0050297

Mapping the Everglades

Roy Welch, Marguerite Madden, and Robert F. Doren

Abstract

The Center for Remote Sensing and Mapping Science at The University of Georgia and the South Florida Natural Resources Center, Everglades National Park, have developed a detailed vegetation database in geographic information system (GIS) format and 1:15,000-scale vegetation maps keyed to 80 U.S. Geological Survey (USGS) 7.5-minute topographic quadrangles covering Everglades National Park, Big Cypress National Preserve, Biscayne National Park, and the Florida Panther National Wildlife Refuge in south Florida, an area of over 10,000 km². National Aerial Photography Program (NAPP) color-infrared (CIR) aerial photographs recorded in 1994/95 were the primary source material, supplemented by extensive GPS-assisted data collections from helicopter reconnaissance missions and field work. The ground control necessary to rectify the vegetation polygons and linear features extracted from the CIR photographs was obtained from geocoded SPOT panchromatic images of 10-m resolution and from USGS 1:24,000-scale topographic line maps. A detailed three-tiered, hierarchical vegetation classification system, the Everglades Vegetation Classification System, was developed specifically for the project. In addition to the vegetation database, a digital database and map products were constructed for off-road vehicle (ORV) trails in Big Cypress National Preserve. The length of trails in the 2,950-km² Preserve totaled over 47,900 km. The databases and maps, constructed through a combination of remote sensing, GIS, GPS, and field studies, provide Park and Preserve managers with detailed baseline information on the status of vegetation and ORV trails in 1995. It is anticipated that, with increased concern over environmental preservation, water demand and expansion of urban development, agricultural land utilization, and ORV use, the databases will prove valuable for a range of management and modeling tasks.

Introduction

Over the last four years, the Center for Remote Sensing and Mapping Science at The University of Georgia, in conjunction with the Everglades National Park, South Florida National Resources Center, has undertaken to develop a detailed vegetation database in ARC/INFO format and associated 1:15,000-scale paper map products for Everglades National Park, Big Cypress National Preserve, Biscayne National Park, and the Florida Panther National Wildlife Refuge, wetland areas occupying approximately 10,000 km² at the southern tip of Florida (Figure 1). These wetland areas will be collectively referred to as the "Parks" in this paper. Early work on the project was previously described by Welch *et al.* (1995) and Welch and Remillard (1996).

As discussed by Doren *et al.* (1999) in this issue of *Photogrammetric Engineering & Remote Sensing*, a detailed vegetation map database is required to document the status of vegetation in the Parks and provide a basis for evaluating changes in the Park lands caused by hurricanes, spread of exotic plants (such as Brazilian pepper (*Schinus terebinthifolius*) and *Melaleuca* (*Melaleuca quinquenervia*)), use of off-road vehicles (ORVs), and patterns of water flow and pollution linked to population expansion and agricultural production in bordering areas. These are problems of concern to the National Park Service and to various federal, state, and local agencies such as the U.S. Army Corps of Engineers, U.S. Geological Survey, U.S. Department of Agriculture, U.S. Environmental Protection Agency, Florida Department of Environmental Protection, South Florida Water Management District, and Dade County, to name some of the more involved groups concerned with maintenance, use, and protection of valuable land and water resources.

At the outset of the project in 1994, three major constraints were apparent:

- The detail requirements for this vast, poorly mapped wetland area could not be met using Landsat or SPOT satellite images. Consequently, up-to-date aerial photographs were needed for mapping, as was adequate ground control. Because of cost factors, the absence of road networks, and lack of dry firm terrain, it was neither possible to pre-mark control nor to survey a ground control network after acquisition of the aerial photographs.
- A vegetation classification system suitable for use with aerial photographs and sufficiently detailed to meet Park requirements did not exist.
- Implementation of mapping and database construction techniques would require a combination of conventional procedures and the development of new procedures, particularly involving the use of satellite images and Global Positioning System (GPS) navigation techniques keyed to the mapping problems.

Consequently, the objective of this paper is to document the methods employed to overcome these constraints and develop digital map databases for vegetation throughout the Parks and ORV trails in Big Cypress National Preserve using satellite images and aerial photographs in combination with GPS, mapping, and geographic information system (GIS) technologies. It is anticipated that the availability of detailed, seamless digital databases, such as the vegetation database shown at greatly reduced scale on the cover of this issue of *Photogrammetric Engineering & Remote Sensing*, will prove to be important assets to scientists addressing problems of concern in South Florida.

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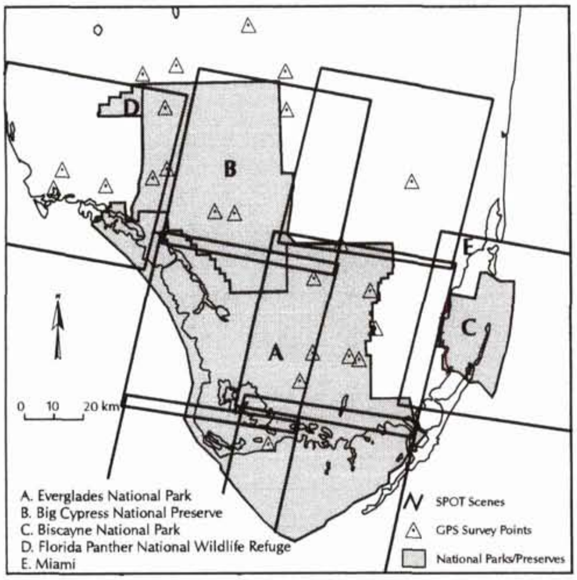


Figure 1. Location map of Everglades National Park, Big Cypress National Preserve, Biscayne National Park, and Florida Panther National Wildlife Refuge, along with the outline of eight SPOT scenes and the locations of 23 GPS survey points.

Data Sources

The data sets needed to construct the vegetation database included existing maps, satellite images, aerial photographs, and information retrieved from field surveys and sampling procedures. Each of these data sources is described in the following paragraphs.

Maps

In most projects involving the mapping or inventory of natural resources, the ground control points (GCPs) necessary to fit detail extracted from satellite images or aerial photographs to a map coordinate system are obtained from existing map coverage at large to medium scale. However, at the initiation of the project, the best available map coverage of the Parks included approximately 80 U.S. Geological Survey (USGS) 7.5-minute quadrangles at 1:24,000 scale. Of these quadrangles, conventional line maps meeting National Map Accuracy Standards (NMAS) (i.e., ± 7.2 m $RMSE_{xy}$) were available for the land areas along the north and east margins of the Parks. The interior regions were covered by quadrangles in orthophotomap format produced from aerial photographs recorded in the 1960s and 1970s that were subjected to cartographic treatment involving the overprinting of color patterns, lettering, and symbols that tended to mask the vegetation patterns. Most importantly, however, the possibility for deriving GCPs of sufficient accuracy and density from these orthophotomaps was limited. It was virtually impossible to find stable points of detail visible on both the orthophotomaps and the 1994/1995 color-infrared (CIR) aerial photographs employed for this project. For these reasons, the orthophotomaps were deemed unsatisfactory. Unfortunately, the excellent USGS Digital Orthophoto Quarter Quads only became available as the vegetation mapping project neared completion. Other maps available for the project included general locational maps distributed to visitors by the Parks and dated vegetation maps of limited resolution described by Doren *et al.* (1999).

Satellite Images

Although there have been numerous applications of satellite images for thematic classification of vegetation, there simply is not sufficient spatial resolution in Landsat or SPOT multispectral images for the identification of Everglades wetland vegetation species and communities — or for the construction of a vegetation database having a minimum mapping unit of approximately 1 hectare (ha) (Rutchey and Vilchek, 1994; Welch *et al.*, 1995). However, these satellite images have excellent geometric integrity and can be easily rectified to a standard map coordinate system to within ± 0.5 to ± 1 pixel, provided that six to eight well-distributed GCPs can be identified in a given scene. Given the large area coverage per SPOT scene (approximately 60 by 60 km) and the availability from the South Florida Water Management District of eight contiguous digital SPOT panchromatic images of 10-m resolution providing complete coverage of the study area in 1993, a decision was made to rectify these scenes and use them as a source of GCPs for the aerial photographs (see Figure 1). The ground control required to rectify the SPOT images was established by conducting a differential GPS survey that extended from Flamingo at the southern land margins of Everglades National Park along existing roads northward through Everglades National Park and Big Cypress National Preserve, and then eastward to the boundary with the South Florida Water Management District's Water Conservation Area 3A. Universal Transverse Mercator (UTM) grid coordinates referenced to the North American Datum of 1983 (NAD 83) were established for 23 road intersections and bridges identifiable on the SPOT images. By using these GCPs in combination with road intersections taken from the line maps of the more populated areas at the margins of the Parks (and with coordinates converted from NAD 27 to NAD 83), each of the SPOT scenes was rectified to an accuracy of approximately ± 0.5 to ± 0.9 pixel (± 5 to ± 9 m). These scenes were then joined to create a continuous digital mosaic of the project area. The rectified SPOT scenes and mosaic subsequently proved to be excellent sources of ground control for the CIR aerial photographs employed to build the vegetation database.

Aerial Photographs

Color-infrared aerial photographs of 1:40,000 scale obtained in January, March, and December 1994 and January and October 1995 as part of the USGS National Aerial Photography Program (NAPP) have been employed as the primary source material in building the vegetation database. These photographs were recorded on Eastman Kodak SO-134 film and are registered to the 7.5-minute topographic quadrangles (Plate 1).

In order to expedite the interpretation of the photographs, facilitate the construction of vegetation coverages in digital format, and minimize any errors in the identification and digitizing of GCPs, the 1:40,000-scale CIR film transparencies were enlarged and reproduced as nominal 1:10,000-scale CIR paper prints. The ground control necessary to rectify features delineated on the aerial photographs was obtained by locating points of detail (bushes, stream junctions, small ponds) common to both the SPOT images and the aerial photographs, measuring the UTM coordinates of these points of detail on the rectified digital SPOT images and assigning the coordinates for these "control points" to their respective features on the CIR enlargements. Typically, rectification coefficients developed using a second-degree polynomial for this vast area of flat terrain yielded $RMSE_{xy}$ values at independent check points of approximately ± 4 to ± 5 m per photo. These results are compatible with NMAS for the USGS 1:24,000-scale topographic maps and verified the validity of using the

0050299

rectified SPOT images as a source of control for the CIR aerial photographs.

Field Studies

Fieldwork involved the GPS surveys mentioned above, GPS-assisted reconnaissance of areas to be mapped, and GPS-assisted accuracy checks of areas previously mapped. These GPS-assisted activities required extensive use of helicopters as well as the more traditional automobile and foot travel for the collection of field data. In particular, the GPS-assisted helicopter data collection techniques developed for this project proved invaluable in establishing the Everglades Vegetation Classification System, providing the ground truth necessary to interpret the CIR enlargements and confirming the accuracy of the resulting database and map products.

The Bell Jet Ranger 206 helicopters employed by the National Park Service are equipped with GPS receivers that enable the pilots to pre-define their flight track, to conduct real-time navigation guided by the GPS unit, and to record the coordinates of landing points or features of interest. In order to maximize the advantage of this positioning technology, the SPOT image mosaic was loaded into a Dell laptop computer along with the Desktop Mapping System (DMS) (*R-WEL*, Inc.) and FieldNotes (PenMetrics, Inc.) software packages. A Trimble Pathfinder Professional (six-channel) GPS receiver with an external antenna mounted on the forward hull of the helicopter was connected to the serial port of the computer. This set-up enabled a person in the rear seat of the helicopter to hold the computer on his or her lap, display the satellite image mosaic, and track in real time the flight path of the helicopter. It also provided a means of collecting ground truth information linked to coordinates provided by the GPS receiver. Upon reaching an area of interest, the helicopter circled or landed to allow identification of plants. Species attribute information and additional notes pertaining to hurricane damage, fire history, or exotic control measures that may have influenced the area were entered into the computer and linked with the GPS coordinates.

Back in the laboratory, the flight path of the helicopter (defined by the GPS coordinates) was plotted at 1:10,000 scale and registered to the appropriate CIR air photos. Attributes describing the plant species collected during the flight and tagged with GPS coordinates were also registered to the photographs, providing the interpreters with a comprehensive set of notes that enabled the correlation between photo signatures and vegetation classes. Correspondingly, once a map was printed as a draft copy, it was possible to define the UTM coordinates of points to be visited as part of a map revision or accuracy check procedure, and to input these to the flight navigation system of the helicopter. Overall, these procedures, when fully developed, provided a rapid and cost-effective means of obtaining the ground truth information necessary to complete the project. They also permitted the total time spent in helicopters to be reduced by an estimated 30 to 40 percent. With helicopter rental rates varying from $450 to $650/hour, any reduction in flying time translated to a significant savings in cost.

Vegetation Database and Map Products

Construction of the vegetation database and associated 1:15,000-scale map products from the various source materials involved the following steps: (1) interpretation of the CIR aerial photographs and delineation of the vegetation classes on clear plastic overlays registered to the photos, (2) scanning of the overlays, (3) data conversion to vectors in digital format, (4) editing and attributing the vector files to produce map coverages keyed to the USGS 7.5-minute topographic quadrangle boundaries, (5) quality control and accuracy checks, and (6) generation of final map plots and digital data files.

Interpretation of the aerial photographs required the consideration of two key issues. The first was whether to use scanned aerial photographs and undertake on-screen, heads-up digitizing, or to employ more traditional analog photointerpretation techniques. The disadvantages of using digital technology were immediately evident. For example, in 1994, the cost associated with scanning a large number of CIR photos was prohibitive. Furthermore, in order to capture the detail in the contact scale aerial photographs, a scanning resolution of approximately 25 to 30 μm (1,000 dpi to 800 dpi) was required. At this resolution, it was necessary to store a file between 250 and 150 megabytes per photo or over 40 gigabytes of image data for the study area. These large file sizes slow computer operations and were not easily accommodated in 1994. In addition to these issues, there was the problem associated with training the interpreters in image processing techniques and of establishing a relatively expensive workstation for each interpreter. Most important, however, was the reality of overcoming the problems associated with computer screen resolution which largely eliminated the synoptic view and required the interpreter to work on very small patches of terrain, making it difficult to map the vegetation patterns within the context of surrounding features. Tests conducted to evaluate the efficiency of heads-up interpretation and digitizing confirmed that this approach offered more problems than solutions.

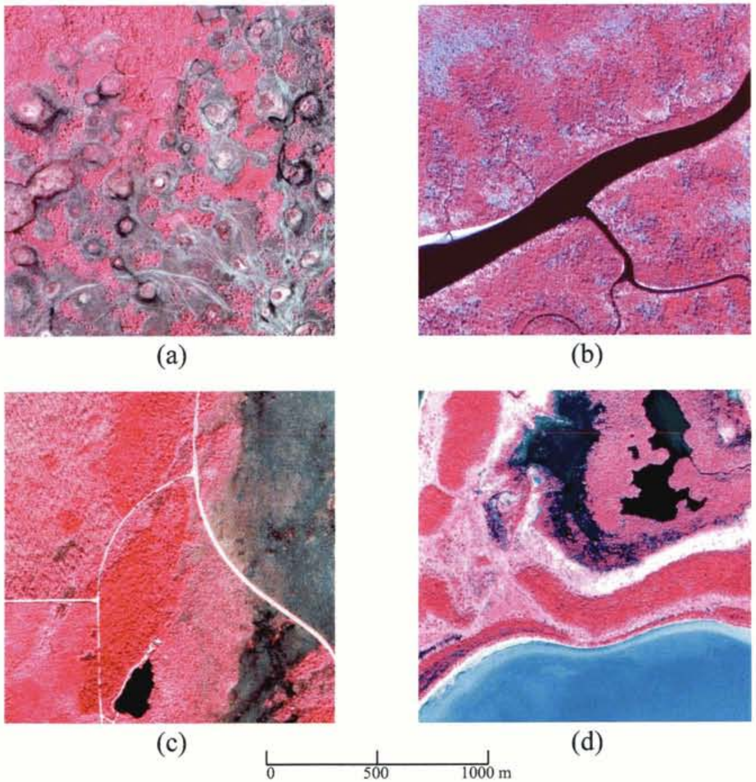
The alternative to using the image data in digital format was to employ aerial photographic enlargements, and to transfer the data to overlays as described below. Costs were low, technology was simple, and the speed with which an interpreter could identify and delineate features on a per-photo basis was greatly enhanced.

The second issue was the establishment of a vegetation classification system that would provide the detail required by Park and South Florida Water Management District personnel, yet prove suitable for use with aerial photographs. Madden *et al.* (1999) describe the evolution of the Everglades Vegetation Classification System derived by representatives from the Parks, Center for Remote Sensing and Mapping Science, and South Florida Water Management District. Basically, this classification system includes 89 vegetation and land-cover classes that can be identified on the CIR photographs and a hierarchical organization that allows classes to be readily collapsed for compatibility with existing vegetation classification schemes being used elsewhere in south Florida. The Everglades Vegetation Classification System also includes categories of invasive exotic plants, indicators of human influence such as ORV trails, and three hurricane damage classes.

The interpretation of aerial photographs was conducted by a team of skilled photointerpreters using the CIR photographic enlargements in paper print format. These enlargements (approximately 1 by 1 m) were placed on a large light table which enabled the interpreter to employ either front or back lighting as the situation demanded. A clear polyester overlay was then registered to the photograph using the fiducials in the margins of the paper print. The locations of all GCPs were annotated, and the vegetation polygons and land/water features were viewed under magnification and delineated on the overlays. When additional detail or stereoviewing was required, the interpreters were able to refer to the original film transparencies and examine these under high magnification using a Bausch & Lomb Zoom 95 Stereoscope.

Once all the control points, vegetation polygons, and appropriate land and water features were delineated on the large transparent photo overlays, these overlays were sent to Electronic Services, Inc., Athens, Georgia, for scanning at a resolution of 65 μm (400 dpi). The scanned overlay files in Tagged Image File Format (TIFF) were then transferred back

0050300



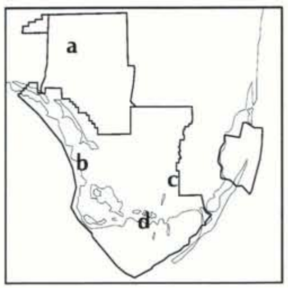


Plate 1. Selected sections of color-infrared aerial photographs reveal the diversity of vegetation patterns in the Parks.

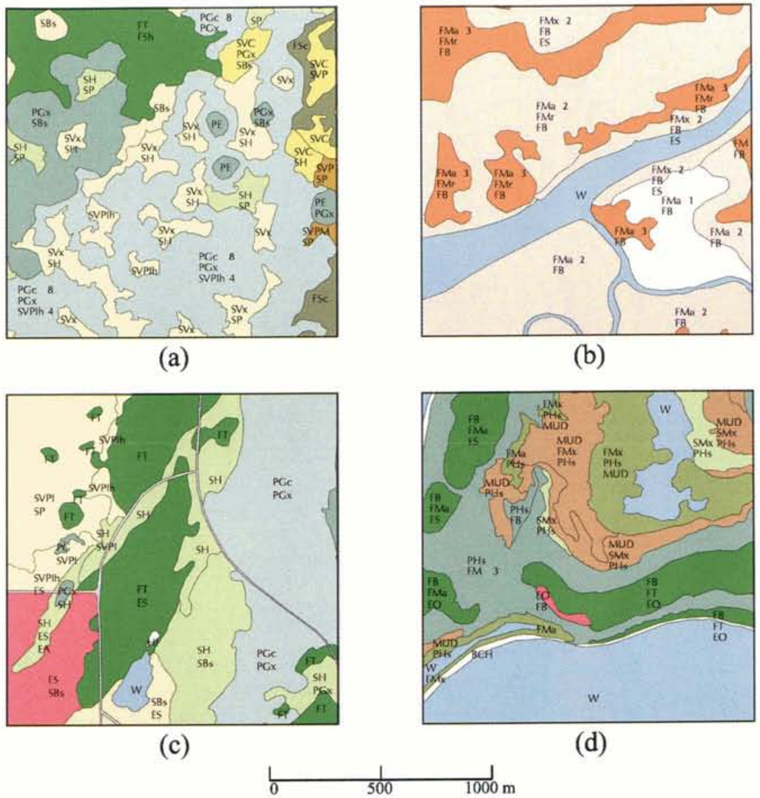


Plate 2. Portions of the Everglades vegetation map database corresponding to the photo areas in Plate 1. Dominant plant communities include (a) subtropical hardwood forest (FT), sawgrass prairie (PGc), and slash pine savanna with sabal palms (SVx) in Big Cypress National Preserve; (b) black mangrove (Fma), red mangrove (FMr), and buttonwood forest (FB) with low (1), medium (2), and extreme (3) hurricane damage in Everglades National Park; (c) exotic Brazilian pepper (ES), slash pine savanna with hardwoods (SVPlh), shrubland (SH), and sawgrass prairie (PGc) in Everglades National Park; and (d) halophytic herbaceous prairie (PHs), mixed mangrove scrub (SMx), and exotic lather leaf (EO) along the south coast of Everglades National Park.

0050301

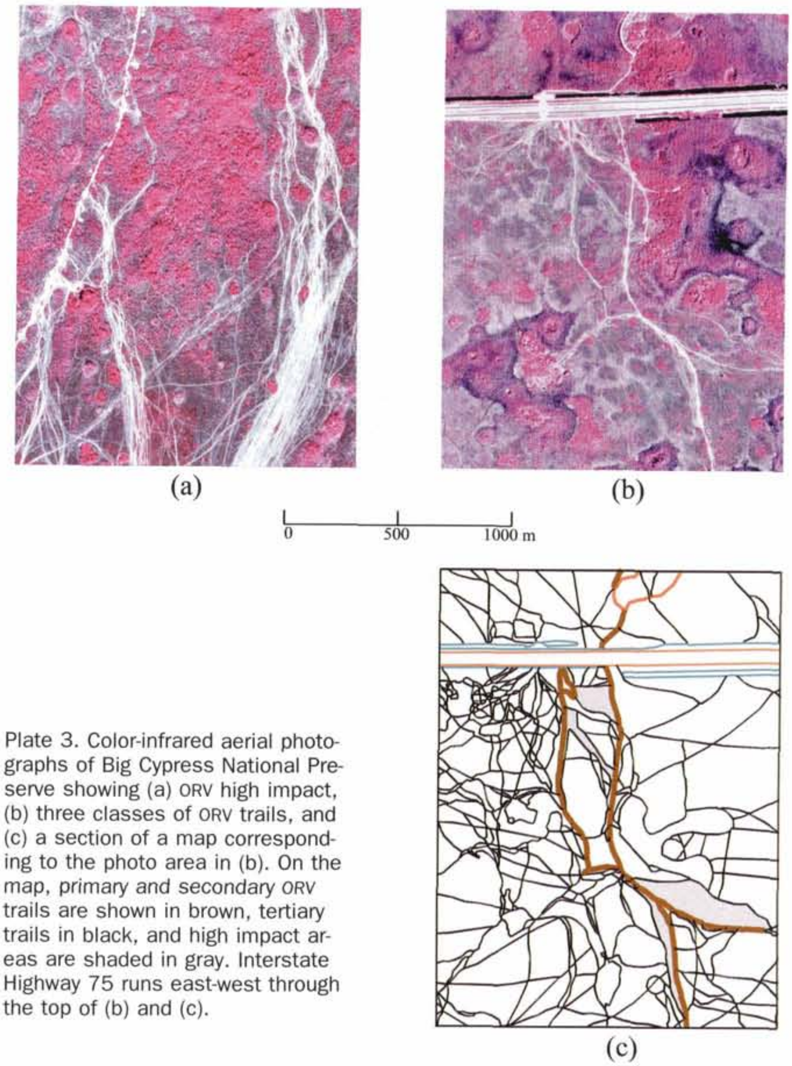


Plate 3. Color-infrared aerial photographs of Big Cypress National Preserve showing (a) ORV high impact, (b) three classes of ORV trails, and (c) a section of a map corresponding to the photo area in (b). On the map, primary and secondary ORV trails are shown in brown, tertiary trails in black, and high impact areas are shaded in gray. Interstate Highway 75 runs east-west through the top of (b) and (c).

to the Center for Remote Sensing and Mapping Science for use on a personal computer equipped with a Pentium II microprocessor operating under Windows 95 and running the R2V (Able Software Company, Lexington, Massachusetts) and DMS software packages. The R2V software was employed to convert the raster overlay files to digital vector files. These vector files were subsequently rectified (geocoded) to an accuracy of about ±4 to ±5 m (RMSE) using the DMS software and the previously identified GCPs in the UTM coordinate system. They were then output in ARC/INFO Generate format to a Sun Unix Workstation for editing, attributing, edge-matching (of six or more overlays), and construction of vegetation map coverages corresponding to the USGS 7.5-minute topographic quadrangles. The ARC/INFO Version 7.03 workstation software, supplemented by modules developed at the Center for Remote Sensing and Mapping Science for attributing, visualization, and hardcopy output, were used for these tasks. The time required to prepare a complete data set for a single map area corresponding to a USGS topographic quadrangle varied with the complexity of the plant communities, ranging from about 125 hours for relatively non-complex areas to over 250 hours for the complex vegetation patterns found in Big Cypress National Preserve (Plate 2).

In the early stages of the project, draft map products were generated and checked in the field to verify classification accuracy, with revisions undertaken as necessary to create the final digital data sets and 1:15,000-scale paper maps prior to their release to the South Florida Natural Resources Center. As the interpreters gained skill and confidence, however, the extent of field verification and helicopter use was reduced to GPS-assisted reconnaissance missions conducted to obtain over 2,000 coordinate-tagged observations of plant communities distributed throughout the Parks. These observations were employed by the interpreters to insure continued accurate interpretation of plant communities. Independent checks of the vegetation classification accuracy for dominant, secondary, and tertiary vegetation at 88 random sample points on six maps scattered across Everglades National Park yielded values from 77 to 97 percent correct for individual quadrangles, with an average value of 90 percent

0050302

correct. Although funds for more extensive accuracy evaluations were curtailed by the Parks, it is estimated that the average overall classification accuracy averages better than 85 percent for the entire study area.

ORV Trails in Big Cypress National Preserve

Big Cypress National Preserve is a 2,950-km^2 area just north of Everglades National Park, containing primarily cypress forest, pine forest, and graminoid prairies (see Figure 1). The Preserve was created in 1974 within the framework of the National Park System to manage human activities such as hunting, fishing, oil and gas exploration, cattle grazing, and ORV use while maintaining the natural, recreational, and aesthetic values of the area. Much of the area is inaccessible by roads, and users of the Preserve rely heavily on ORVs to access private in-holdings and to partake in the recreational activities for which the Preserve was created (Tebeau, 1966; Duever *et al.*, 1981).

Duever *et al.* (1986) mapped ORV trails from aerial photographs acquired in 1940, 1953, and 1973. Although these maps are valuable records of historical ORV use in Big Cypress, they do not document current conditions within the Preserve. Also, these maps depict heavy-use trails visible on the small-scale aerial photographs employed for the project. In 1953, 250 km of trails had been mapped and were mainly attributed to logging activities. By 1973, over 1,100 km of trails were visible on the aerial photographs and attributed to increased recreational ORV use. Since 1974, ORV use has increased greatly, and in recent years the volume and particularly the impact of this use has been difficult to determine. Consequently, the objective in the current study was to employ the CIR aerial photographs recorded in 1994/1995 to develop a current and comprehensive ORV trail database for the entire Big Cypress area, along with summary statistics on the total length of ORV trails by class and management unit and an assessment of the impact of ORV trails on vegetation.

ORV Trail Database Development

Using procedures previously developed by the CRMS for mapping Everglades vegetation, ORV trails were interpreted from the 1:10,000-scale enlarged prints of the 1994/1995 CIR NAPP air photos and delineated on the overlays. Ground control points were then transferred to the overlays and delineated trails were scanned, vectorized, and registered to the UTM ground coordinate system referenced to NAD 83. In order to be compatible with the Everglades vegetation database, ORV digital vector data were converted to ARC/INFO format, and coverages corresponding to the USGS 1:24,000-scale topographic quadrangles within Big Cypress were compiled. On a quad basis, ORV trail coverages were then edited and attributed to distinguish trail classes, major roads, and canals.

The trails were classified according to the intensity of use as primary (20 to 30 m wide on the ground), secondary (10 to <20 m wide), and tertiary (3 to <10 m wide). Areas of intense ORV rutting with a high density of braided trails that could not be individually delineated as linear features or form an excessively complex network of trails were outlined as polygon features and designated as "high impact" areas (Plate 3). It should be noted that in some cases, because of their similar appearance, linear features such as section lines or trails created by wildlife may be included as ORV trails. These, however, would account for only a small percentage of the total number or lengths of trails. In addition, the exact age of trails and whether or not the trails are currently in use could not be readily determined from the aerial photographs. Therefore all trails visible on the photographs were mapped and included in the database.

The ORV trails were observed on the ground and during helicopter missions conducted in support of the on-going Everglades vegetation mapping project. However, due to budgetary constraints, funds for separate helicopter flights to verify ORV trail interpretations were not provided by the Preserve. It was determined that any detailed ground checks deemed necessary to verify trails were to be conducted by Big Cypress National Preserve personnel.

A total of 32 hardcopy maps of ORV trails corresponding to quad areas were plotted at 1:15,000 scale to depict the detail of delineated trails. These maps are color-coded according to ORV trail class, and high impact areas are shaded gray (see Plate 3).

Summary Statistics of ORV Trail Length

Summary statistics for the total length of ORV trails were tallied by ORV trail class using the ARC/INFO Frequency command. Areas of high impact delineated on the maps as shaded polygons also were summarized and converted to a linear measure of trail length using a conversion factor of 0.03 m of trail length per m^2 of high impact area. This conversion was determined by selecting nine high impact areas (4 to 110 ha in size) within which all trails were delineated. The ratio of the total length of trails to the polygon area ranged from 0.026 to 0.045 and averaged 0.03 m/m^2. Using this conversion factor, the total area of high impact was converted to linear trail length. A coverage of Big Cypress ORV management units obtained from the Preserve was then used to clip the ORV trail database in ARC/INFO (Figure 2). The total lengths of primary, secondary, tertiary, and high impact ORV trails by management unit are summarized in Table 1. The most common class of ORV trail is tertiary, with these trails totaling 32,626 km. Primary and secondary trails total 65 and 367 km, respectively. These ORV class totals, combined with 14,899 km of high impact trails, yielded a grand total of 47,958 km of ORV trails in the Preserve.

Overall, the units most heavily impacted by ORVs are Turner River, Stairsteps, Corn Dance, and the NE Addition Area. It is interesting to note that, although the Loop ORV management unit has been officially closed to ORV traffic for the past 20 years, over 3,545 km of trails were identified in this area. It is believed that the trace of abandoned trails re-

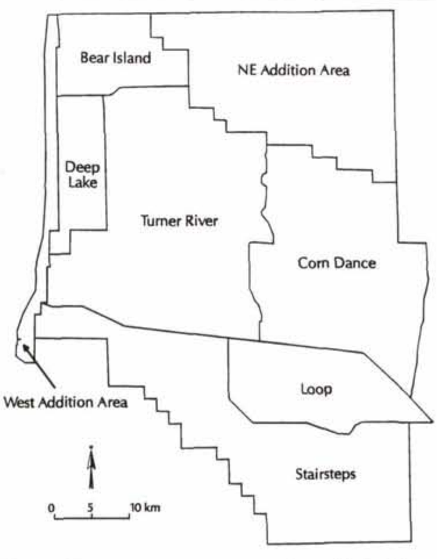


Figure 2. ORV management units within Big Cypress National Preserve.

0050303

Table 1. Total Length of ORV Trails by ORV Management Units in Big Cypress National Preserve

ORV Management Unit	Primary Trail Length (km)	Secondary Trail Length (km)	Tertiary Trail Length (km)	High Impact Trail Length (km)	Total Length of All ORV Trails (km)
West Addition Area	0	5.3	770.2	662.2	1437.7
Deep Lake	0	2.9	1029.3	1211.6	2243.8
Bear Island	0	40.3	1588.9	894.2	2523.4
NE Addition Area	53.0	108.7	5932.0	861.8	6955.5
Turner River	0	56.3	7311.3	5926.0	13293.6
Corn Dance	0.1	25.1	6910.2	1639.1	8574.5
Loop	0.1	0	3291.5	253.6	3545.2
Stairsteps	11.8	128.3	5792.9	3451.1	9384.1
Total	65.0	367.0	32626.4	14899.4	47957.8

mains visible from the air for many years and trails can be interpreted from aerial photographs even after detection on the ground is difficult.

Vegetation Types Impacted by ORV Trails

Because both the ORV trail and vegetation data sets are cast on the same ground coordinate system, UTM NAD 1983, and correspond to the USGS 1:24,000-scale map series, overlay commands were easily implemented to determine the spatial coincidence between the two data sets. Four representative quadrangles were selected for the analysis of ORV impact on vegetation analysis. Extending from north to south and located in the center of the Preserve, ORV trails in the Whidden Lake, Airplane Prairie, Monroe Station NE, and Gator Hook Swamp quadrangles were intersected with corresponding vegetation coverages. Summary statistics were then compiled to determine the total length of primary, secondary, tertiary, and high impact trails that passed through each vegetation community classified according to the Everglades Vegetation Classification System. These data were collapsed to summarize vegetation into nine vegetation types, namely, exotics, hardwood forest, mangrove forest, cypress forest, cypress savanna, pine savanna, hardwood scrub/shrub, mangrove scrub, and prairie. Additional classes include human influence (e.g., camps) and small water bodies.

An analysis of spatial coincidence between ORV trails and vegetation communities in the four quad area revealed trails cross many different types of vegetation, from hardwood forests and mangrove scrub to open prairies. Prairie communities were most often crossed (3,344 km), followed by cypress forest (2,774 km) and cypress savanna (2,213 km). Total trails found in various plant communities within the four quad area are presented in Figure 3.

Conclusion

This project has resulted in the compilation of a seamless digital vegetation map database for the 10,000-km² area occupied by Everglades National Park, Big Cypress National Preserve, Biscayne National Park, and the Florida Panther National Wildlife Refuge that is keyed to the 80 USGS 1:24,000-scale topographic quadrangles covering the Parks. In addition, a database delineating some 47,958 km of off-road vehicle (ORV) trails in Big Cypress National Preserve has been developed. In both instances, 1:15,000-scale map products have been produced from the databases.

Construction of the databases required the integration of GPS, remote sensing, and GIS technologies and demonstrated the possibilities for (1) utilizing SPOT satellite images to establish the control necessary to rectify CIR aerial photographs; (2) employing the three-tiered Everglades Vegetation Classification System developed especially for use with remotely sensed data; and (3) using linked, real-time GPS positioning and satellite image display techniques to aid in the navigation of a helicopter and the collection of ground truth necessary for the interpretation of the aerial photographs. It

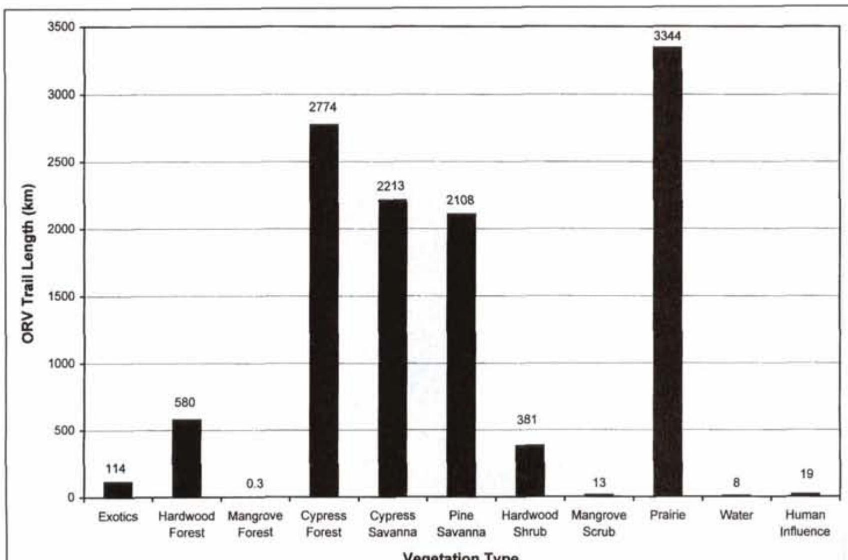


Figure 3. Impact of ORV trails on vegetation communities within the USGS Whidden Lake, Airplane Prairie, Monroe Station NE, and Gator Hook Swamp topographic quadrangles.

0050304

also clearly proved the efficiency for combining conventional analog photointerpretation techniques with computer-based scanning and data transformation procedures to create vegetation and ORV trail coverages of excellent geometric and thematic accuracy that could be edited and attributed within ARC/INFO.

It is anticipated that the databases and maps for the Everglades will provide baseline information on the distribution patterns for vegetation within the Parks and the current status of ORV trails within Big Cypress National Preserve. The vegetation database can be used for a variety of applications, such as monitoring changes in vegetation patterns due to hurricanes, fire, flooding, pollution, and the invasion of exotic plant species. It will allow modeling the impact of man's activities on the distribution of vegetation patterns within the Parks. The ORV trail database documents the spatial patterns of ORV utilization in Big Cypress National Preserve and should prove valuable for monitoring the effectiveness of future ORV use and permitting procedures. With increased attention being given to the preservation of natural resources and wildlands, it is hoped that the Parks will devote the resources necessary to explore the applications of the Everglades databases, and to maintain their currency and accuracy.

Acknowledgments

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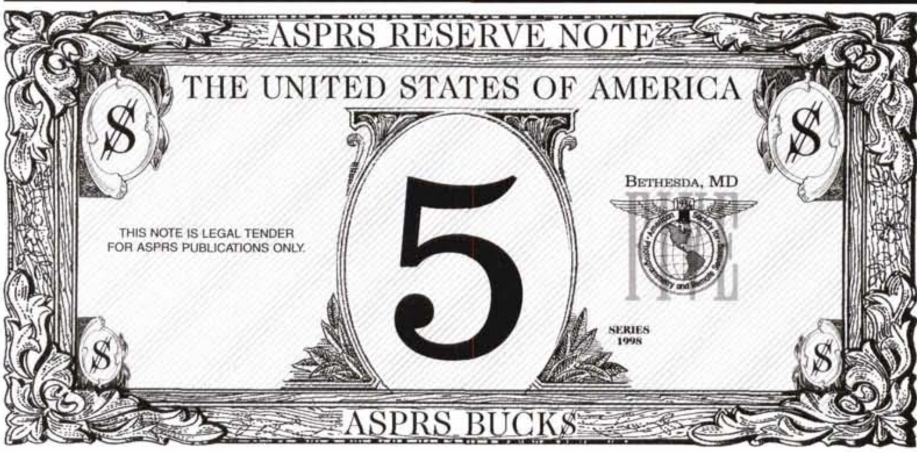

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