Mapping Exotic Vegetation in the Everglades from Large-Scale Aerial Photographs

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Abstract

A detailed vegetation study was conducted at a site in the East Everglades to map the distribution of Melaleuca quinquenervia, *an aggressive exotic species targeted for eradication. This high-resolution mapping effort involved the use of 1:7,000-scale color-infrared (CIR) aerial photographs and integrated geographic information system (GIS) and Global Positioning System (GPS) technologies to create a digital database of native and exotic vegetation within a 1.5- by 11-km study area. Hardcopy maps were produced at 1:5,000 scale depicting plant species distributions and information on* Melaleuca *height and density classes interpreted from the CIR air photos. An accuracy assessment conducted using a helicopter yielded an overall map accuracy of 94 percent. It is anticipated that these products will allow Park managers to assess the effectiveness of exotic vegetation management practices and help to insure the preservation of native plant communities in this section of the Everglades.*

Introduction

South Florida is the only region within the conterminous United States where tropical, subtropical, temperate, and endemic vegetation communities coexist, creating a unique and floristically diverse ecosystem (Doren, 1991; Davis and Ogden, 1994). Exotic plant species, such as *Melaleuca* (*Melaleuca quinquenervia*), Brazilian pepper (*Schinus terebinthifolius*), and Australian pine (*Casuarina* spp.), however, pose a significant and immediate threat to Everglades ecosystems by permanently displacing native vegetation communities and irreversibly modifying habitat (Bodle *et al.*, 1994). One of these, *Melaleuca* (commonly known as paperbark, cajeput, and punk tree), is a native of eastern Australia and has seriously impacted much of the Everglades (DeVries and Doren, 1992; Figure 1). The unique mosaic of vegetation in the Everglades is highly susceptible to invasion and subsequent displacement by *Melaleuca*, especially following natural and anthropogenic disturbance. Expansion of *Melaleuca* is currently contributing to ecological deterioration of the unique vegetation communities found in Everglades National Park (Hofstetter, 1991).

Melaleuca has been designated a Category I Exotic Pest Plant by the Florida Exotic Pest Plant Council (FEPPC), a Florida Prohibited Aquatic Plant by the Florida Department of Natural Resources (FDNR), and a Federal Noxious Weed by the U.S. Department of Agriculture (USDA) (FDNR, 1993; USDA, 1993; FEPPC, 1997). These designations prohibit its transport within the state of Florida as well as its import into the United States (Bodle *et al.*, 1994). The presence of *Melaleuca* in Everglades National Park was first documented in 1967, but was not recognized as a problem until the late 1970s, when it was observed to have become widely distributed near the northern and eastern boundaries of the Park (DeVries and Doren, 1992; LaRosa *et al.*, 1992). In recent years, particularly since the occurrence of Hurricane Andrew in August of 1992 which caused extensive damage to native forest communities and created favorable conditions for the spread of *Melaleuca*, expenditures to control *Melaleuca* have increased (Duever *et al.*, 1994). To-date, well over 1.7 million dollars have been spent to curtail the growth of *Melaleuca*.

Park managers require information about the area of *Melaleuca* infestation and the height, density, and spatial distribution of individual stands in order to determine the most effective allocation of current and future resources. Consequently, the goal of this study was to provide Everglades National Park with a detailed geographic information system (GIS) digital database and corresponding hardcopy map products documenting the spatial distribution of *Melaleuca* in what is referred to as Everglades National Park Site 26 (ENP 26) (Figure 2). Specific objectives are listed below:

- Interpret large-scale color-infrared (CIR) aerial photographs of ENP 26 to compile a 1:5,000-scale detailed vegetation map and GIS digital database for monitoring the distribution of *Melaleuca* as well as additional exotic and native vegetation within ENP 26.
- Identify characteristics of *Melaleuca*, such as height and density classes, that can be discerned on the aerial photographs; conduct an accuracy assessment verifying the photointerpretation; and provide Park managers with spatial statistics documenting the extent of *Melaleuca* invasion.
- Define mapping procedures that can be extended to other areas of Everglades National Park threatened by the invasion of exotic plant species.

Study Site

The study site, known as Everglades National Park 26 (ENP 26) located in the East Everglades Acquisition Area (EEAA), measures 1.5 km (north-south) by 11.2 km (east-west) and encompasses an area of 1,680 hectares (ha). At present, ENP 26 is characterized by large expanses of seasonally inundated sawgrass marshes (*Cladium jamaicense*) interspersed with lesser amounts of muhly grass (*Muhlenbergia filipes*), various mixed graminoids, and forbs. Tall sawgrass and cattail flats (*Typha* spp.) account for the appearance of localized topography, although actual terrain relief is negligible. Willow (*Salix caroliniana*) and wax myrtle (*Myrica cerifera*) thickets are scattered throughout the area, as well as tree island communities dominated by bayhead and/or tropical hardwood hammock species (Hoffstetter and Hilsenbeck, 1979). *Melaleuca* occurs throughout the study area, ranging in density from in-

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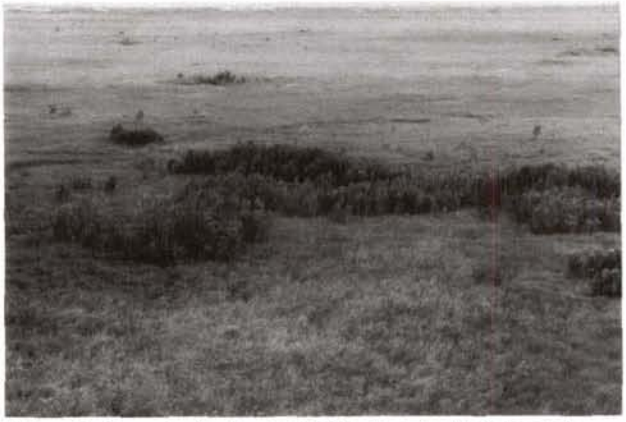

Figure 1. Monotypic stand of high density *Melaleuca* invading a sawgrass (*Cladium jamaicense*) prairie.

dividual plants (outliers) to large monotypic forests comprised of several age classes (DeVries *et al.*, 1993). Its close proximity to a prodigious seed source of dense *Melaleuca* forests outside of the Park in Dade County, coupled with conditions favorable to *Melaleuca* establishment (e.g., frequently fluctuating hydrologic regimes and wildfires), make the EEAA vulnerable to conversion from a seasonally inundated prairie to a forested wetland dominated by exotic plant species (Molnar *et al.*, 1991).

Mapping Techniques

Previous studies conducted by the Center for Remote Sensing and Mapping Science identified CIR large-scale, low altitude aerial photographs as the best primary data source for mapping *Melaleuca* in the Everglades (Welch *et al.*, 1995; Welch *et al.*, 1999). A single strip of 20 1:7,000-scale CIR photographs were acquired of ENP 26 from an altitude of 1,167 m on 29 May 1996 using a Zeiss RMK A 15/23 mapping camera (f = 153 mm). These photographs, with a ground resolution of better than 30 cm, were the primary source of information employed in developing a detailed digital database in the Environmental Systems Research Institute (ESRI) ARC/INFO format and associated 1:5,000-scale vegetation maps of the study site.

A dense network of natural feature ground control points (GCPs) such as individual trees or small tree islands were transferred to the 1:7,000-scale photographs from 1:40,000-scale U.S. Geological Survey (USGS) National Aerial Photography Program (NAPP) photographs employed in the above mentioned 1:15,000-scale vegetation mapping project (Welch *et al.*, 1999). The locations of the GCPs are specified in the Universal Transverse Mercator (UTM) ground coordinate system referenced to the North American Datum of 1983 (NAD 83) and are correct to within approximately ± 3 m. Approximately 20 GCPs were identified for each 1:7,000-scale photograph, including common pass points shared between stereopairs. The GCPs enabled a second-degree polynomial solution using the Desktop Mapping System (DMS) software package (*R-WEL*, Inc.) to establish rectification coefficients for each photograph. With these rectification coefficients, the UTM coordinates of features identified on the 1:7,000-scale CIR air photos (which cover a fraction of the area of the 1:40,000-scale NAPP photo) were established to better than ± 2.5 m (RMSExy) for each of the photographs, equivalent to less than ± 0.5 mm at the final map scale of 1:5,000.

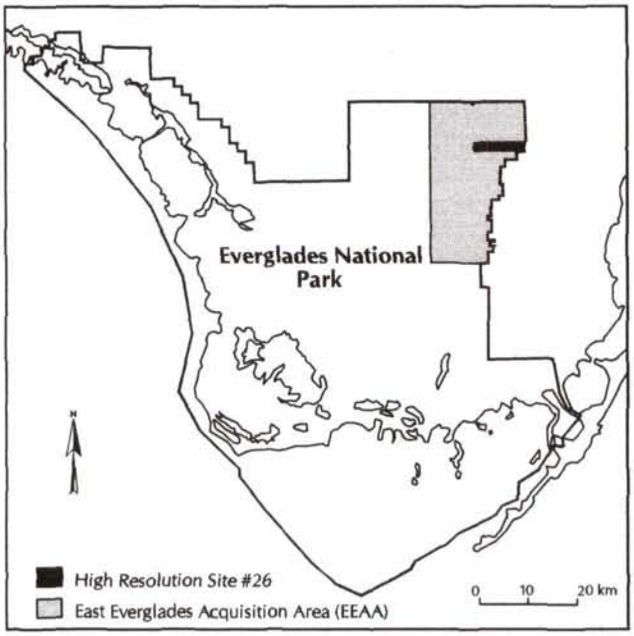

Figure 2. ENP 26 is located at the eastern boundary of Everglades National Park. The wet prairies of East Everglades are particularly susceptible to invasion by *Melaleuca* due to favorable environmental conditions and nearby seed sources.

Photointerpretation Procedures

Prior to beginning photointerpretation, field reconnaissance was undertaken by Center for Remote Sensing and Mapping Science and Everglades National Park personnel using a National Park Service Bell Jet Ranger helicopter. Field measurements of density and height were recorded for six randomly selected sites of *Melaleuca* infestation within the study area. The UTM coordinates associated with these field sites were recovered using a Trimble Basic GPS unit. In addition, a Dell Latitude XPi Pentium laptop computer loaded with Field Notes software (PenMetrics, Inc.) was employed to enter annotations regarding site conditions and vegetation cover. The laptop computer was connected to the GPS unit via a serial connection, and satellite signals were received using an external antenna (Welch *et al.*, 1995). In this way, the photointerpreter is able to efficiently collect field site information linked to specific coordinates. These data, in turn, were used to correlate site conditions with unique signatures identified on the aerial photographs.

In order to include a higher level of detail on height and density of vegetation in ENP 26, additional classes were added to the Everglades Vegetation Classification System developed for the parent 1:15,000-scale mapping project (Jones *et al.*, 1999; Madden *et al.*, 1999). *Melaleuca* height classes were defined as (1) seedlings estimated at less than 1 m in height, (2) saplings at between 1 and 3 m, and (3) mature trees taller than 3 m. Four density classes also were distinguished on the aerial photographs. Scattered individuals indicated areas in which *Melaleuca* occupied less than 10 percent cover. Low density designated those areas where *Melaleuca* occupied 10 to 25 percent cover, medium density was estimated at between 26 and 75 percent cover, and high density was indicative of greater than 75 percent cover (Table 1).

Overall, 11 classes of native vegetation, human influence, open water, and four exotic species were added to the Everglades Vegetation Classification System. In this study,

TABLE 1. *MELALEUCA* WAS AGGREGATED INTO THREE CLASSES OF RELATIVE DENSITY AND HEIGHT

Density	Height
Scattered Individuals (less than 10 percent cover)	Seedings (less than 1 m)
Low Density (10 to 25 percent cover)	Saplings (1 to 3 m)
Medium Density (26 to 75 percent cover)	Mature (greater than 3 m)
High Density (greater than 75 percent cover)	

numeric modifiers indicating human influence, hurricane damage, and scattered individuals also were added and used in conjunction with vegetation classes. Vegetation classes were identified on the 1:7,000-scale CIR air photos and delineated in stereo using a Bausch and Lomb Zoom Stereoscope, Model 95 with 10× eyepieces. The optical magnification of the Zoom 95 system (approximately 7 to 20×) allowed the three height classes to be distinguished. Interpreted linework, along with fiducial marks, neatlines, GCP locations, and annotations, were scribed on a clear polyester overlay registered to the left photograph of each stereopair using a cartographic technical pen providing a line thickness of 0.18 mm.

During the photointerpretation process, special attention was paid to the identification of *Melaleuca* stands. *Melaleuca* tends to grow in dense, monotypic stands which decrease in density away from the center of invasion. High density stands of *Melaleuca* are characterized on the air photos by reddish-orange signatures (Plate 1). Additionally, its cylindrical crown shape, distinct shadow, and relatively fine texture allowed *Melaleuca* to be easily distinguished from native vegetation in ENP 26. Low density *Melaleuca* seedlings and/or small saplings were occasionally difficult to identify on the CIR photographs because they are often obscured by the surrounding matrix of taller, denser sawgrass. Each vegetation polygon identified on the photograph was labeled with a dominant vegetation category. If more than one species occurred in the polygon, secondary and/or tertiary vegetation classes were added as needed.

Although the ground resolution of the aerial photographs was better than 30 cm, the minimum mapping unit (MMU) for this project was established at 0.02 hectares, equivalent to a square area of 2 by 2 mm on the 1:7,000-scale aerial photographs. This is approximately equivalent to a 14- by 14-m area on the ground. Features that were of special interest but smaller than the MMU, such as individual seed trees and associated recruits, were denoted on the photographs by single points and subsequently added to the final map as a separate point coverage.

Database Development and Map Production

The production of a large-scale vegetation map and associated digital files from the annotated polyester overlays required several steps. These included (1) scanning the polyester overlays to create digital files, (2) registering the digital files to the UTM coordinate system, (3) editing and attributing the digital files, and (4) plotting draft map products for field verification. As a precursor to general map production, all point, line, and polygon vegetation boundaries delineated on the clear polyester overlays were converted to digital format and rectified to a common ground coordinate system. To do so, each overlay of delineated linework, point features, and GCPs was digitally scanned at 600 dots-per-inch (42 μm resolution). The raster image files were saved in Tagged Image File Format (TIFF) and imported to a SUN Sparc-10 workstation for use with the VTRAK (LaserScan, Inc.) software package. The VTRAK software is designed for raster-to-vector conversion using semi-automatic or fully automatic line-following algorithms.

Upon completion of the raster-to-vector conversion, all data were converted to the ARC/INFO ASCII exchange format (.LIN), also compatible with DMS. The DMS software was then employed to geocode the vector data using the rectification coefficients previously developed. After all vector data were rectified to the NAD 83 UTM coordinate system, the geocoded vectors were subsequently imported to ARC/INFO for editing, attributing, and map compilation.

With ARC/INFO, all polygons containing *Melaleuca* were classified as containing low, medium, and high density *Melaleuca*. Map collar information, including legend text, scale, locator inset map, and title, was added using the ARCPLOT module of ARC/INFO. To facilitate the practical use of hardcopy maps in the field, the final map was partitioned into two parts, denoted as ENP 26 West and ENP 26 East. These maps were plotted separately at a scale of 1:5,000 (Plate 2).

Quality control checks of the draft maps were performed by creating a point coverage of the annotated field data and plotting their respective locations directly onto the draft map. Each point was numbered and linked to a text file that described the ground conditions and vegetation cover as identified in the field. In this way, the photointerpreter could verify the correct attribute was assigned to a polygon containing field information. A second quality control check was performed by a photointerpreter other than the author, who reviewed the linework, map attributes and label placement to insure that no evident errors occurred during map compilation or interpretation.

Accuracy Assessment

Accuracy assessments of the vegetation maps required a pragmatic balance between helicopter rental cost of about $600 per hour and an adequate sample size to reliably estimate map accuracy. In this instance, constraints on helicopter use and available budgets limited flying time to about two hours. It was determined that, with this constraint, approximately 45 to 50 sample points could be visited for accuracy assessment. Additionally, based on the binomial distribution theory equation, the number of points necessary to achieve 85 percent accuracy (± 10 percent) was determined to be 49 sample points (Fitzpatrick-Lins, 1981). Subsequently, a coverage of 49 points located according to a systematic stratified random sampling scheme was developed for the study area. In some cases, more than one of the sample points fell within the same large (background) polygon of sawgrass. To reduce redundancy in sampling and increase representation of all vegetation classes, these points were repositioned from their original locations to the next closest polygon. In this way, the accuracy of vegetation classes that tended to occur in smaller polygons also was checked. Additionally, points which fell close to the edge of a polygon were moved to the center of the polygon in order to avoid ambiguity.

Navigation to the sample point locations by helicopter required input of their locations in geographic coordinates (latitude and longitude) to the National Park Service helicopter's GPS unit. This allowed a team of Center for Remote Sensing and Mapping Science and National Park Service personnel to navigate directly to the sample points and identify the existing vegetation cover. If more than one species was present, the team visually estimated the percentage of vegetation types in terms of dominant, secondary, and tertiary categories. In order to avoid introducing bias, observers had no *a priori* knowledge of the attribute associated with each point.

The accuracies of the dominant, secondary, and tertiary vegetation classes were established as the percentage of poly-

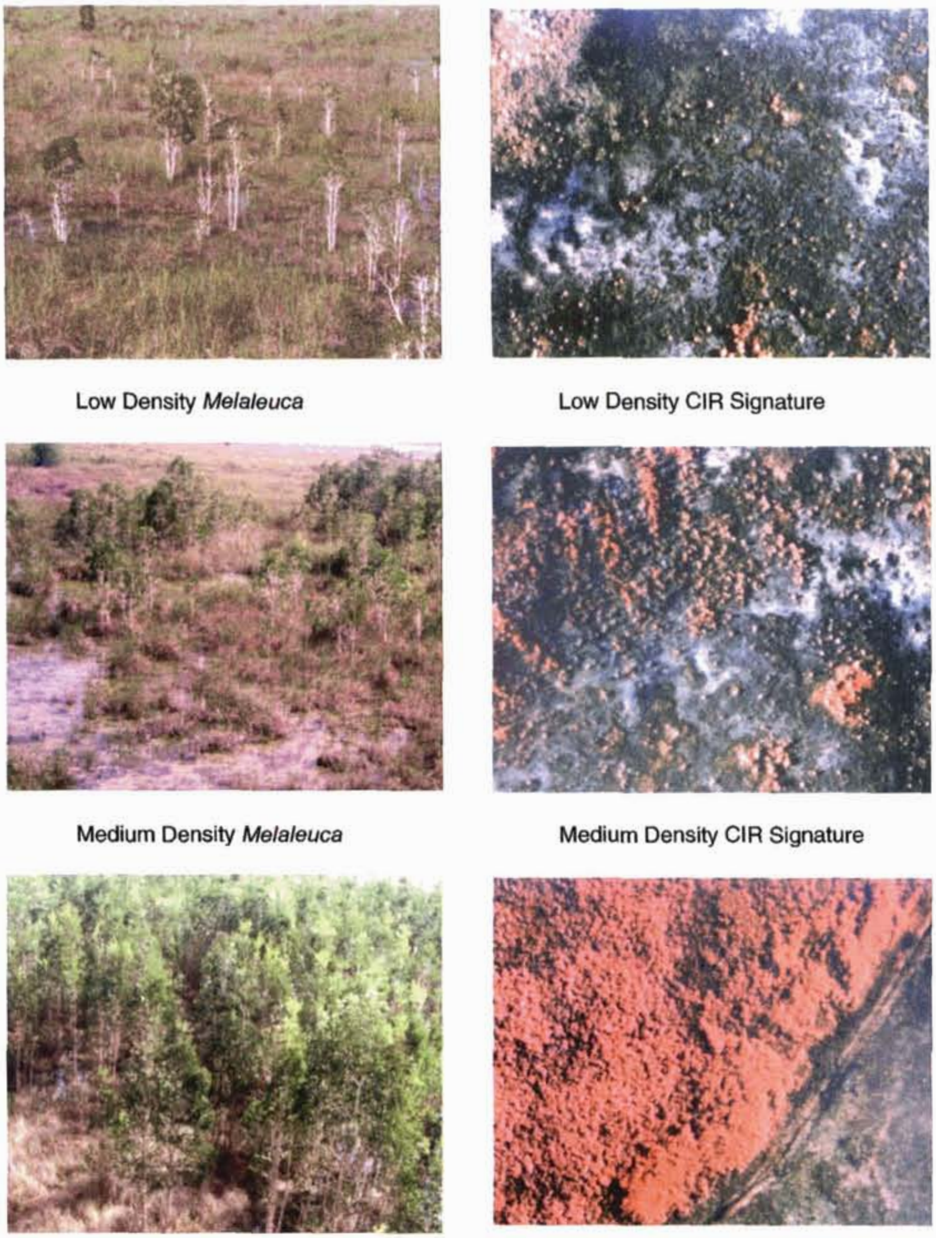

Plate 1. Helicopter (left) and aerial (right) photos define the density classes of *Melaleuca* in this study.

gons correctly identified on the map. Based upon the results of the field checks, the overall accuracy of the dominant vegetation class was 94 percent. The accuracy of the secondary and tertiary vegetation classes was better than 85 percent. *Melaleuca* was correctly interpreted from aerial photographs as the dominant vegetation at 21 out of 23 sample points (or 91 percent correct). The height and density modifiers interpreted from aerial photographs also corresponded well with field observations. *Melaleuca* density and height were correctly interpreted at 22 out of 23 sample points (96 percent correct).

Distribution of *Melaleuca*

The distribution of *Melaleuca* throughout the study area shows a general trend of advancement from east to west. This is in accordance with observations made by Park exotic vegetation managers (DeVries *et al.*, 1993). *Melaleuca* was found in 1,096 out of a total of 1,751 vegetation polygons in the ENP 26 study area, with the majority of the *Melaleuca*-dominant polygons being 0.5 ha or less in size. In Figure 3, the total area of polygons dominated by *Melaleuca* (approximately 364 ha) is broken down by height and density classes.

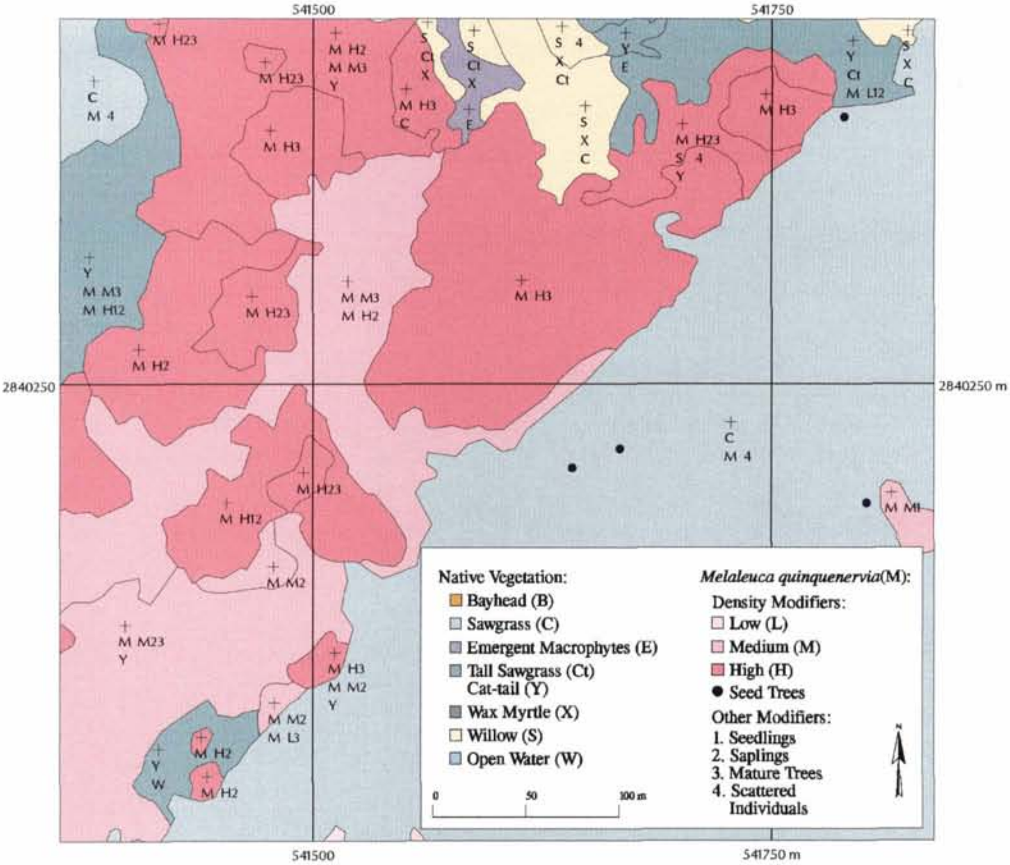

Plate 2. A subset of the ENP 26 West map depicting *Melaleuca* density classes and native vegetation.

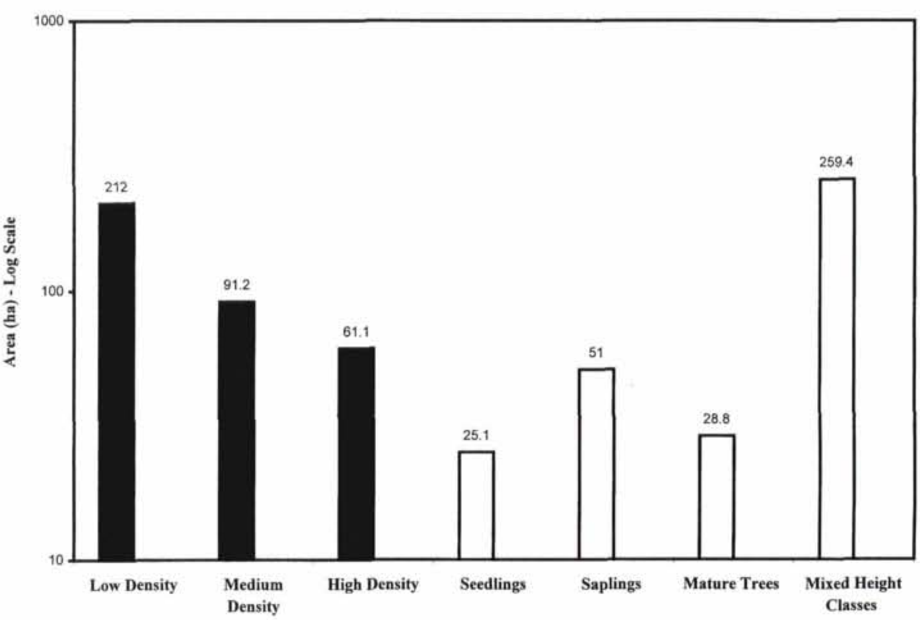

Figure 3. Total area of *Melaleuca* by density and height in the dominant vegetation class. Mixed height classes include combinations of one or more height classes (i.e., seedlings, saplings, and/or mature trees.)

High density *Melaleuca* comprised 61.1 ha in the dominant vegetation class throughout the entire study area, medium density *Melaleuca* occupied 91.2 ha, and low density *Melaleuca* 212 ha. In terms of tree height, seedlings covered 25.1 ha, saplings represented 51 ha, and mature trees 28.8 ha. Mixed height polygons accounted for the vast majority of the area dominated by *Melaleuca* (over 259 ha).

In addition to polygons of *Melaleuca*, there were 162 seed trees, indicated by point features on the map. These were either individual trees, or very small, dense clusters of one to four seed trees, with associated seedlings/sapling recruits. Because mature seed trees release a significant amount of viable seeds, it is essential that Park exotic vegetation managers be informed of their coordinate locations.

Patterns become more complex when the study area is analyzed in terms of western (ENP 26 West) and eastern (ENP 26 East) portions. In the western portion of the study area, *Melaleuca* tended to be aggregated in large, homogeneous polygons of mixed height classes, particularly mixed seedling-sapling classes. The majority of high and medium density *Melaleuca* polygons in the western portion of ENP 26 were found invading the "tail" of a large tree island formerly dominated by native species such as willow, wax myrtle, and sawgrass (see Plate 2). The close proximity of this tree island to a very large polygon of low density seedling-sapling-sized *Melaleuca* suggests that the *Melaleuca* stands within the "tail" region serve as a major foci for seed release and dispersal within the western portion of the study area. There were 375 polygons of *Melaleuca* in the western portion of ENP 26 that were 0.5 ha or smaller. Of these, 177 polygons contained low density *Melaleuca*, 88 were medium density, and 110 were high density.

The eastern half of ENP 26 is dominated by medium-to-high density *Melaleuca* distributed in a "patchy" mosaic relative to the western half of the study area. Of the 535 *Melaleuca*-dominant polygons less than or equal to 0.5 ha in size, 230 were low density, 120 were medium density, and 185 were high density. The occurrence of medium-to-high density *Melaleuca* polygons in the eastern half of the study area may indicate older invaded sites with the probable seed source being outside of the Park's boundary.

Conclusions

The results of this study confirm that large-scale CIR aerial photographs and manual photographic interpretation techniques are superior for identifying and mapping exotic species, particularly *Melaleuca*, in Everglades National Park. Information on *Melaleuca* distribution, density, and height are critical to Park exotic vegetation managers who must decide on efficient and effective management strategies. The digital database of *Melaleuca* distributions will be utilized to establish vegetation monitoring sites within ENP 26 for evaluating the efficacy of chemical, biological, and mechanical management strategies and determining the costs associated with implementing treatment in various *Melaleuca* density and size classes. Exotic vegetation managers agree that the most effective strategy for containing the infestation of *Melaleuca* in ENP 26 will require a combination of remote sensing, GIS, and GPS techniques for mapping *Melaleuca* distributions and monitoring changes over time.

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