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Remote Sensing Survey of *Melaleuca*

The spread of *Melaleuca* in South Florida, and areas susceptible to invasion, were not readily identified on LANDSAT imagery.

Introduction

This project attempted to employ advanced remote sensing techniques by using computer analysis of Earth Resources Technology Satellite (ERTS, now LANDSAT) imagery to determine the areal extent of the exotic tree, *Melaleuca quinquenervia* (commonly called cajeput or punk tree) in south Florida. The need for such information became apparent during the course of the University of Florida's Center for Wetlands study, "Carrying Capacity for Man and Nature in South Florida."[1] There was concern that *Melaleuca* dominated a significant part of the south Florida environment and that it

Abstract: *Remote sensing was used to attempt to define the areal extent of the introduced tree* Melaleuca quinquenervia *in selected portions of south Florida. The area occupied by* Melaleuca *has increased markedly in recent years, in part because of population-induced site modifications including hydroperiod changes resulting from artificial drainage, cutting of the native vegetation, and burning. LANDSAT imagery and computer analysis of the imagery by the General Electric Company's IMAGE-100 machine were used to attempt to determine the extent of* Melaleuca *over much of Lee County and portions of Collier County in southeastern Florida. It was possible to identify some areas occupied by* Melaleuca, *but not with adequate precision for purposes of detailed mapping. Efforts using the GE IMAGE-100 Pattern Recognition System were largely unsuccessful in identifying a unique signature for* Melaleuca *because the tree is found on a wide variety of sites, it occurs in various degrees of mixture with other species, and in widely varying densities and size classes. Signatures which identified all of the known large, mature stands dominated by* Melaleuca *also identified portions of other ecosystems which do not contain* Melaleuca, *particularly cypress and mangrove. Signatures narrow enough to exclude cypress and mangrove failed to identify all of the large, nearly pure* Melaleuca *stands. Some preliminary testing of the technique was done with other south Florida ecosystems in the hopes of being able to identify those ecosystem types which might be potentially susceptible to* Melaleuca *invasion. Ecosystems which are structurally simple such as barren areas, improved pastures, and some mangroves were readily identified, whereas those with a more complex structure such as pine forests, cypress swamps, and mixed pine-cypress-hardwood stands proved difficult to identify.*

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was rapidly invading a variety of sites, possibly displacing native vegetation.

South Florida has been susceptible to the establishment and rapid spread of a number of introduced plants and animals. The facility to which exotic species can be introduced has aroused the concern of both federal and state land management agencies and local conservation organizations. Although the concern is justified, a lack of knowledge of the ability of exotics to invade different sites, coupled with misconceptions about distribution patterns and the factors that influence and control spread, has resulted in labelling the exotics as the agents responsible for *causing* environmental change, rather than recognizing the exotics as *indicators* of already existing environmental changes.

Two complementary theories are often cited to explain the causes of the exotic-plant-and-animal problem in south Florida. First, due to its unique geographical position and configuration—a peninsula jutting into the tropics—Florida has been biogeographically isolated. As a consequence, aggressive exotic species preadapted to the extant conditions can easily become naturalized once introduced. Second, much of south Florida has been altered by drainage projects, water control programs, and subjected to the introduction of nutrient-rich waters from agricultural runoff and sewage effluent. These have altered the natural ecosystems, thus permitting the establishment of many species that are characteristic colonizers of disturbed sites. Also, ecosystems may have been created that are more suitable for new species which can out-compete native vegetation.

Melaleuca was introduced into Florida in the early 1900's. Two independent introductions occurred, one in Broward County near

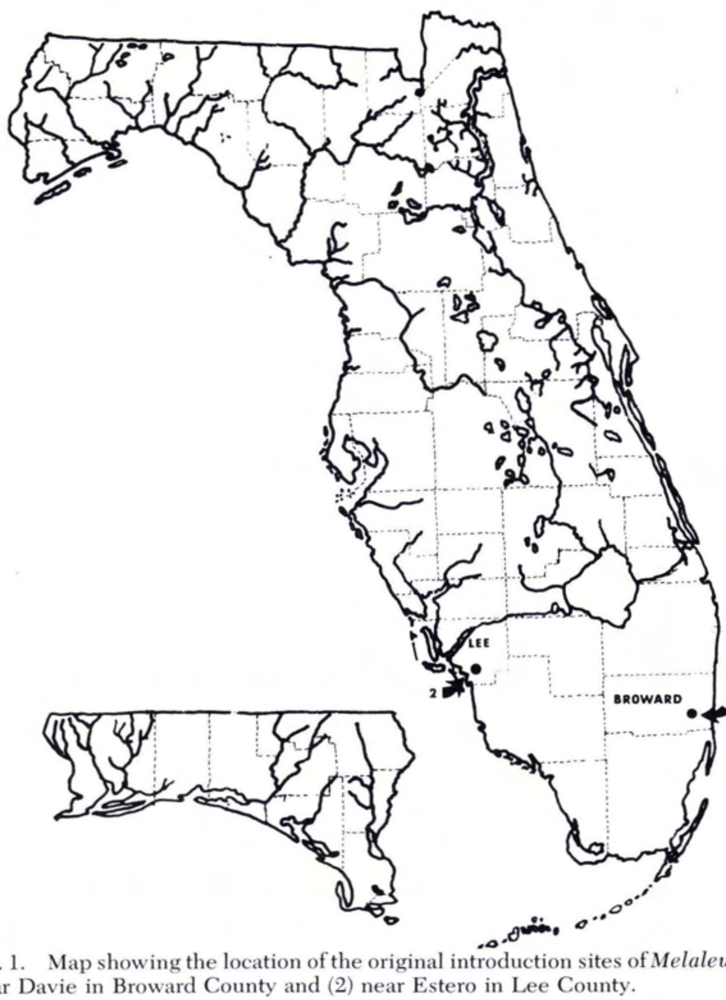

FIG. 1. Map showing the location of the original introduction sites of *Melaleuca*: (1) Near Davie in Broward County and (2) near Estero in Lee County.

Davie, the other in Lee County near Estero. (Figure 1). The original hope was that *Melaleuca* would provide a resource for a new forest products industry. Although major economic utilization never materialized, the spread of *Melaleuca* was enhanced through its use as wind breaks and fence rows, and its popularity as a fast-growing ornamental.

The present general distribution pattern of *Melaleuca* is largely confined to the two coastal regions as is shown in Figure 2. Although the largest stands are centered around the areas of original introduction, its spread tends to lie within an area which has been greatly altered by human activities. Very little *Melaleuca* has invaded the relatively undisturbed inland portions which include the Everglades National Park, Conservation Area 3, and the Big Cypress Swamp.

The results of field studies carried out as part of the original Center for Wetlands' project[2] indicated that *Melaleuca* will readily invade many areas where the ecosystems have been altered and simplified by human activities. Undisturbed natural vegetation types were found to be resistant to invasion. A continuation of these studies under this project has produced additional results which further substantiate the existence of these invasion patterns. It appears that *Melaleuca* may become the dominant vegetation type only in those areas where it already occurs or where disturbance has been relatively recent. In other words, existing young stands will tend to consolidate, but further spread will be limited to newly disturbed areas, Where conditions are uniform, such as the drained prairies of the east coast, these consolidated stands may be rather extensive. On the west coast, where the native

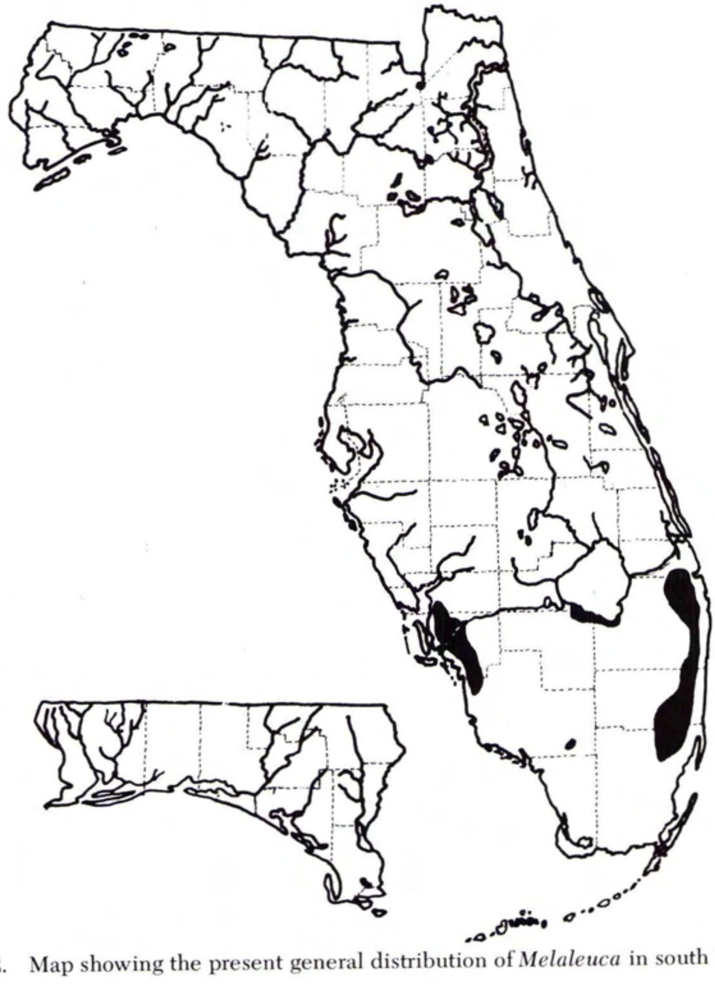

FIG. 2. Map showing the present general distribution of *Melaleuca* in south Florida.

vegetation consists of a mosaic of different types, a patchy pattern of *Melaleuca* stands appears to be developing.

It should be emphasized that *Melaleuca* does not displace native vegetation but replaces that which has already been lost through environmental alteration. For example, in drained sawgrass prairies or cypress forests the native vegetation can no longer maintain itself. *Melaleuca* appears to be best suited to altered conditions. Even without the invasion of *Melaleuca*, these sites would not maintain their original vegetation.

Further verification and assessment of these conclusions would be greatly enhanced by a detailed accurate map delineating the present mature and developing stands of *Melaleuca*. However, the extensive ground truth and aerial surveys carried out as part of this project revealed that large uniform stands of *Melaleuca* are few, and actively expanding areas are indeed restricted to the more heavily disturbed coastal regions of the state. Also, the areal extent of *Melaleuca* is considerably less than first appears from cursory observation, because the tree tends to be common along roadsides where it is readily visible.

An original purpose of this project had been to produce baseline data on the present extent of *Melaleuca* for comparison with similar scans at a later date. However, the conditions described above, along with the inherent variability found within and among *Melaleuca* stands due to different ages, density, stand composition, and substrate, proved to be insurmountable obstacles in producing a region-wide distribution map of *Melaleuca* from LANDSAT imagery. The problems encountered and the results obtained are discussed in later sections of this paper.

Remote Sensing Systems

Recent technological advances have made unobtrusive observation and measurement of environmental systems *in situ* not only possible but practical for routine and continuous application. Remote sensing has eased the burden on the researcher for obtaining data in isolated areas and has minimized errors in data collection associated with the presence of human operators.

For the project under consideration, the opportunity is presented to explore several methods of remote sensing with the long-range goal of finding a method appropriate to long-term monitoring of all natural and urban systems in the area. Because this research is exploratory, the emphasis is on suitability of the total remote sensing system to accomplish the task, discounting economic considerations. However, preliminary cost comparisons were made to aid the selection of a remote sensing method assuming that all methods are equally suitable.

To narrow the choices of potential methods, the system chosen must be capable of identifying *Melaleuca* in the six-county, 25,000-square-mile-area of south Florida. Resolution of approximately one acre would be acceptable. The method also should be capable of identifying *Melaleuca* under various conditions including pure stands, mixed stands, and various ages.

In order to meet these requirements, five alternative methods were introduced as possible candidates. The methods include field survey, aerial survey, aerial photography, arial multispectral scanning and satellite multispectral scanning. A summary of the principal advantages and disadvantages is provided in Table 1.

The combination of the multispectral scanner and an earth orbiting satellite produces one of the most powerful remote sensing systems currently available. One of the main advantages of this technique is that the satellite provides periodic coverage every 18 days of any location on the earth's surface. This allows temporal comparisons to be made in a very simple manner. A major advantage is that the greatest part of the cost of using such systems is borne by the U.S. Government in providing the LANDSAT system. Thus, the user pays only a small fraction of the actual data collection cost. The cost involved in information storage and retrieval, and the cost of the magnetic tapes, are the only costs actually incurred by the user. Of course, the cost of computer analysis of the data is significant to the user, but perhaps the benefits of this automated analysis would far outweigh the costs. The two main disadvantages are the limited resolution (about 1.5 acres), and the fact that the fixed-band multispectral scanners are not appropriate for sensing every desired ground feature.

The combination of satellite multispectral scanning systems such as LANDSAT and a computer processing system has the potential to fulfill the remote sensing requirements of many projects associated with monitoring natural and manmade features of the earth's surface. Because technology is advanced, limitations in resolution and band selection for spectral analysis can be overcome in order to make this method of remote sensing a standard tool for the earth researcher.

Remote Sensing Methodology

Following a review of the available methods of conducting the *Melaleuca* survey, it was decided that the relatively new techniques of image interpretation would be explored as a parallel goal of the project in order to determine if image interpretation techniques could be used in natural vegetation studies. The methodology devised to accomplish these goals divided the project into three major phases:

- Feasibility of the satellite survey/image interpretation for identifying *Melaleuca*;
- A production run of the entire survey area to produce a *Melaleuca* range map; and
- Evaluation of results concerning accuracy and suitability.

The methodology was contingent on the assumption that the feasibility could be demonstrated.

The feasibility of utilizing the LANDSAT data and image interpretation was expedited by the convenience of a nearby GE-100 facility maintained by NASA at the Kennedy Space Center. One of the purposes of this installation is to help potential users decide if their application is amenable to the image interpretation process. Thus, with preliminary ground truth data of known areas of *Melaleuca*, a trip was arranged to visit this facility. The GE-100 machine was set up with a scene which included an area on the west coast of Florida near Ft. Myers that contains a large stand of *Melaleuca*. The machine was then entered into the analysis mode and a sample signature was constructed. The signature was then used to alarm all other areas that have similar signatures and these in turn were displayed on the CRT. The process was repeated three times until a signature was developed that would alarm areas that could possibly contain *Melaleuca*.

At this point, it was felt that the technique could be useful to complete the project, although full feasibility had not been proven.

Remote Sensing Results

The initial trip to the NASA Kennedy Space Center Earth Resources Office seemed to indicate that a unique signature for *Melaleuca* could be obtained from a LANDSAT scene by using the GE-100 pattern recognition machine. Following this initial feasibility trip, a contract was let to perform the production work involved in producing *Melaleuca* maps for six counties in South Florida. A second trip to the NASA facility was conducted to further determine the feasibility of using additional ground truth data obtained since the first trip. The results were quite disappointing because the

Table 1. Available Remote Sensing Methods Applicable For Use in Identifying *Melaleuca*

Method	Principal Advantages	Principal Disadvantages
Field Survey	No special equipment, little training of personnel.	Lose areas of inaccessability, relatively small coverage, requires maintenance of field crews for survey of large areas.
Aerial Survey	Covers large tracts of ground.	Requires expense of airplane, loss of accuracy in pinpointing isolated features, possibility of missing sites.
Aerial Photography	Minimize flying time, time available for detailed analysysis. Photographs can be used for other purposes to reduce cost.	Requires airplane expense, requires trained photogrammetrist, requires special aerial cameras, not all ground features identifiable.
Aerial Multiscanning	Permits more detailed analysis of ground features	Requires airplane expense, requires scanners, requires computer software to analyze data.
Satellite Multiscanning	Data available from existing sources, permits more detailed analysis. of ground features, amenable to long term study.	Requires computer software to analyze data, resolution limited.

more complete ground truth data allowed definite conclusions to be drawn regarding the nature of many of the alarmed areas in the GE-100 display. Although a number of large mature stands of *Melaleuca* were correctly identified, the majority of the alarmed areas were definitely not stands of *Melaleuca*. In addition, several known areas which contained fairly significant stands of *Melaleuca* were not alarmed at all. Several attempts to refine the signature were made, but similar disappointing results were obtained.

Following this second trip to the NASA KSC facility, discussions with the contractor were held regarding their expectations after hearing of this extremely limited success in *Melaleuca* idenitification by using the best ground truth data. They stated that their superior facilities should provide the means necessary to successfully identify *Melaleuca* using ERTS data. A substantial amount of training time, about 12 hours, was budgeted in their contract, and they felt that this would be sufficient to allow use of a wide range of special-purpose training techniques available in their GE-100.

A series of LANDSAT scenes covering south Florida were obtained from the NASA KSC Earth Resources Office. In addition, a recent LANDSAT scene was obtained from the NASA LANDSAT data bank in Sioux Falls, South Dakota. At this time the contractor was sent copies of reports on the ecology of *Melaleuca*, and maps delineating the ground truth data for stands of *Melaleuca*. Shortly after they received all of this data, one of the authors flew to the contractor's facility to work with them for four days. At the end of this period, no significantly better results were produced as compared to those from the second NASA KSC trip. The contractor felt that some additional training time using different scenes, and a temporal analysis obtained by looking at two tapes of different dates simultaneously, would give the added information to allow a unique spectral signature for *Melaleuca*. However, even after attempting these additional techniques, they were forced to conclude that no unique signature for *Melaleuca* would be found.

This original effort to obtain a signature for *Melaleuca* and to produce a *Melaleuca* range map resulted in limited success as shown in Plate 1. This figure shows the area south of Ft. Myers which contains the largest stands of mature *Melaleuca* known in South Florida. The circles in Plate 1 show areas alarmed in response to the best signature which could be determined for *Melaleuca*. These circles contain alarm areas which are know to be large, mature stands of *Melaleuca*. However, the circles also contain areas known to contain mature *Melaleuca* which are not alarmed. Major areas to the southwest in Plate 1 are alarmed as *Melaleuca*, but in fact are known to be pure mangrove. Major areas to the southeast are alarmed as *Melaleuca*, but in fact are known to be mixed cypress and pine forests. In addition, the entire image of Plate 1 contains a substantial amount of *Melaleuca* in young and/or mixed stands which is not alarmed at all. Thus, this best signature underestimates the known amount of *Melaleuca*, and erroneously identifies some mangrove and some mixed cypress and pine as *Melaleuca*. As the young stands of *Melaleuca* grow and mature, their spectral properties should more closely represent those of present mature stands, and should be more readily identified by using LANDSAT data in the future.

The reason for the ambiguity between the signature for *Melaleuca* and that of mangrove, cypress, and pine can be seen by examining Figure 3. This figure shows that the spectral properties of *Melaleuca*, mangrove, cypress, and pine are so similar in the band of frequencies used by LANDSAT that it would be extremely difficult to uniquely separate the signature of *Melaleuca*.

At this stage of the project, it became clear that the original goal of producing county

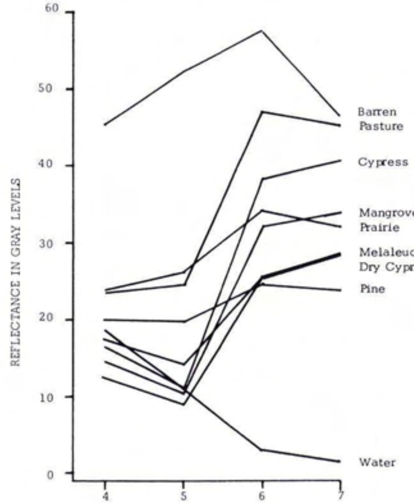

FIG. 3. Mean spectral signature of LANDSAT classification units. Bandwidths (micrometres) are 4, 0.5 to 0.6; 5, 0.6 to 0.7; 6, 0.7 to 0.8; and 7, 0.8 to 1.1.

PLATE 1. Two-date composite LANDSAT image. *Melaleuca* classification is shown in orange.

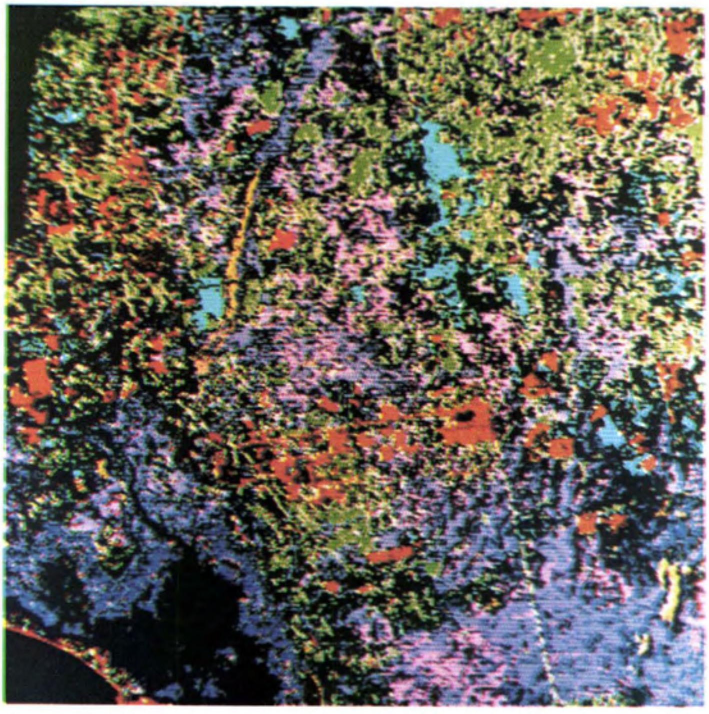

PLATE 2. Thematic composite of classification derived from LANDSAT-II image of Fort Myers test area. Themes are *Melaleuca* (orange), mangrove (blue), wet cypress (yellow), dry cypress (purple), pine (pink), prairie (green), pasture (cyan), and barren (red). Unclassified areas including water are black.

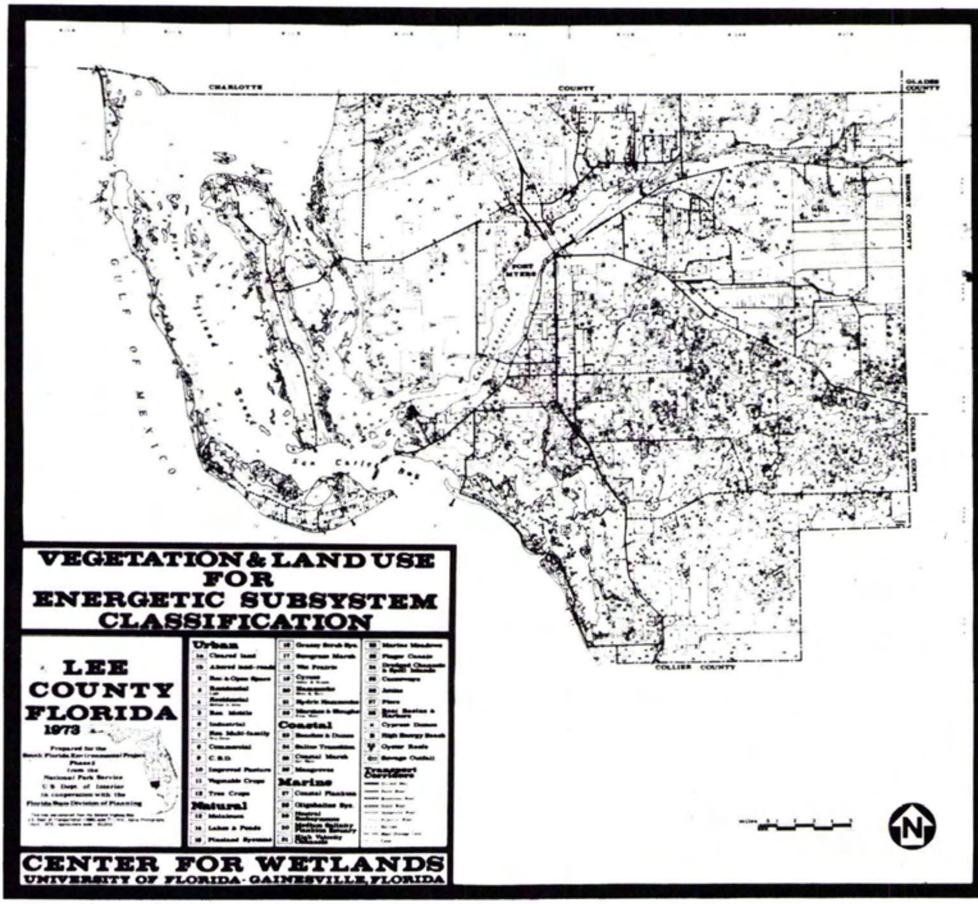

FIG. 4. Vegetation and land use map of Lee County, Florida, prepared by the Center for Wetlands, University of Florida.

Melaleuca maps for south Florida was not going to be a worthwhile effort. The contract goal was modified from producing county maps to that of a feasibility study using LANDSAT data in order to identify several types of natural vegetation in the Ft. Myers area. Training and classification of the data produced a vegetation map for the Ft. Myers area which was broken down into the following classifications: *Melaleuca*, Mangrove, Wet Cypress, Dry Cypress, Pine, Prairie, Pasture, Barren, Water, and Unclassified. The composite of all of these vegetation types is shown in Plate 2. To a reasonable extent these LANDSAT image classifications match those of the vegetation map for the Ft. Myers area produced by the University of Florida Center for Wetlands. See Figure 4.

Ecosystems of structural simplicity such as barren areas, pasture, and some mangrove were correctly identified as can be determined by comparing the distribution of these ecosystems as shown in the composite (Plate 2) and the Wetlands Vegetation map (Figure 4). Ecosystems with a more complex structure such as *Melaleuca*, cypress, and pine were delineated less accurately than the simpler ecosystems.

TABLE 2. AREA OF LANDSAT CLASSIFICATION UNITS FOR FT. MYERS TEST SITE

Classification Unit	Hectares	Percent
Melaleuca	344.3	0.4
Mangrove	1,526.6	1.8
Wet Cypress	434.9	0.5
Dry Cypress	10,694.9	12.5
Pine	4,727.9	5.5
Prairie	10,754.2	12.5
Pasture	2,027.6	2.4
Barren	4,680.4	5.5
Water	9,260.7	10.9
Unclassified	41,197.6	48.0

Almost 84 percent of the total area in the test site is accounted for by four of the ten classification units: dry cypress, prairie, water, and unclassified. Only 0.4 percent of the total area was determined to contain large mature stands of *Melaleuca* (Table 2).

Conclusions

Current monitoring of the spread of *Melaleuca* in South Florida

The results obtained in this project lead us to the conclusion that ERTS imagery is at best an imperfect tool for monitoring complex successional vegetation types dominated by *Melaleuca* in south Florida. The General Electric IMAGE-100 machine is a sophisticated hardware/software package for analyzing LANDSAT imagery, yet even through its use by experienced scientists we were unable to accurately delineate the extent of *Melaleuca* in the study area. We conclude that the reason the technique is unsatisfactory stems from the fact that *Melaleuca* stands are extremely diverse and therefore have a great deal of spectral reflectance variability. Many of their spectral reflectance properties are similar to those of other common (and also variable) south Florida vegetation types. *Melaleuca* occupies a wide variety of sites, occurs in varying densities, and is found in conjunction with a broad range of other plant species. These properties prohibit the characterization of a single kind of vegetation as being dominated by *Melaleuca*. Numerous spectral signatures would therefore be required to encompass the range of vegetation types in which *Melaleuca* is a prominent component.

Future monitoring of *Melaleuca*

We conclude that future studies aimed at monitoring *Melaleuca* in South Florida should be feasibility oriented rather than production oriented. It is clear that the LANDSAT approach has many problems, yet the system is flexible enough to warrant further investigation, perhaps exploring the possibility of characterizing a variety of different kinds of ecosystems containing *Melaleuca*. The use of LANDSAT data holds great promise for the future, but a significant effort will be required to obtain useful spectral signatures for natural vegetation types. *Melaleuca* is very difficult to distinguish on standard black-and-white aerial photographs, so the only viable options to the LANDSAT approach are the possible use of false-color infrared photography, color aerial photography, and manned ground and aerial observation techniques, all of which are expensive and time-consuming.

Current extent of *Melaleuca* in South Florida

It is clear that *Melaleuca* is an extremely important biological force in south Florida ecosystems and that its importance is increasing. Right now, however, it occupies relatively few dense, mature stands of sizeable area. Rather, it is much more commonly encountered as an aggressive successional invader of disturbed habitats such as roadsides and those ecosystems which have been modified through drainage, fire, logging, and agriculture. These young, variable density stands will determine subsequent importance of *Melaleuca* in south Florida. Future patterns of hydroperiod, mechanical disturbance, and fire will play important roles in the fate of *Melaleuca*. It is an extremely important species and one which certainly merits further research, observation, and close monitoring.

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