca.

Reviewer's comments/ weaknesses of study: Evidence for allelopathy is largely inconclusive or circumstantial.

Figure 1   Distribution of Melaleuca in South Florida

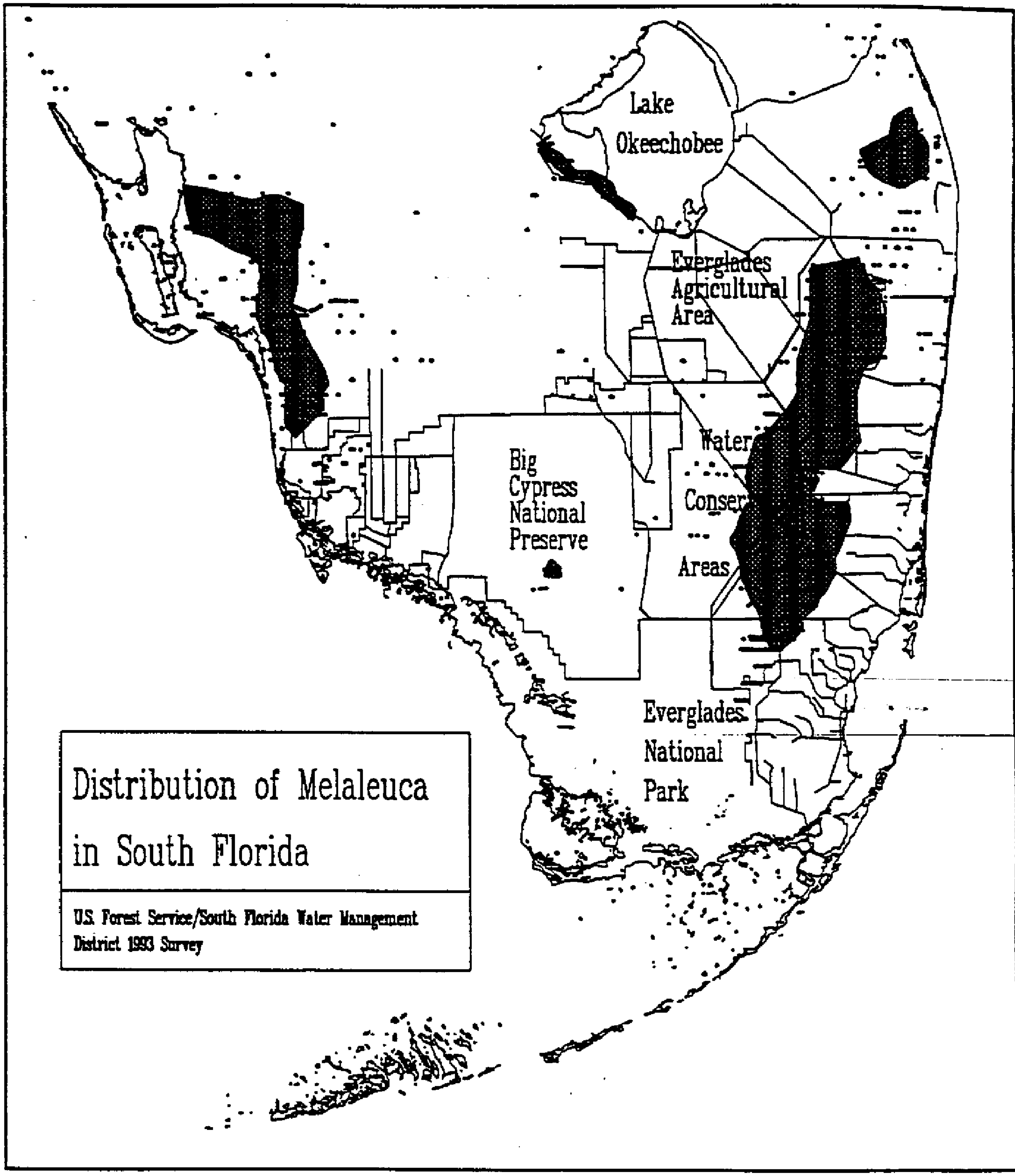

Figure 2 Richness vs. Cover Category - Species (based on Dalrymple & Dalrymple (1996))

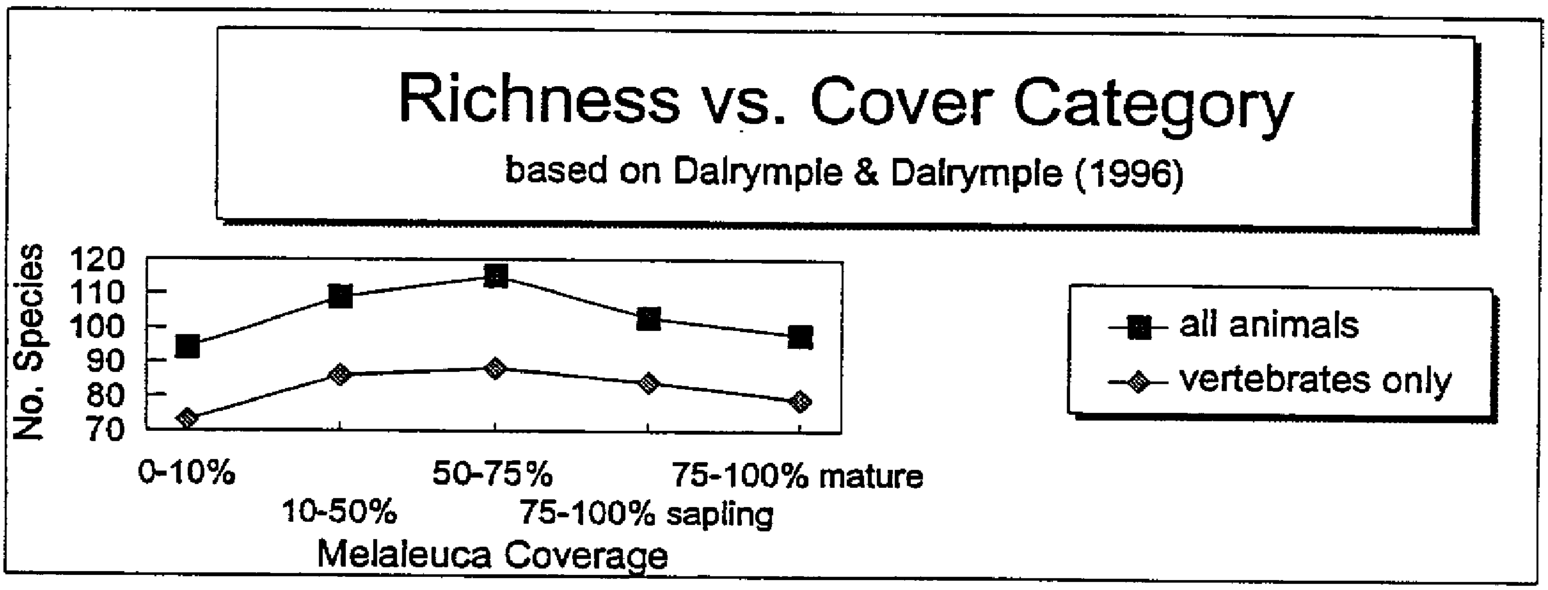

Figure 3 Abundance vs. Cover Category - Individuals (based on Dalrymple & Dalrymple (1996))

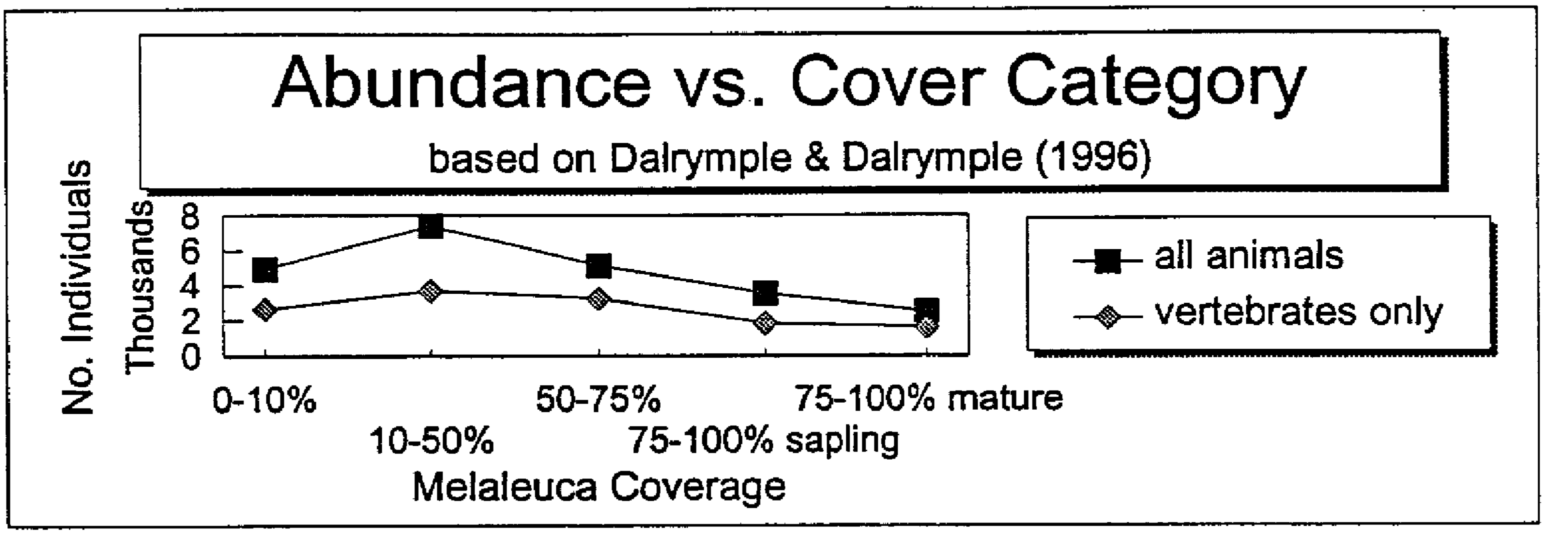

Figure 4 Percent Non-Native vs. Cover Category (based on Dalrymple & Dalrymple (1996))

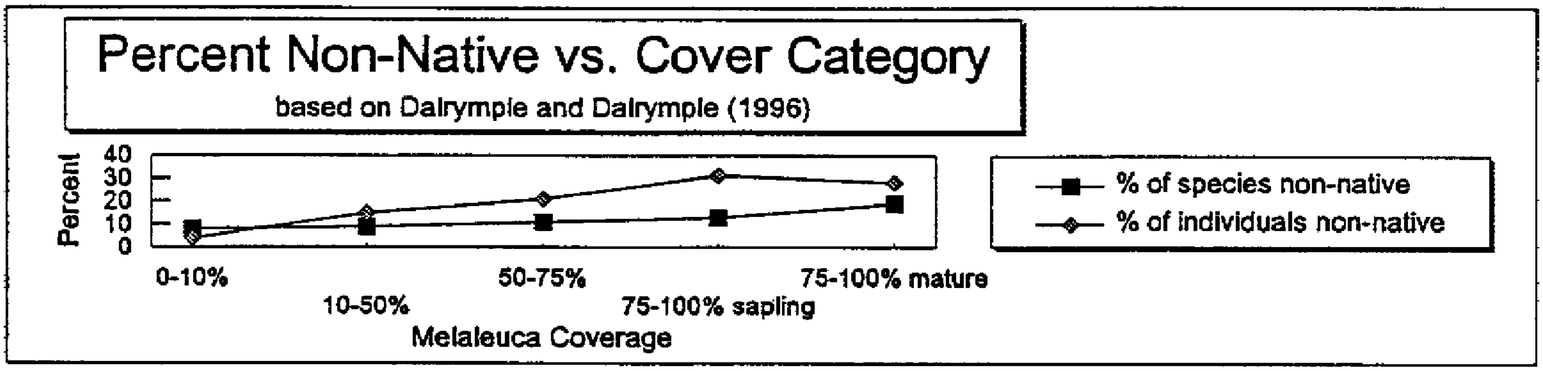

Figure 5 Percent Species by Habitat Association (based on Dalrymple & Dalrymple (1996))