GIS Database Development for South Florida's National Parks and Preserves

R. Welch, M. Remillard, and R.F. Doren

Abstract

The University of Georgia's Center for Remote Sensing and Mapping Science (CRMS) is working in conjunction with the U.S. Department of Interior's National Park Service (NPS) to construct a geographic information system (GIS) database and associated detailed vegetation maps for the Everglades National Park, Biscayne National Park, Big Cypress National Preserve, and the Florida Panther Refuge. Preservation of these south Florida wetland areas, threatened by urban expansion, nutrient runoff from agricultural lands, encroachment of exotic plant species, and increased recreational use, is a topic of national concern. Development of the database and maps is made possible by the integration of Global Positioning System (GPS), satellite remote sensing, air photo interpretation, and helicopter-assisted field verification procedures. A digital satellite image mosaic prepared from eight SPOT panchromatic images of 10-m resolution and geocoded to ground control points in the UTM (NAD 83) coordinate system to an accuracy of ±1 to ±1.5 pixels forms the coordinate reference layer for the GIS database. Vegetation patterns and, where appropriate, hydrographic and transportation features are digitized directly from 4× paper print enlargements of National Aerial Photography Program (NAPP) color infrared aerial photographs recorded in 1994 and 1995. These digitized vector files are rectified to ground control transferred from the rectified SPOT satellite images. Planimetric errors generally are less than ±10 m. The vegetation layers in the GIS database are classified according to a prototype Everglades Vegetation Classification System being developed by NPS, CRMS, and South Florida Water Management District (SFWMD) personnel. Ground truth collection and verification of the thematic accuracy of interpreted vegetation polygons and boundaries is facilitated through the aid of the SPOT satellite image mosaic, and a laptop computer interfaced to a GPS receiver mounted in a helicopter. The flight track of the helicopter is displayed in real time on the SPOT image mosaic, and, as required, attribute information is entered into the computer. The digital GIS database and 1:24,000-scale vegetation maps will provide the NPS with the detailed, up-to-date spatial information needed to manage the Parks of south Florida.

Introduction

The Center for Remote Sensing and Mapping Science (CRMS) at The University of Georgia is working with the U.S. Department of Interior's National Park Service (NPS) to utilize a combination of satellite imaging, aerial photographic, Global Positioning System (GPS), and geographic information system (GIS) technologies to develop a database in GIS format for over one million hectares (ha) of ecologically unique Everglades wetlands in south Florida. Although the southern tip of Florida was the entry point for early explorers into the New World, the Everglades remain one of the last portions of the United States to be accurately mapped at any level of detail.

This vast, flat terrain, wetland study area includes Everglades National Park, Biscayne National Park, Big Cypress National Preserve, and the Florida Panther Refuge (Figure 1). Collectively, this area will be referred to as the "Parks." It extends roughly from Miami on the east to Naples on the west, southward to Florida Bay, and represents the remaining lands of the greater Big Cypress Swamp and Everglades ecosystems that once covered approximately one-third of the Florida peninsula (Light and Dineen, 1994). The growth of the Miami urban area, the encroachment of exotic plants such as *Melaleuca quinquenervia* (cajeput) and *Schinus terebinthifolius* (Brazilian pepper), the expansion of agricultural land along the margins of the Parks, and increased recreational use combine to threaten the flora and fauna in this region (Duever *et al.*, 1986; Doren *et al.*, 1990; Davis and Ogden, 1994).

Although portions of the Parks have been mapped for particular research interests, neither detailed maps nor a comprehensive database of Everglades vegetation exists at this time (e.g., McPherson, 1973; Gunderson and Loope, 1982; Olmstead *et al.*, 1983; Rose and Draughn, 1991). The South Florida Water Management District (SFWMD) recently used satellite image data to develop a land-cover map of SFWMD Water Conservation Area 2A, located northeast of the Everglades National Park (Rutchey and Vilchek, 1994; Jensen *et al.*, 1995). Rutchey and Vilchek (1994) concluded, however, that, due to the diverse nature of Everglades vegetation, the accuracy of thematic classification results may be improved by using low altitude aircraft multispectral scanner data and aerial photographs. The SFWMD is now cooperating with the NPS to coordinate and develop joint mapping proce-

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Photogrammetric Engineering & Remote Sensing, Vol. 61, No. 11, November 1995, pp. 1371–1381.

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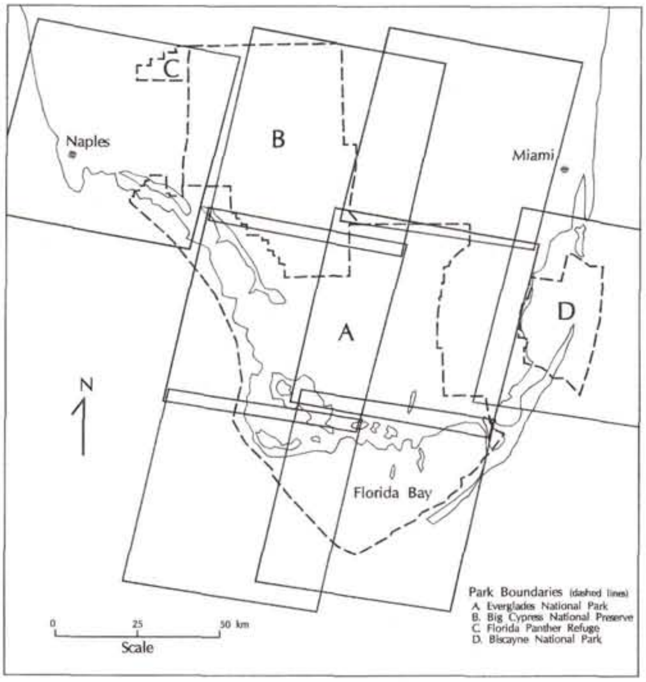


Figure 1. The South Florida National Parks and Preserves study area is shown by a dashed line, and the SPOT images employed to create a geocoded mosaic are indicated by solid lines.

dures and vegetation classifications to create a vegetation database for the Parks and water conservation areas.

With limited road access to extensive tracts of the study area and overland travel made difficult by wetlands, exposed pinnacle rock, and entangled mangrove forest, it was determined that GPS surveys in conjunction with satellite image data would be required to bridge the remote areas and provide an accurate control network for GIS database development (Welch *et al.*, 1992; Welch and Remillard, 1994). Also, it was concluded that detailed mapping of vegetation, hydrography, and transportation features should be undertaken with aerial photographs. Consequently, the objectives of this project were defined as follows:

- Construct a geocoded satellite image mosaic of the Parks that will provide the reference layer for a GIS database;
- Produce a detailed GIS database in digital format that conforms to an accuracy standard of approximately ± 10 m root-mean-square error ($RMSE_{xy}$) for well-defined planimetric features, and includes the distribution of plant communities within the Parks; and
- Assess vegetation damage caused by Hurricane Andrew.

In order to meet these objectives, it was necessary to accurately geocode satellite images and develop techniques for using control transferred from the satellite images to rectify several hundred aerial photographs; establish efficient photo-interpretation and feature encoding procedures compatible with a new classification system that takes into account vegetation species, human impacts, and hurricane damage; and integrate GPS surveys with attribute recording and digital image processing on a laptop computer to facilitate the real-time collection of ground truth information by helicopter surveys. The surveying, remote sensing, and GIS procedures being used to build the database are described in this paper.

Data Sources

Data sources for the project include maps produced by the U. S. Geological Survey (USGS) and the NPS South Florida Natural Resource Center (SFNRC), satellite image data, and color infrared (CIR) aerial photographs. The majority of the USGS 1:24,000-scale quadrangles of the Parks were produced from aerial photographs in the 1960s and early 1970s as multicolor orthophotomaps (Pumpelly, 1967). These orthophotomaps have extensive cartographic treatment such as color patterns, lettering, and symbols placed on the photo image which tend to mask vegetation patterns. Although statements on these orthophotomaps indicate that they comply with U.S. National Map Accuracy Standards (NMAS) (± 7.2 $RMSE_{xy}$ for well-defined features), many of the map sheets for the Everglades National Park and Big Cypress National Preserve show extensive wetland areas with no "well-defined" features. Thus, for the interior of the study area, the USGS orthophotomaps are dated, provide limited detail, and are of questionable geometric reliability. By contrast, the standard 1:24,000-scale USGS topographic line maps for the developed areas surrounding the Parks (revised in the 1980s) are a valuable source for ground control points (GCPs) on the perimeter of the study area.

Large scale vegetation maps (1:14,000 to 1:43,000 scale) produced by the SFNRC in the 1970s and early 1980s provide detailed vegetation information for limited areas of the Everglades National Park and Big Cypress National Preserve. Although these maps are useful for confirming the identification of vegetation in a few specific locations, they only cover a small fraction of the study area and do not conform to specific geometric accuracy standards.

Existing map coverage of the Parks, therefore, was inadequate for deriving a GCP network of sufficient density and accuracy to create a GIS database directly from available CIR aerial photographs. Alternative sources of control, namely GPS, aerotriangulation, and satellite image data, were considered. Aerotriangulation was ruled out because of the characteristics of the National Aeronautics and Space Administration (NASA) aerial photographs (described below) available at the outset of the project and the difficulties in establishing a control network for several hundred photographs. Satellite images, however, in combination with a GPS survey and USGS 1:24,000-scale topographic line maps for the perimeter of the study area, offered a rapid and economical means of establishing a dense network of GCPs of sufficient planimetric accuracy to control the aerial photographs. Although the use of satellite images to provide control for aerial photographs is contrary to traditional practice, past experience has shown that, because of their excellent internal geometry, only four to six GCPs per image are required to geocode a SPOT satellite image to a planimetric accuracy of ±0.5 to ±1.0 pixel — or ±5 to ±10 m on the ground (Welch, 1985; Welch *et al.*, 1985). Such accuracies are compatible with NMAS for 1:24,000-scale maps and were considered acceptable for establishing a geocoded image database.

Satellite images recorded by three different sensor systems were considered as potential source material for a geocoded image database: (1) SPOT panchromatic images of 10-m pixel resolution, (2) Russian KATE-200 images of 12-m pixel resolution (Spradley, 1994), and (3) Landsat Thematic Mapper (TM) images of 28.5-m pixel resolution (Table 1A; Figure

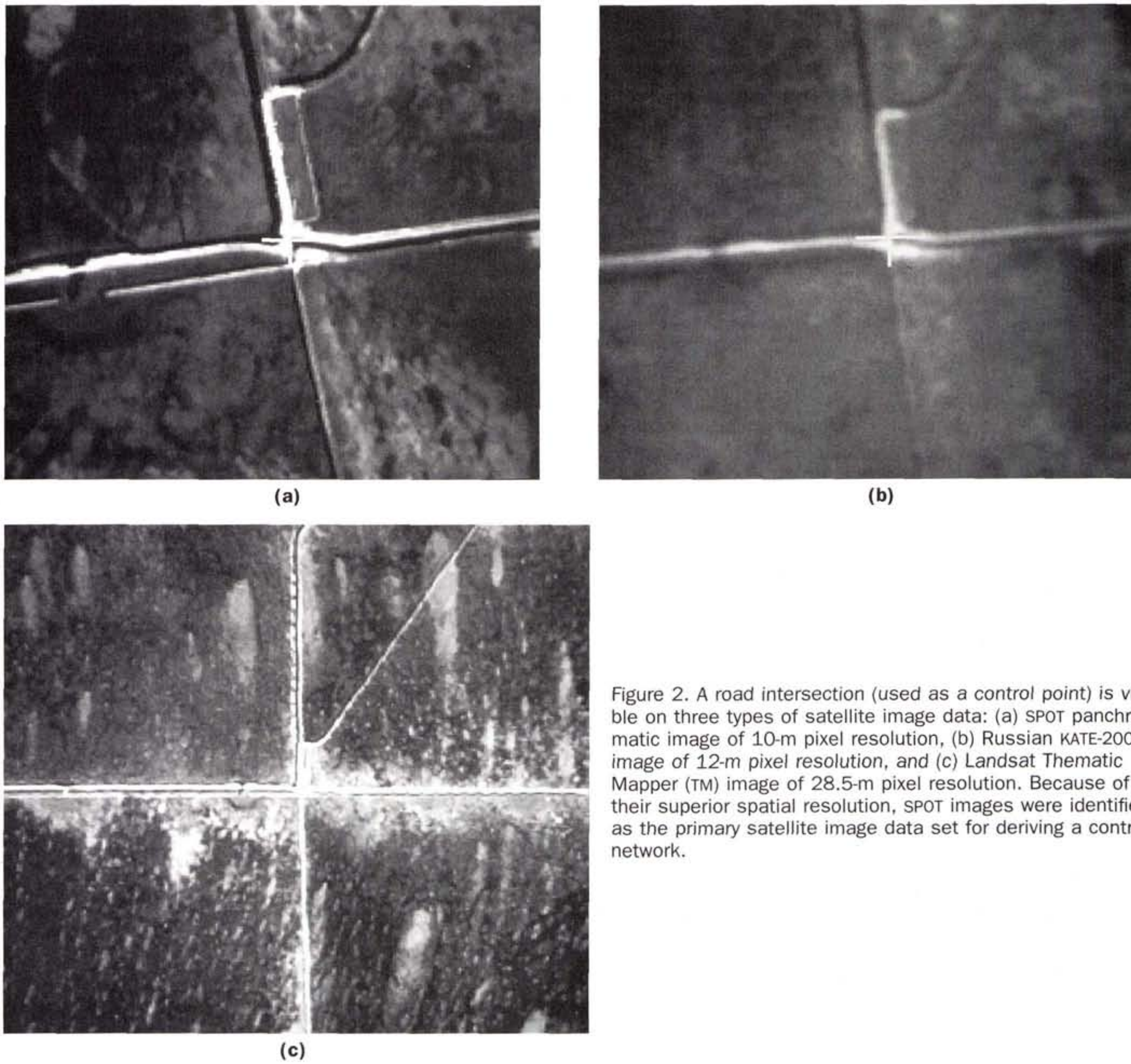


Figure 2. A road intersection (used as a control point) is visible on three types of satellite image data: (a) SPOT panchromatic image of 10-m pixel resolution, (b) Russian KATE-200 image of 12-m pixel resolution, and (c) Landsat Thematic Mapper (TM) image of 28.5-m pixel resolution. Because of their superior spatial resolution, SPOT images were identified as the primary satellite image data set for deriving a control network.

2). Because of their recent date of acquisition (1993), superior 10-m spatial resolution, and availability from the NPS and SFWMD, the SPOT images were identified as the primary satellite image data set (Figure 3). The Russian KATE-200 image covered the entire study area, but poor contrast limited its use. Both the KATE-200 and multispectral Landsat TM images were used to plan the locations of GPS control points and to locate supplemental control points needed to geocode the SPOT images.

Aerial photographs were acquired with mapping cameras (23- by 23-cm format) and frame reconnaissance cameras (23- by 46-cm format) from an altitude of 19,800 m (65,000 ft) by the NASA U-2 research aircraft on 5 April 1990 and on 30 November and 3 December 1992, approximately three months after Hurricane Andrew (Table 1B). Although the timing of these photographs is excellent for hurricane damage assessment, the 1:65,000-scale photos (23 by 23 cm) lack sufficient detail for vegetation studies. The 1:32,500-scale (23- by 46-cm) photos, on the other hand, depict adequate detail, but their use is complicated by the large, rectangular format and the non-standard, cross-track (instead of along-track) orientation of the long axis (46 cm) of the camera focal plane during photo acquisition. For example, it is difficult to locate any commercial company or civilian government agency that can (or will) produce full format photographic enlargements from 23- by 46-cm film transparencies, and it is exceedingly cumbersome to work with stereo models having dimensions of 13 by 46 cm.

TABLE 1.
A. SATELLITE IMAGE DATA FOR SOUTH FLORIDA

Satellite Sensor	Pixel Size	Spectral Bands	Areal Coverage	No. of Scenes Required
Landsat TM	28.5 m	Multispectral (7 bands)	185 by 185 km	2
SPOT HRV	10 m	Panchromatic (1 band)	60 by 60 km	8
KATE-200	12 m	Panchromatic (1 band)	192 by 228 km	1

B. Recent Aerial Photographic Coverage of South Florida

Date	Format	Scale	Film Type	Camera	Focal Length	Agency
05 Apr 90	23 by 23 cm	1:65,000	SO-131 (CIR)	Wild (Leica) RC-10	304.97 mm (12 in.)	NASA
05 Apr 90	23 by 46 cm	1:32,500	SO-131 (CIR)	Hycon HR 732	609.6 mm (24 in.)	NASA
30 Nov 92 and 03 Dec 92	23 by 23 cm	1:65,000	SO-131 (CIR)	Wild (Leica) RC-10	304.97 mm (12 in.)	NASA
30 Nov 92 and 03 Dec 92	23 by 46 cm	1:32,500	SO-131 (CIR)	Hycon HR 732	609.6 mm (24 in.)	NASA
15 Mar 94 and Mar 95	23 by 23 cm	1:40,000	SO-134 (CIR)	Zeiss RMK A 15/23	153.224 mm (6 in.)	USGS NAPP

During 1994 and 1995, as part of the USGS National Aerial Photography Program (NAPP), 1:40,000-scale CIR aerial photographs of the study area were recorded with standard 23- by 23-cm format mapping cameras. The NAPP photos offer several advantages over the NASA photos: (1) superior quality and color contrast, (2) standard 23- by 23-cm format, (3) stereo coverage registered to the 7.5-minute topographic quadrangles, and (4) a current record of vegetation patterns in south Florida (Plate 1). These photos are being used as the primary remote sensing data set for mapping vegetation. The 1990 and 1992 NASA photographs are available for assessing the damage caused by Hurricane Andrew.

Methodology

In order to meet the initial objectives of providing a geocoded satellite image mosaic and to ensure the registration of vegetation, transportation, and hydrographic features in a GIS database, it was first necessary to establish a network of GCPs distributed throughout the study area adequate for rectifying the eight SPOT images. The survey to establish GCPs was influenced by the existing road network and by the availability

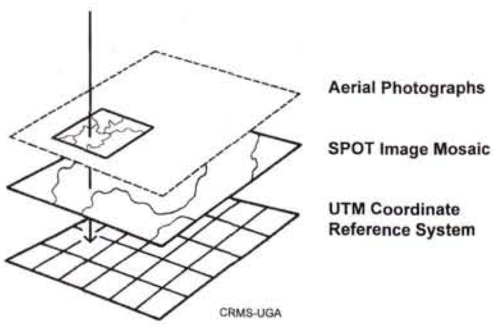


Figure 3. Remote sensing data for the project included color infrared aerial photographs and SPOT panchromatic images of 10-m resolution. The SPOT images form a geocoded mosaic tied to the North American Datum of 1983 (NAD 83).

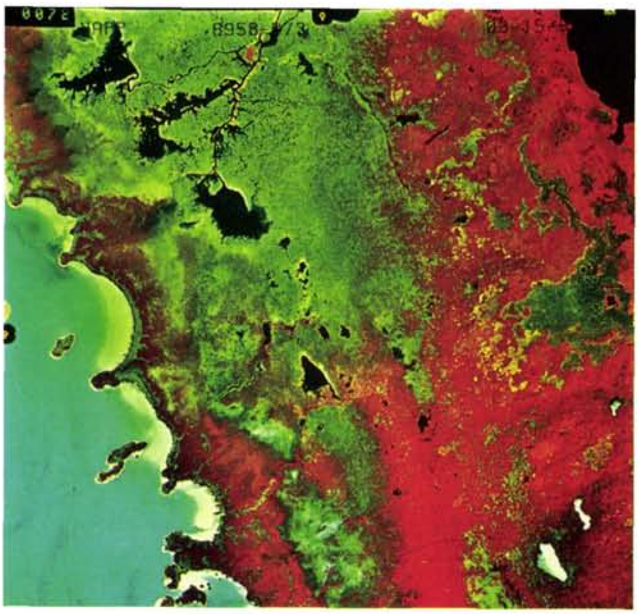
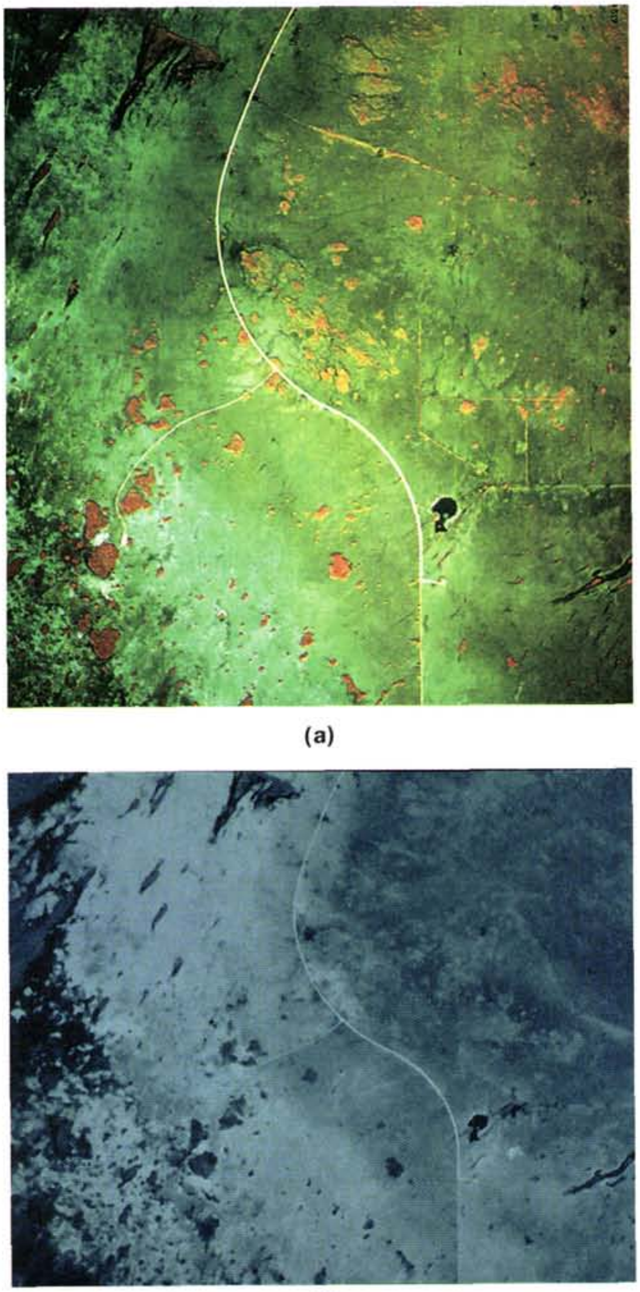


Plate 1. Sample 1994 NAPP color infrared (CIR) aerial photograph of mangrove forest located on the west coast of Everglades National Park. Note the contrast between healthy mangrove (red) and damaged mangrove forest (green) caused by Hurricane Andrew.

of 1:24,000-scale topographic line maps of recent vintage for the lands adjoining the Parks. Thus, it was decided to use the existing maps for perimeter control and to conduct the GPS survey along the few roads through the middle of the study area in order to provide the interior control necessary to rectify the satellite images.

The ground survey was conducted by Global Satellite Surveys, Decatur, Alabama, with assistance from CRMS and NPS personnel. Four Trimble Navigation 4000SE Land Surveyor receivers were employed using static differential GPS surveying techniques to establish a network of 23 image identifiable GCPs along 300 km of roads through the study area (Figure 4). These control points included the intersections of roads and of roads and canals, both of which are easily located on the SPOT 10-m panchromatic images. In addition, the survey included eight monumented National Geodetic Survey (NGS) and Florida GPS (FLGPS) base points of Order B (1:1,000,000) accuracy (or better) which were used to adjust the network. Based on checks conducted in the post-processing adjustment of the GPS observations, the accuracy to which the Universal Transverse Mercator (UTM) coordinates of the 23 points were established as referenced to the North American Datum of 1983 (NAD 83) was about ± 0.05 m ($RMSE_{xy}$).



(a)

(b)

Plate 2. Features such as road intersections, tree islands, and small ponds can be located on both the CIR air photos (a) and the SPOT image mosaic (b). The UTM ground coordinates of such features are digitized from the SPOT image and provide planimetric control for the CIR aerial photographs.

Geocoded Image Mosaic

Initially, consideration was given to using a block adjustment approach to create a seamless mosaic (Lenzen and Foresman, 1993). However, this approach necessitated the use of Level 1A SPOT data rather than the Level 1B data available for the project. Also, there was some uncertainty as to whether the coordinates of pass points could be established to an accuracy of about ± 1 pixel over the entire data set. For these reasons, it was decided to rectify each of the SPOT images individually, and then join them together to create the mosaic (see Figure 1 for SPOT scene locations).

The eight SPOT panchromatic images of 10-m pixel resolution were rectified to the UTM coordinate system using six to 15 GCPs per image obtained from the GPS survey and/or digitized from the existing USGS 1:24,000-scale topographic maps. All GCPs digitized from the USGS maps were referenced to the North American Datum of 1927 (NAD 27). These GCPs were converted to NAD 83 values using the U.S. Army Corps of Engineer's CORPSCON program available from the NGS offices in Rockville, Maryland. In a few instances, supplemental control in the form of small ponds or clumps of vegetation identifiable on the geocoded Landsat TM image were utilized to reinforce the rectification of the SPOT images over the more remote areas of the Everglades National Park. An assessment of the planimetric coordinate errors for each rectified SPOT panchromatic image produced $RMSE_{xy}$ values ranging from ± 5 to ± 9 m, with the average RMSE for the eight scenes equivalent to ± 7 m (i.e., ± 0.7 pixel).

The SPOT image mosaic was created from the individual SPOT scenes using the Desktop Mapping System (DMS)™ software package. Each digital SPOT image (or tile) was placed at its correct location (according to the UTM coordinates of the upper left corner pixel) within a coordinate box for the entire study area. An approximate 1-km wide by 60-km long gap between two adjacent SPOT scenes (visible in Figure 1) was patched with a strip of Landsat TM Band 3 image data geocoded and resampled to 10-m resolution. Once the mosaic was assembled, a median filter was employed to minimize banding and reduce artifacts along the margins of overlap between adjacent images. In order to facilitate its use, a UTM grid (NAD 83) with 5,000-m spacing was registered to the mosaic (Figure 5). The planimetric accuracy of the *geocoded mosaic* was evaluated at 29 withheld control points (check points) and was better than $\pm$ 1.5 pixels. The

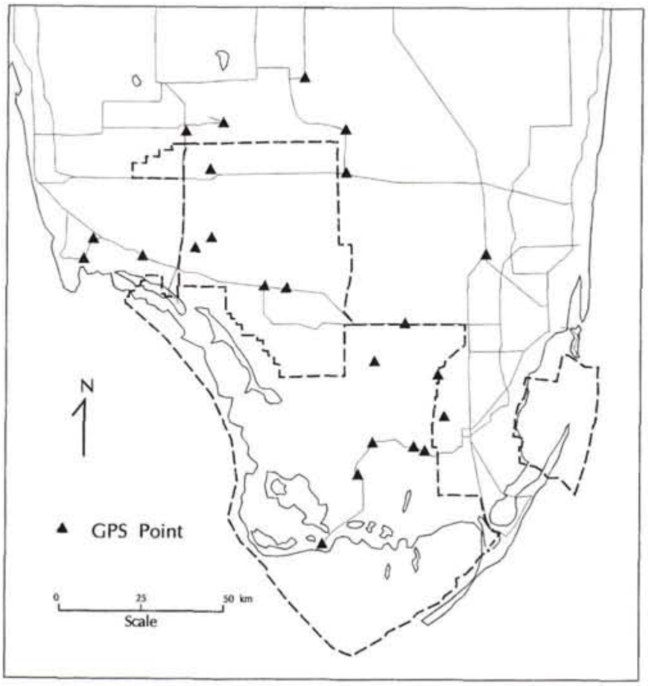


Figure 4. Distribution of 23 GCPs established by a GPS survey in 1994 along the roads through the Everglades National Park and Big Cypress National Preserve.

mosaic occupies slightly more than 200 Mbytes of disk space and is resident on NPS computers at Everglades National Park.

Interpretation of Aerial Photographs for the Development of a Vegetation Database

The timely development of an accurate, detailed vegetation database in GIS format for the Parks requires the use of remotely sensed data of sufficient resolution to identify and delineate vegetation classes to an accuracy of approximately 90 percent or better on one-hectare or larger plots, and of adequate geometric fidelity to locate class boundaries and parcels to accuracies generally compatible with NMAS for 1:24,000-scale map sheets. These requirements precluded the use of Landsat TM (28.5 m) or SPOT HRV (20 m) multispectral imagery for the development of the vegetation database. Instead, the use of the NAPP and NASA CIR aerial photographs of 1-m (or better) resolution was considered essential for the project.

In order to expedite the interpretation of the photographs and facilitate the construction of vegetation coverages in digital format, vegetation classes are delineated directly on CIR paper print enlargements (4×) produced from the CIR film transparencies. In addition, point features identified on the SPOT images and the air photo enlargements are annotated and numbered, and their UTM coordinates (obtained from the geocoded SPOT images) are employed to establish a GCP file for each photograph (Plate 2).

The annotated features on the photographs are then digitized, beginning with the GCPs. By digitizing the GCPs first, a set of photo rectification coefficients are generated which allow *x,y* digitizer coordinates for the annotated vegetation class boundaries to be transformed to UTM map coordinates (Easting, Northing) as the digitizing occurs. This procedure permits a segregation of tasks (interpretation, digitizing, editing) and greatly "speeds-up" the development of the vegetation database. Tests conducted to assess the accuracy to which the features are digitized have yielded $RMSE_{xy}$ values of between ±5 and ±10 m.

Vegetation Classification and Field Verification with GPS Assisted Helicopter Surveys

A hierarchical system of vegetation classification was developed (and is still being refined) for the Parks that includes information on plant species associations, land use, degree of human influence, and damage caused by Hurricane Andrew. Existing vegetation classification schemes such as the USGS *Land-Use and Land-Cover Classification System for Use with Remote Sensor Data* (Anderson *et al.*, 1976), the *U.S. Fish and Wildlife Service Cowardin System for Wetlands and Deepwater Habitats of the United States* (Cowardin et *al.*, 1979), the Florida Department of Transportation Classification System, and the Florida Biological Diversity Project Classification System (FBDP, 1994) do not contain the level of detail required for this vegetation mapping project. It was therefore decided that a new classification system should (1) contain classes at the individual species or species association level that can be identified from the CIR aerial photographs and (2) have a hierarchical organization that allows classes to be readily collapsed for compatibility with existing vegetation classification schemes being used elsewhere in south Florida.

The new Everglades Vegetation Classification System is being developed in conjunction with personnel from both the NPS and SFWMD and includes nine proposed classes of plant community types/land uses and an additional category

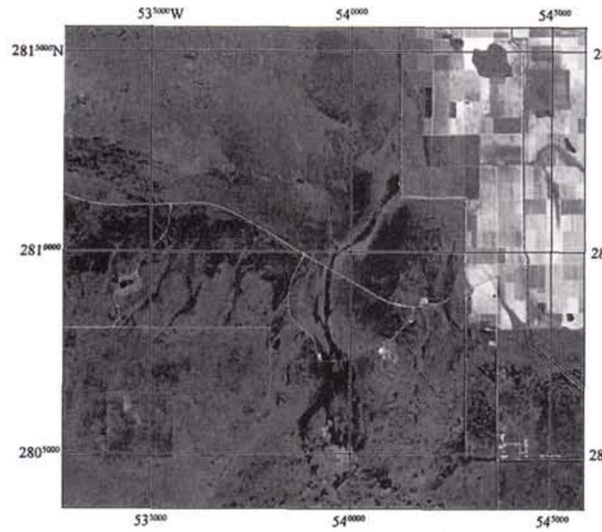


Figure 5. A portion of the SPOT image mosaic (10-m spatial resolution) at the eastern boundary of the Everglades National Park with 5,000-m UTM grid (NAD 83) superimposed. Note the agricultural land use adjacent to the Park.

TABLE 2. PROPOSED VEGETATION CLASSES FOR SOUTH FLORIDA NATIONAL PARKS AND PRESERVES

A. Forest
1. Buttonwood Forest
2. Mangrove Forest
3. Pine Forest
4. Hardwood Forest

B. Scrubland
1. Buttonwood Scrub
2. Mangrove Scrub

C. Hammock
1. Tropical Hardwood Hammock
2. Oak-Sabal Hammock
3. Fan Palm Hammock
4. Buttonwood Hammock
5. Sabal Palmetto Hammock

D. Savannah
1. Palm Savannah
2. Cypress Savannah
3. Pine Savannah

E. Swamp
1. Mixed Hardwood Swamp
2. Cypress Swamp
3. Bay Head Swamp
4. Willow Head Swamp

F. Prairie/Marsh
1. Wet Prairie
2. Dry Prairie
3. Halophytic Herbaceous Prairie
4. Broad Leaved Emergent Marsh

G. Exotics
1. *Melaleuca quinquenervia* (cajeput)
2. *Casuarina* spp. (Australian pine)
3. *Colubrina asiatica* (lather leaf)
4. *Schinus terebinthifolius* (Brazilian pepper)

H. Open Water
1. Lakes/Ponds
2. Rivers/Streams
3. Canals
4. Air Boat Trails

I. Non-Vegetated
1. Beaches
2. Mud (Tidal) Flats
3. Exposed Rock (i.e., pinnacle rock)
4. Off Road Vehicle (ORV) Trails

J. Special Modifiers:
1. Density Classes
2. Hurricane Damage Classes
3. Human Influence

of special modifiers (Table 2). A higher level of detail within the plant community types includes plant associations defined by typical dominant species. For example, under Forest (type) there are four associations: Buttonwood, Mangrove, Pine, and Hardwood. These associations may be further subdivided to include classes for individual species, for example, *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove), and Mixed Mangrove within the Mangrove Forest association. The species descriptions for the Everglades Classification System were compiled from Craighead (1971), McPherson (1973), Davis and Ogden (1994), and several NPS South Florida Research Center Reports (1980-1986) for the Everglades and Big Cypress National Parks/Preserves (e.g., Gunderson and Loope, 1982; Olmstead *et al.*, 1983). The classification information provided here is preliminary and is used to help clarify the photo-interpretation and mapping procedures.

In addition to the floristic characterization of the naturally occurring Everglades plant communities, the classification system includes categories of invasive exotic plants, indicators of human influence such as off road vehicle (ORV) and air boat trails, and four hurricane damage classes. In this way, the Everglades vegetation database will convey details on current vegetation, as well as human impacts and episodic disturbances that influence vegetation species distributions.

The detailed classification system requires that the interpreters be familiar with the classification scheme and the characteristics of the vegetation, as well as extremely skilled in photo-interpretation. Attainment of a high level of classification accuracy also requires the interpreters to have direct association with the plants and to make cross-correlations between the photographic images of the vegetation classes and their appearance in the natural environment. In this context, fieldwork is greatly facilitated by the use of NPS Bell Jet Ranger 206 helicopters that are available for ground truth collection and verification of image interpretations. However, helicopter flight time is expensive (~ $500.00/hr), and a procedure involving use of the SPOT image mosaic and the latest technology in laptop computers, GPS receivers, and image processing/positioning/display software has been developed to expedite data collection and verification. The helicopters are equipped with GPS receivers that enable the pilots to predefine 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 of 10-m pixel resolution was aggregated to a mosaic of 20-m pixel resolution and divided into four tiles, each about 13 Mbytes in size. These image files were then loaded into a Dell Latitude XP 486 laptop computer (100 Mhz) along with the DMS (R-WEL, Inc.) and Field Notes (Pen Metrics, Inc.) software packages. A Trimble Pathfinder Professional (six-channel) GPS receiver with an external antenna mounted on the forward hull of the helicopter was then connected to the serial port of the laptop computer. This set-up enables 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 (Plate 3). Most importantly, it provides a means of collecting ground truth information that is linked to coordinates provided by the GPS receiver. Upon reaching an area of interest, the helicopter circles at low altitude and/or lands to allow identification of plants (Plate 4). Species attribute information and additional notes pertaining to fire history or exotic control measures that may have influenced the area are entered into the computer and linked with the GPS coordinates. This procedure also can be used with vehicle or foot surveys.

The data gathered during the ground and helicopter surveys are used to verify vegetation interpretations from the 1994/1995 USGS NAPP air photos. After verification, the digital vegetation boundary files, along with transportation and hydrographic data in digital format, are input to the ARC/INFO software package resident on an IBM RISC System 6000 workstation, edited, attributed, and edge matched to create the GIS database. Tiles corresponding to the USGS 1:24,000-scale topographic quadrangle series are then plotted as hardcopy maps.

Vegetation Maps and Projected Database Use

The GIS database and vegetation maps are currently being constructed with an anticipated completion date sometime in

Plate 3. Collection of ground truth is facilitated by the use of helicopters and by employing a laptop computer interfaced to a GPS unit and software for image display/ attribute entry. The GPS continually tracks the helicopter. This track is displayed on the SPOT image mosaic and attribute information is recorded in real time.

1996. As the project proceeds, the digital and hardcopy products are being transferred to the South Florida Natural Resource Center, Everglades National Park, and to the GIS units at the Headquarters of Big Cypress National Preserve and Biscayne National Park. Two preliminary samples of vegetation maps are presented in Plate 5. The first depicts Pine Savannah vegetation in the Long Pine Key area of Everglades National Park that suffered stem breakage and defoliation by the strong winds and tornadoes associated with Hurricane Andrew (Plaste 5A). Although considerable damage was noted on the 1992 NASA photographs, recovery of the pine trees was observed during helicopter surveys conducted in 1995. The impact of human activities on vegetation patterns, on the other hand, may be more long lasting. For example, evidence of past row crop planting of vegetable farms abandoned more than 40 years ago remains in Sawgrass Wet Prairie and Cypress Forest areas in the Parks (Plate 5B).

Park researchers and managers will use the maps and digital data sets to study the relationships between human activities, hurricane damage, and vegetation patterns. This information, in turn, will provide a basis for assessing future changes due to the increasing pressures facing the Parks. In addition, higher resolution image subsets of important community and landscape types and features will be established to support a long-term environmental monitoring program for the Parks to assess changes at the individual species and community levels. These image subsets will allow the Parks to monitor the relationship of vegetation change to other environmental variables.

Conclusion

The development of a digital database in GIS format for the Parks of south Florida is made possible by the availability of recent SPOT panchromatic satellite image data of 10-m resolution, CIR aerial photographs recorded in 1994-1995, and new approaches to the integration of GPS, image processing, and GIS technologies to facilitate rectification, analysis, and verification of data. It is envisioned that the geocoded SPOT image mosaic will provide NPS personnel with a quick and reliable means of pinpointing features of interest and developing image subsets that will aid Park managers, scientists, rangers, and law enforcement officers in their various roles.

The GIS database and associated 1:24,000-scale hardcopy vegetation maps will provide the NPS with the first comprehensive, up-to-date spatial data to support park management personnel in evaluating the status of vegetation and the threats caused by urban expansion, the intense use of bordering agricultural lands, and the encroachment of exotic plant species. In particular, the database will provide a means for assessing damage caused by natural stochastic events such as Hurricane Andrew. The methodologies employed in this project, which include the construction of a geocoded satellite

Plate 4. The University of Georgia and NPS personnel examine Sawgrass Wet Prairie vegetation in Big Cypress National Preserve. The use of helicopters and real-time position/data entry greatly expedites field verification and provides a computer record that is used in the laboratory to facilitate photo interpretation of vegetation classes.

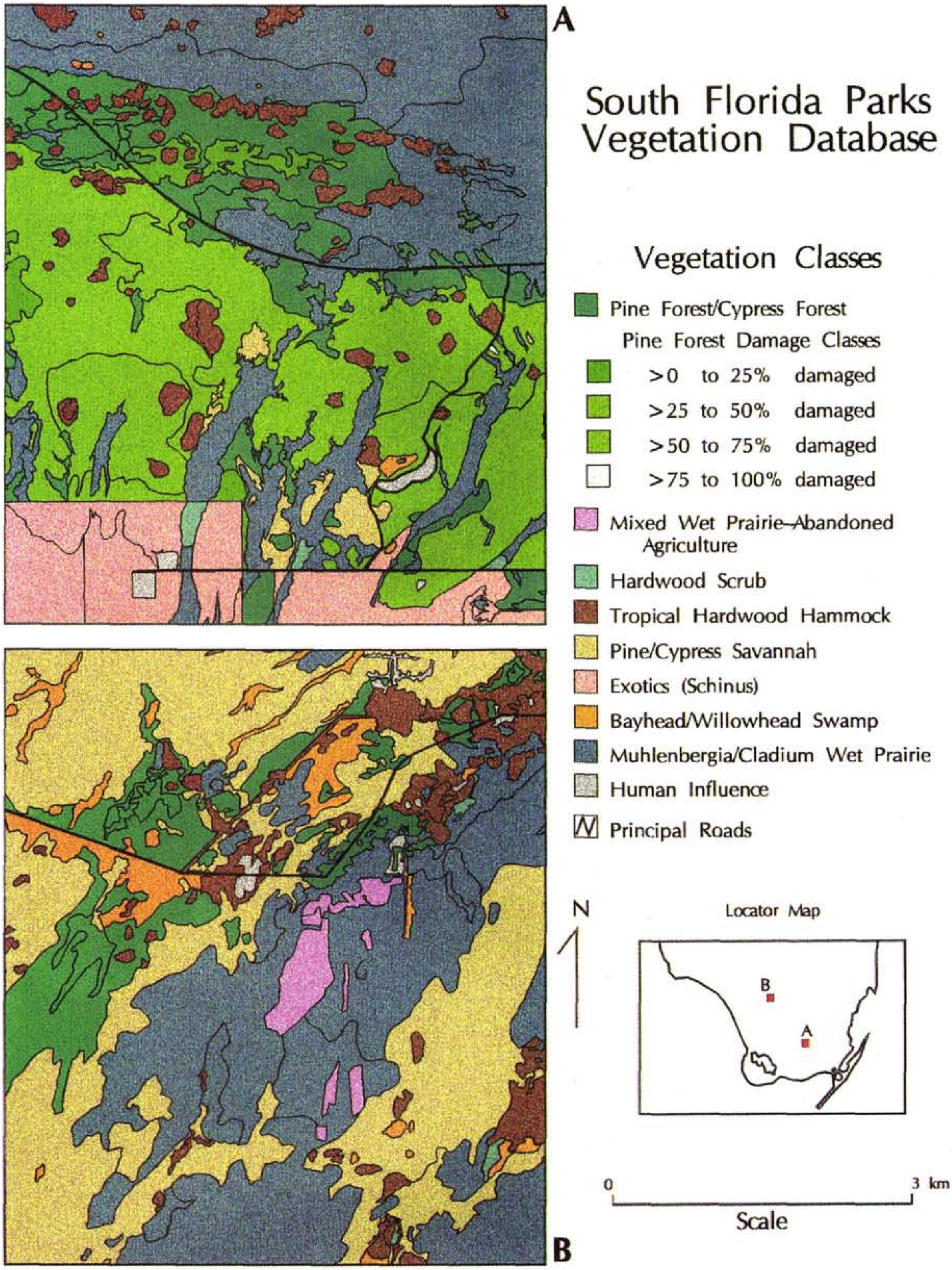


Plate 5. Preliminary vegetation maps for portions of Everglades National Park and Big Cypress National Preserve. (A) Pine Savannah vegetation in a portion of Everglades National Park classified according to levels of damage caused by Hurricane Andrew. (B) Evidence of human influence and abandoned agricultural fields detected in Big Cypress National Preserve communities of Mixed Wet Prairie.

image mosaic to use in conjunction with aerial photographs, and the combination of GPS, helicopter, and ground survey techniques to verify photo interpretation, can be used in other remote and/or inaccessible areas to facilitate the generation of detailed databases vital for the preservation of unique environments.

Acknowledgments

This research project is sponsored by the U.S. Department of Interior, National Park Service (NPS), through Cooperative Agreement #5280-4-9006. The assistance of the Florida Department of Environmental Protection, St. Petersburg, Florida; the South Florida Water Management District, West Palm Beach, Florida; SPOT Image Corporation, Reston, Virginia; and Survey Resources International, Inc., Houston, Texas is gratefully appreciated. Mr. William Harris of Global Satellite Surveys, Decatur, Alabama, worked tirelessly to ensure that an accurate GPS survey was accomplished on schedule.

References

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer, 1976. *A Land Use and Land Cover Classification System for Use with Remote Sensor Data*, U.S. Geological Survey, Professional Paper 964, U.S. Government Printing Office, Washington, D.C., 28 p.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe, 1979. *Classification of Wetlands and Deepwater Habitats of the United States*, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C., 103 p.

Craighead, F.C., Sr., 1971. *The Trees of South Florida, Vol. I. The Natural Environments and Their Succession*, University of Miami Press, Coral Gables, Florida, 212 p.

Davis, S.M., and J.C. Ogden (editors), 1994. *Everglades: The Ecosystem and its Restoration*, St. Lucie Press, Delray Beach, Florida, 826 p.

Doren, R.F., L.D. Whiteaker, G. Molnar, and D. Sylvia, 1990. Restoration of former wetlands within the Hole-in-the-Donut in the Everglades National Park, *Proceedings of the Seventh Annual Conference on Wetlands Restoration and Creation*, Plant City, Florida, pp. 33–50.

Duever, M.J., J.E. Carlson, J.F. Meeder, L.C. Duever, L.H. Gunderson, L.A. Riopelle, T.R. Alexander, R.L. Myers, and D.P. Spangler, 1986. *The Big Cypress National Preserve*, Research Report Number 8, National Audubon Society, New York, New York, 455 p.

Florida Biological Diversity Project, 1994. *Florida Biological Diversity Project (FBDP) Newsletter*, Fall Issue, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, Florida, 8 p.

Gunderson, L.H., D.P. Brannon, and G. Irish, 1986. *Vegetation Cover Types of Shark River Slough, Everglades National Park, Derived from Landsat Thematic Mapper Data*, Technical Report SFRC-86/03, South Florida Research Center, National Park Service, U.S. Department of Interior, Homestead, Florida, 6 p.

Gunderson, L.H., and L.L. Loope, 1982. *An Inventory of the Plant Communities within the Deep Lake Strand Area, Big Cypress National Preserve*, Technical Report T-666, South Florida Research Center, National Park Service, U.S. Department of Interior, Homestead, Florida. 39 p.

Jensen, J.R., K. Rutchey, M.S. Koch, and S. Narumalani, 1995. Inland wetland change detection in the Everglades Water Conservation Area 2A Using a Time Series of Normalized Remotely Sensed Data, *Photogrammetric Engineering & Remote Sensing*, 61(2): 199–209.

Lenzen, T.W., and T.W. Foresman, 1993. Digital image databases support GIS operations, *GIS World*, 6(11):36–38.

Light, S.S., and J.W. Dineen, 1994. Water control in the Everglades: A historical perspective, *Everglades: The Ecosystem and Its Restoration* (S.M. Davis and J.C. Ogden, editors), St. Lucie Press, Delray Beach, Florida, pp. 47–84.

Loope, L., M. Duever, A. Herndon, J. Snyder, and D. Jansen, 1994. Hurricane impact on uplands and freshwater swamp forest, *Bioscience*, 44(4):238–246.

McPherson, B.F., 1973. *Vegetation Map of Southern Parts of Subareas A and C, Big Cypress Swamp, Florida*, Hydrologic Investigations Atlas HA-492, Florida Department of Natural Resources and U.S. Geological Survey, Washington, D.C., 1 p.

Olmstead, I.C., W.B. Robertson, Jr., J. Johnson, and O.L. Bass, Jr., 1983. *Vegetation of Long Pine Key, Everglades National Park*, Technical Report SFRC-83/05, South Florida Research Center, National Park Service, U.S. Department of Interior, Homestead, Florida, 64 p.

Pimm, S.L. G.E. Davis, L. Loope, C.T. Roman, T.J. Smith III, and J.T. Tilmant, 1994. Hurricane Andrew, *Bioscience*, 44(4):224–229.

Pumpelly, J.W., 1967. Color-separation and printing techniques for photomaps, *Surveying and Mapping*, 27(2):227–280.

Rose, M., and F. Draughn, 1991. GIS applications at Everglades National Park, *GIS World*, 4(3):49–51.

Rutchey, K., and L. Vilchek, 1994. Development of an Everglades vegetation map using a SPOT image and the global positioning system, *Photogrammetric Engineering & Remote Sensing*, 60(6): 767–775.

Spradley, L.H., 1994. Cost-effective data for regional GIS bases, *Proceedings of the ISPRS Commission IV Symposium on Mapping and Geographic Information Systems* (R. Welch and M. Remillard, editors), *International Archives of Photogrammetry and Remote Sensing, Athens*, Georgia, 30(Part 4):203–208.

Welch, R., 1985. Cartographic potential of SPOT image data, *Photogrammetric Engineering & Remote Sensing*, 51(8):1085–1091.

Welch, R., T.R. Jordan, and M. Ehlers, 1985. Comparative evaluations of the geodetic accuracy and cartographic potential of Landsat-4/-5 TM data, *Photogrammetric Engineering & Remote Sensing*, 51(9):1249–1262.

Welch, R., M. Remillard, and J. Alberts, 1992. Integration of GPS, remote sensing and GIS techniques for coastal resource management, *Photogrammetric Engineering & Remote Sensing*, 58(11): 1571–1578.

Welch, R., and M. Remillard, 1994. Integration of GPS, digital image processing and GIS for resource mapping applications, *Proceedings of the ISPRS Commission IV Symposium on Mapping and Geographic Information Systems* (R. Welch and M. Remillard, editors), *International Archives of Photogrammetry and Remote Sensing*, Athens, Georgia, 30(Part 4):10–14.

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FORTHCOMING ARTICLES

The following list includes only those articles scheduled for publication in *PE&RS* through April 1996.

R. M. Batson and *E. M. Eliason*, Digital Maps of Mars.

Michael F. Baumgartner and *Albert Rango*, A Microcomputer-Based Alpine Snow Cover Analysis System (ASCAS).

Michel Boulianne, Rock Santerre, Paul-André Gagnon, and *Clément Nolette*, Floating Lines and Cones for Use as a GPS Mission Planning Aid.

Gregory J. Carbone, Sunil Narumalani, and *Michelle King*, Application of Remote Sensing and GIS Technologies with Physiological Crop Models.

Allen E. Cook and *John E. Pinder III*, Relative Accuracy of Rectifications Using Coordinates Determined from Maps and Global Positioning Systems.

Christopher Deckert and *Paul V. Bolstad*, Forest Canopy, Terrain, and Distance Effects on Global Positioning System Point Accuracy.

Bon A. Dewitt, Initial Approximations for the Three-Dimensional Conformal Coordinate Transformation.

Sam Ekstrand, Landsat TM-Based Forest Damage Assessment: Correction for Topographic Effects.

Yasser El-Manadili and *Kurt Novak*, Precision Rectification of SPOT Imagery Using the Direct Linear Transformation Model.

Maurice S. Gyer, Methods for Computing Photogrammetric Refraction Corrections for Vertical and Oblique Photographs.

Christian Heipke, Wolfgang Kornus, and *Anton Pfannenstein*, The Evaluation of MEOSS Airborne Three-Line Scanner Imagery: Processing Chain and Results.

Matthew Heric, Carroll Lucas, and *Christopher Devine*, The Open Skies Treaty: Qualitative Utility Evaluations of Aircraft Reconnaissance and Commercial Satellite Imagery.

Peter E. Joria and *Janet C. Jorgenson*, Comparison of Three Methods for Mapping Tundra with Landsat Digital Data.

Ronald Kwok and *Tom Baltzer*, The Geophysical Processor System at the Alaska SAR Facility.

Rongxing Li, Design and Implementation of a Photogrammetric Geo-Calculator in a Windows Environment.

Tang Liang and *Christian Heipke*, Automatic Relative Orientation of Aerial Images.

Donald L. Light, Film Cameras or Digital Sensors? The Challenge Ahead for Aerial Imaging.

Donald C. Rundquist, Luoheng Han, John F. Schalles, and *Jeffrey S. Peake*, Remote Measurement of Algal Chlorophyll in Surface Waters: The Case for the First Derivative of Reflectance near 690 NM.

Soren Ryherd and *Curtis Woodcock*, Combining Spectral and Texture Data in the Segmentation of Remotely Sensed Images.

Eric M. Sanden, Carlton M. Britton, and *James H. Everitt*, Total Ground-Cover Estimates from Corrected Scene Brightness Measurements.

Howard Schultz, Shape Reconstruction from Multiple Images of the Ocean Surface.

Tian-Yuan Shih, A Photogrammetric Simulator for Close-Range Applications.

Mohammed E. Shokr, Laurence J. Wilson, and *Dwayne L. Surdu-Miller*, Effect of Radar Parameters on Sea Ice Tonal and Textural Signatures Using Multi-Frequency Polarimetric SAR Data.

Lawrence V. Stanislawski, Bon A. Dewitt, and *Ramesh L. Shrestha*, Estimating Positional Accuracy of Data Layers within a GIS through Error Propagation.

Steve Stehman, Estimating the Kappa Coefficient and Its Variance Under Stratified Random Sampling.

Daniel R. Steinwand, John A. Hutchinson, and *John P. Snyder*, Map Projections for Global and Continental Data Sets and an Analysis of Pixel Distortion Caused by Reprojection.

Antonio Maria Garcia Tommaselli and *Clésio Luis Tozzi*, A Recursive Approach to Space Resection Using Straight Lines.

Paul C. Van Deusen, Unbiased Estimates of Class Proportions from Thematic Maps.

Howard Veregin, Error Propagation through the Buffer Operation for Probability Surfaces.

Gary M. Wohl, Operational Sea Ice Classification from Synthetic Aperture Radar Imagery.

Ding Yuan, Natural Constraints for Inverse Area Estimate Corrections.