Inland Wetland Change Detection Using Aircraft MSS Data

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ABSTRACT: Non-tidal wetlands in a portion of the Savannah River swamp forest affected by reactor cooling water discharges were mapped using 31 March 1981 and 29 April 1985 high-resolution aircraft multispectral scanner (MSS) data. Due to the inherent distortion in the aircraft MSS data and the complex spectral characteristics of the wetland vegetation, it was necessary to implement several innovative techniques in the registration and classification of the MSS data of the Pen Branch Delta on each date. In particular, it was necessary to use a piecewise-linear registration process over relatively small regions to perform image-to-image registration. When performing unsupervised classification, an iterative "cluster busting" technique was used which simplified the cluster labeling process. These procedures allowed important weltand vegetation categories to be identified on each date. The multiple-date classification maps were then evaluated using a post-classification comparison technique yielding estimates of change in the wetland classes.

INTRODUCTION

A NUCLEAR REACTOR at the Savannah River Plant in South Carolina has discharged cooling water into Pen Branch since 1954. The water eventually reaches the Savannah River swamp (Figure 1) and affects the Deciduous Swamp Forest (DSF) which is composed primarily of bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). The area of damaged forest at the Pen Branch delta totalled 152 ha (377 ac) in 1984, and has been increasing at a rate of about 10.5 ha (26 ac) per year (Gladden *et al.*, 1985).

The reduction of Deciduous Swamp Forest in the vicinity of the Pen Branch Delta is thought to result from an interaction of the high temperature of the thermal effluent and the flood stage of the Savannah River as it flows through the Savannah River swamp system. For example, non-flood and flood conditions have been documented using pre-dawn, thermal infrared imagery (Plate 1) (Shines and Tinney, 1983; Negri and Shines, 1986). The Savannah River in flood stage caused the thermal effluent from Pen Branch to "hug" the terrace bank along the northern border of the swamp, concentrating hot water along the terrace for extended periods of time and damaging the Deciduous Swamp Forest (Scott *et al.*, 1985). Conversely, when the river was in a non-flood stage, the effluent dissipated more uniformly throughout the delta. Thus, the major agents causing the wetland change are tentatively understood; what is lacking is a precise, quantitative method of monitoring the types of wetland change taking place through time.

This paper describes the use of high-resolution, aircraft multispectral scanner (MSS) data to monitor the wetland change on the Pen Branch Delta from 1981 to 1985. It reviews techniques used to perform image-to-image registration, to interactively cluster and classify the wetland vegetation, and to produce maps and statistics documenting the spatial distribution of wetland change.

THE CHANGE DETECTION PROBLEM

Howarth and Wickware (1981) and Jensen (1981, 1986) reviewed several important sensor system considerations and environmental conditions which must be addressed when digital change detection is attempted. The remote sensor systems should acquire imagery at approximately the same altitude using the same spectral bands with the same instantaneous field-of-view (IFOV) on at least two successive dates. This study used Daedalus AADS-1260 and AADS-1268 multispectral scanning systems (MSS) which collected data at approximately 10:30 A.M. on 31 March 1981 and 29 April 1985, respectively. The spectral bandwidths of these sensor systems are generally comparable (Table 1). The sensors were flown at 8000 ft (2438 m) above ground level with a 2.5-milliradian field-of-view, resulting in pixels with a spatial resolution of 5.6 by 5.6 m on each date. The data were digitized to 8-bits (brightness values from 0 to 255) using both systems. The sensor systems were operated by EG&G of Las Vegas, Nevada, for the U.S. Department of Energy.

TABLE 1. SPECTRAL CHANNELS (IN μM) OF THE AADS-1260 AND AADS-1268 DAEDALUS MULTISPECTRAL SCANNING SYSTEMS (MSS)

Channel	AADS-1260	AADS-1268
1	0.38– 0.42	0.42– 0.45
2	0.42– 0.45	0.45– 0.52
3	0.45– 0.50	0.52– 0.60
4	0.50– 0.55	0.60– 0.62
5	0.55– 0.60	0.63– 0.69
6	0.60– 0.65	0.69– 0.75
7	0.65– 0.70	0.76– 0.90
8	0.70– 0.79	0.91– 1.05
9	0.80– 0.89	1.55– 1.75
10	0.92– 1.10	2.08– 2.35
11	8.00–14.00	8.50–14.00

It is important to hold constant as many environmental variables as possible on each date. Ideally, near-anniversary dates of imagery are acquired. Unfortunately, this is not always possible due to cloud cover or aircraft availability. In this study, the closest near-anniversary MSS data were obtained on 29 April 1985. This resulted in two data sets with slightly different sun angles. Sun angle effects can be removed by calibrating the data over an oligotrophic lake (Verdin, 1985). Unfortunately, no lakes were present within the flightlines so such a correction was not possible. Both overflights took place approximately three days after the passage of a low pressure system, resulting in stable, cloud-free atmospheric conditions and similar soil moisture conditions.

To perform change detection, the remotely sensed imagery on each date must be registered to a planimetric base map (image

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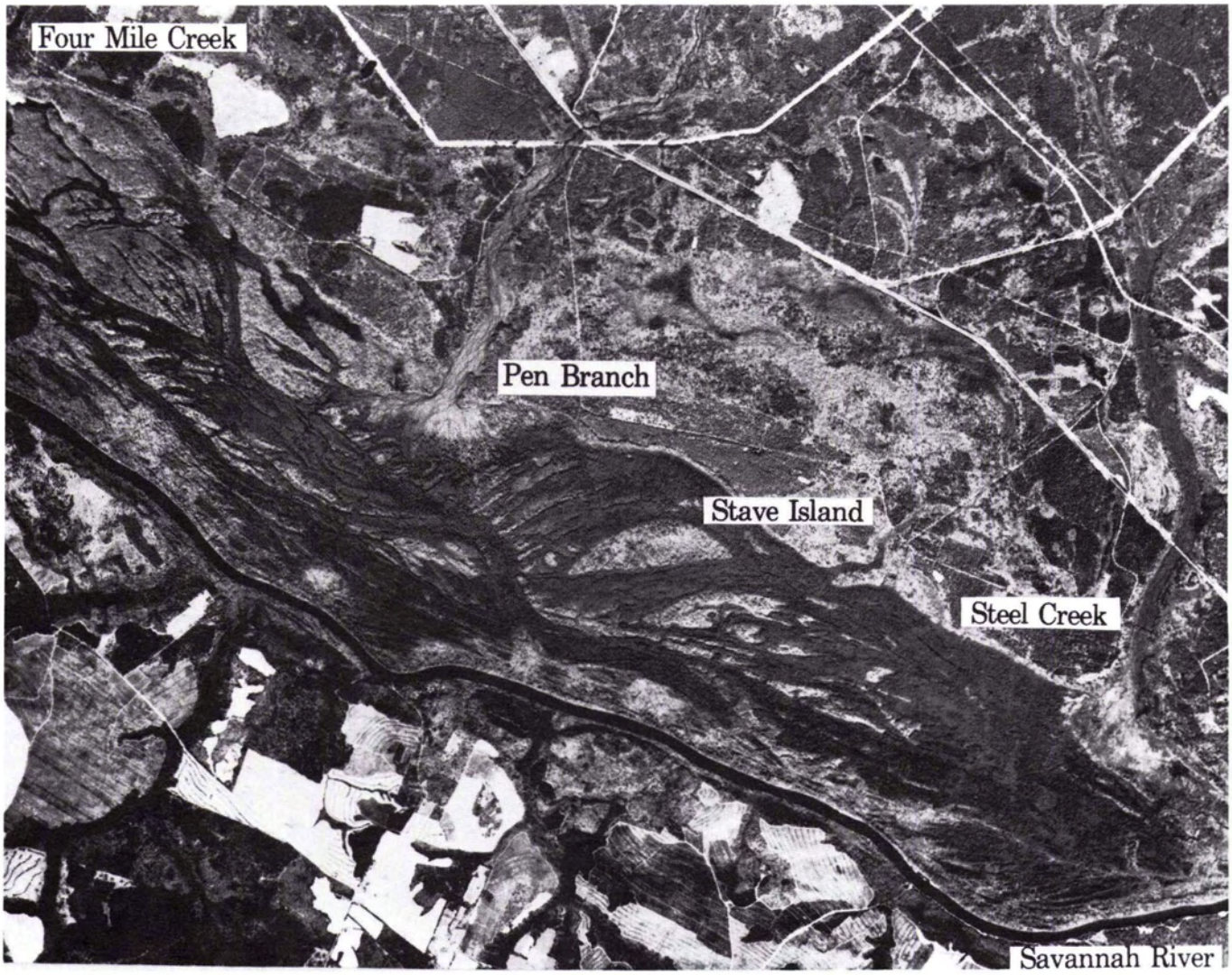

FIG. 1. A National High Altitude Photography Program photograph of the Savannah River swamp adjacent to the Savannah River Plant in South Carolina. Thermal effluent from nuclear reactor cooling operations reaches the Savannah River swamp through Four Mile, Pen Branch, and Steel Creek. Deltas have formed at the junctions of the creeks and the swamp where the indigenous cypress-tupelo forest has been affected.

rectification) *or* one image must be registered to the other (image-to-image registration). In this study image-to-image registration was used because, as is typical in wetland environments, there were insufficient ground control points (GCPs) visible on both the imagery and a 7.5-minute U.S. Geological Survey planimetric map of the study area to perform image rectification.

With the multiple date imagery registered, it was necessary to select a suitable change detection algorithm. Weismiller *et al.*, (1977) and Jensen (1981, 1986) summarized the prevalent methods. This research utilized **post-classification comparison**, which required that a separate wetland classification be made for each date of the analysis. The two classification maps were then compared on a pixel-by-pixel basis so that the wetland class of individual pixels could be evaluated through time. A change detection map was produced along with relevant change detection statistics.

IMAGE REGISTRATION RESULTS

Digital Landsat MSS or TM data are commonly used for urban-suburban change detection (Jensen and Toll, 1982; Adeniyi, 1985). These data have also been used to monitor wetland changes (Carter, 1977; Weismiller *et al.*, 1977; Gilmer *et al.*, 1980; Wickware and Howarth, 1981; Carter, 1982; Butera, 1983). However, to our knowledge no investigators have used aircraft MSS data to conduct wetland change detection. The cost of acquiring MSS data and problems in image registration are important reasons.

Satellite platforms remain relatively stable approximately 900 km above the Earth. Movements that occur are usually minor and are systematically spread over large geographic areas. Because the distortion is usually linear, a simple least-squares regression approach may be used to model the distortion and accurately register the different images to within ± 1 pixel (Weismiller *et al.*, 1977; Adeniyi, 1985). Also, image-to-map rectification is much simpler because only one data set contains distortion (the image), whereas in image-to-image registration two sets of distortion must be matched.

With aircraft MSS data, image distortion can be a much greater problem. Lateral winds and vertical turbulence can cause random and sometimes severe aircraft movements (roll, pitch, and yaw) or variations in altitude and/or velocity while the sensor is scanning (Bernstein, 1983). Because of these problems, few studies have attempted geometric correction of aircraft MSS data. When geometric correction is attempted, most investigators geometrically rectify a single flightline of MSS data to a map (Gillespie and Kahle, 1977; Ungar, 1982; Otepka, 1978; and Kraus, 1978). Only a few have mosaicked several flightlines together (McGlone *et al.*, 1979; McGlone and Mikhail, 1985; Gibson, 1985). Leckie (1980) found that aircraft MSS data could be registered

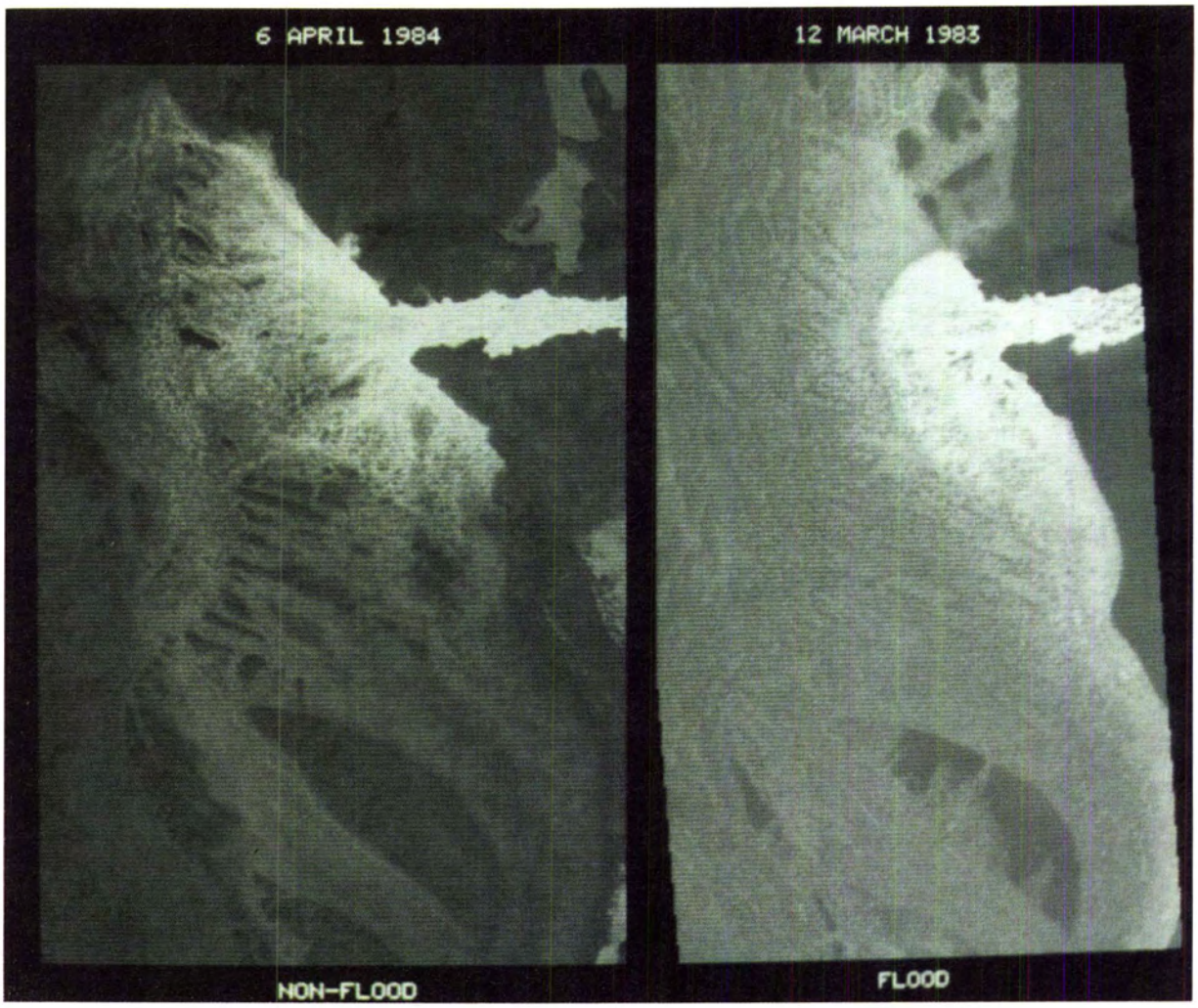

PLATE 1. Thermal infrared imagery (8 to 14 μm) obtained on 6 April 1984 and 12 March 1983 demonstrate how Savannah River flood conditions can cause the thermal effluent entering the swamp system to "hug" the upland terrace.

image-to-image if a sufficient number of ground control points were available (>25). Although the hypothesis was not specifically tested, he suggested that ". . .applications may take the form of using short, low degree polynomial approximations within small segments of the image. In many applications the gains obtained by using lengthy polynomials with terms of high degree may not be sufficient to warrant the additional cost."

In our study, the focus was on a portion of the Pen Branch delta referred to as the Pen Branch tail. This area extended southeast for approximately 2 km along the upland terrace adjacent to the Savannah River swamp. To detect change along the entire region being influenced by the thermal effluent (shown in Figure 2), it was necessary to register a relatively large area. This resulted in two 375-ha images being selected from the 1981 and 1985 MSS data (Plate 2). Twenty-eight ground control points (GCPs) were used in a preliminary geometric registration. This involved the use of linear regression to calculate six coefficients for the first-order linear transformation equations. Brightness values from the original distorted 1985 image were then transferred to the grid of the registered 1985 output image using nearest-neighbor interpolation. A root-mean-square-error (RMSE) evaluation was then performed between the 1981 and registered 1985 imagery GCPs to assess image-to-image registration accuracy. It was hoped that an RMSE of approximately 1.0 could be obtained, as is commonly found in many remote sensing investigations (Jensen, 1986). Unfortunately, the initial results were unsatisfactory, with an overall RMSE greater than 5.0. A subsequent reregistration involving 97 GCPs revealed persistent image-to-image misregistration of the same magnitude.

An alternate methodology was used to register the 1985 imagery to the 1981 imagery based on the method suggested by Leckie (1980). First, the original analog recordings of each flightline were evaluated. The 1985 imagery exhibited several "notches" in the sides of the flightline, indicative of aircraft movement. Therefore, the 1985 flightline along the Pen Branch tail was carefully evaluated and divided into four subscenes determined by the direction of geometric distortion (Plate 3). The topmost subscene covered an area skewed left, while the lower subset was skewed right. These four 1985 image subscenes were then registered individually to the 31 March 1981 imagery. Registration results were significantly improved for all subimages. Note that four different adjustments were needed to align the 1985 data with the 1981 imagery (Plate 3). The RMSE for the 1985 subscenes ranged from 1.52 to 2.63 (Table 2).

One more registration was performed in an attempt to achieve sub-pixel registration accuracy. Unfortunately, no significant improvement in precision resulted. Bernstein (1983) suggested that more than two iterations using new GCPs each time may provide no significant increase in registration precision. The average RMSE for the 1985 to 1981 image-to-image registration was 2.26 using 87 GCPs. Although the average registration precision was not high compared to studies based on satellite data, it was sufficient to monitor the relatively homogeneous areas of change found in the Pen Branch tail.

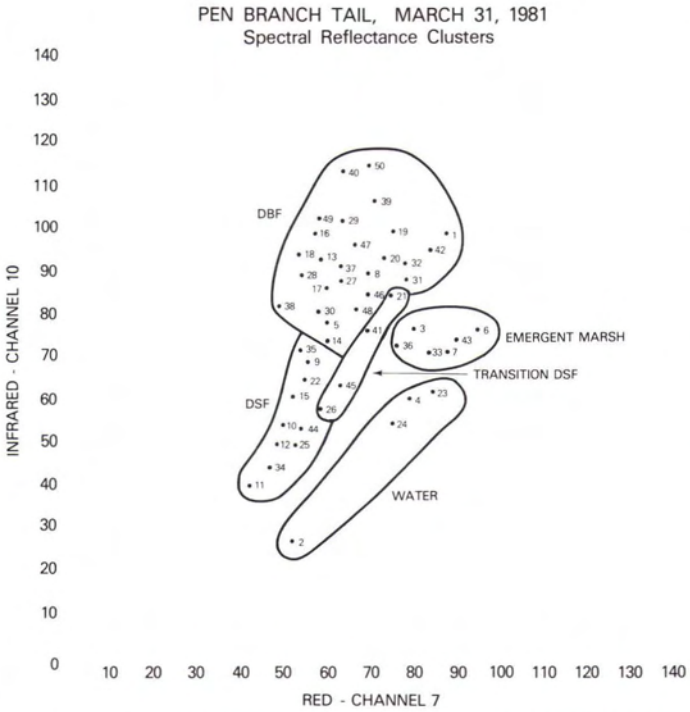

FIG. 2. Fifty clusters extracted from the 31 March 1981 aircraft MSS data shown in two-dimensional feature space (red and near-infrared brightness values). The classes are described in Table 3.

TABLE 2. RESULTS OF THE PIECEWISE LINEAR REGISTRATION OF THE PEN BRANCH TAIL IMAGERY OBTAINED ON 31 MARCH 1981 AND 29 APRIL 1985

Subscene #	Subscene Hectares	Number of Ground Control Points (GCPs)	Average RMSE
1	116	22	2.63
2	30	7	1.52
3	125	19	2.36
4	140	39	2.55
Total	411	87	2.26

IMAGE CLASSIFICATION AND CHANGE DETECTION RESULTS

It was possible to classify the remotely sensed data into the following wetland vegetation classes once the multiple-date imagery were registered to one another:

- EM – Emergent Marsh (Persistent and Nonpersistent)
- DSF – Deciduous Swamp Forest
- T-DSF – Transition Deciduous Swamp Forest
- DBF – Deciduous Bottomland Forest
- OW – Open Water

The wetland classes selected were compatible with the U.S. Fish and Wildlife wetland classification system (Cowardin *et al.*, 1979). The dominant species within each wetland class are summarized in Table 3.

Results of image classification in other areas having complex terrain suggest than an unsupervised classification is usually superior (Townshend and Justice, 1980; Shreirer *et al.*, 1982). When performing an unsupervised classification, each pixel is assigned by the computer to a "cluster" based on its statistical characteristics in n-dimensional feature space. Theoretically, pixels representing a given land-cover type (e.g., Emergent Marsh) will cluster together in a unique region of spectral space. The pixels assigned to the various wetland vegetation clusters are then labeled by the analyst according to the position of a cluster in feature space and their relationship to the analyst's "real-world" knowledge of the landscape.

Even though up to eleven spectral channels were available for analysis on each date, only four channels were used in each unsupervised classification. Based on transformed divergence statistics computed by Jensen *et al.*, (1984, 1986a), channel 5 (0.55 to 0.60 μm), channel 7 (0.65 to 0.70 μm), channel 8 (0.70 to 0.79 μm), and channel 10 (0.92 to 1.10 μm) accounted for most of the variation in the AADS-1260 aircraft MSS data when performing wetland classification in this area. For the AADS-1268 data, channel 3 (0.52 to 0.60 μm), channel 5 (0.63 to 0.69 μm), channel 8 (0.91 to 1.05 μm), and the middle-infrared channel 9 (1.55 to 1.75 μm) were optimum. Differences between the AADS-1260 and the AADS-1268 bandwidths (Table 2) precluded the use of the exact same channels in the analysis; e.g., there was no 0.70 to 0.79 μm channel on the AADS-1268 scanner. Also, it was not surprising that the middle infrared channel 9 (1.55 to 1.75 μm) band was selected in the AADS-1268 data due to its known wetland sensitivity (Jensen *et al.*, 1986a). Other wetland mapping investigations have found that one green, one red, and at least one infrared band are usually optimal (Best *et al.*, 1981).

Initially, 50 clusters were extracted from both the 1981 and 1985 imagery. Plots of the clusters in red and near-infrared, two-dimensional feature space are shown in Figures 2 and 3. In March, the healthy Deciduous Swamp Forest (DSF) was not fully leafed-out and did not reflect as much near-infrared or red energy as the Deciduous Bottomland Forest (DBF). This can be seen by examining the two color infrared scenes in Plate 2 and the DSF and DBF clusters in Figure 2. As the growing season progressed through April, the healthy Deciduous Swamp Forest (DSF) leafed out and the canopy coalesced. This caused the Deciduous Swamp Forest (DSF) clusters to migrate in two-dimensional feature space to a region having approximately the same amount of near-infrared reflectance as the Deciduous Bottomland Forest (DBF) and slightly greater red reflectance. Because the Deciduous Bottomland Forest (DBF) was more completely leafed out early in the growing season than the Deciduous Swamp Forest (DSF), it reflected less (actually absorbed more) red radiant flux in April. The close proximity of the DSF and DBF clusters in feature space on the 29 April 1985 imagery caused considerable confusion between these classes. Emergent Marsh (EM) pixels were composed of a mixture of low-lying herbaceous vegetation and water, integrated over the dimension of a pixel (5.6 × 5.6 m). Therefore, it was not surprising to find the EM clusters located close to water clusters on both dates.

An important class of Deciduous Swamp Forest hereafter referred to as Transition Deciduous Swamp Forest (T-DSF) was found in both the 1981 and 1985 imagery. It consisted of Deciduous Swamp Forest that had a sparse canopy, which allowed radiant flux from emergent marsh below to be integrated within the IFOV of a typical pixel. This resulted in pixel brightness values which were rather persistent in their location in two-dimensional feature space on the two dates (refer to Figures 2 and 3) between the healthy Deciduous Swamp Forest (DSF) and Emergent Marsh (EM). The sparse Deciduous Swamp Forest (T-DSF) was documented *in situ* in the Pen Branch tail by Scott *et al.*, (1985) and radiometrically by Jensen *et al.* (1986b). There was no confusion between the Transition Deciduous Swamp Forest (TDSF) clusters and any of the other clusters using either date of imagery.

Unfortunately, there was confusion between some of the Deciduous Swamp Forest (DSF) and Deciduous Bottomland Forest (DBF) clusters as the vegetation in the area leafed out. Eight mixed clusters were encountered using the 29 April 1985 data. Therefore, to accurately discriminate between these very important clusters, an iterative "cluster busting" technique was used to understand and properly label these mixed clusters. It represented a refinement of the image stratification technique described by Rohde (1978).

The procedure for separating the mixed clusters into either Deciduous Bottomland Forest (DBF) or Deciduous Swamp For-

TABLE 3. WETLAND CLASSIFICATION SCHEME FOR THE PEN BRANCH TAIL USING 31 MARCH 1981 AND 29 APRIL 1985 AIRCRAFT MSS IMAGERY

Class	Common Name	Scientific Name
EM-Emergent Marsh	Water Primrose	*Ludwigia* spp.
	Ammannia	*Ammannia coccinea*
	Hypericum	*Hypericum mutilum*
	Cyperus	*Cyperus* spp.
	Bidens	*Bidens frondosa*
DSF-Deciduous Swamp Forest	Bald Cypress	*Taxodium distichum*
	Water Tupelo	*Nyssa aquatica*
DBF-Deciduous Bottomland Forest	Oak (Deciduous and Non-Deciduous)	*Quercus* spp.
	Sweetgum	*Liquidambar styraciflua*
	Red Maple	*Acer rubrum*
	Hickory	*Carya* spp.
OW-Open Water		

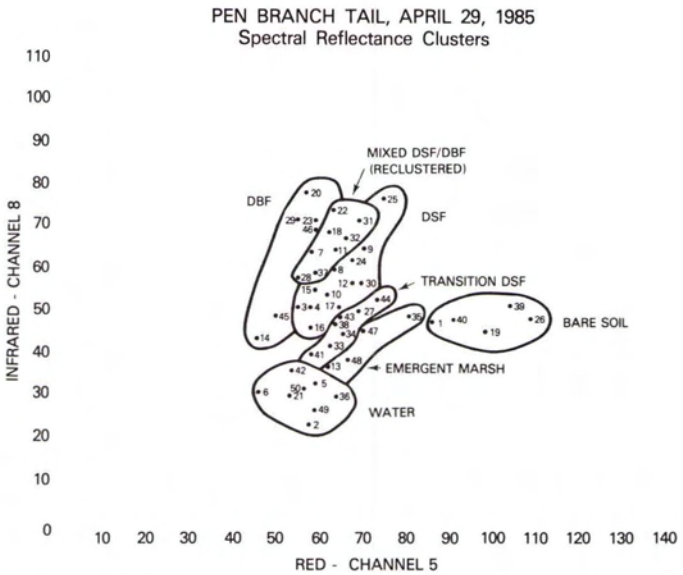

FIG. 3. Fifty clusters extracted from the 29 April 1985 aircraft MSS imagery are shown in two-dimensional feature space (red and near-infrared). The classes are described in Table 3. Eight of the clusters could not be accurately labeled as being Deciduous Swamp Forest (DSF) or Deciduous Bottomland Forest (DBF) on this date. Therefore, an iterative clustering procedure was used to isolate and label the clusters.

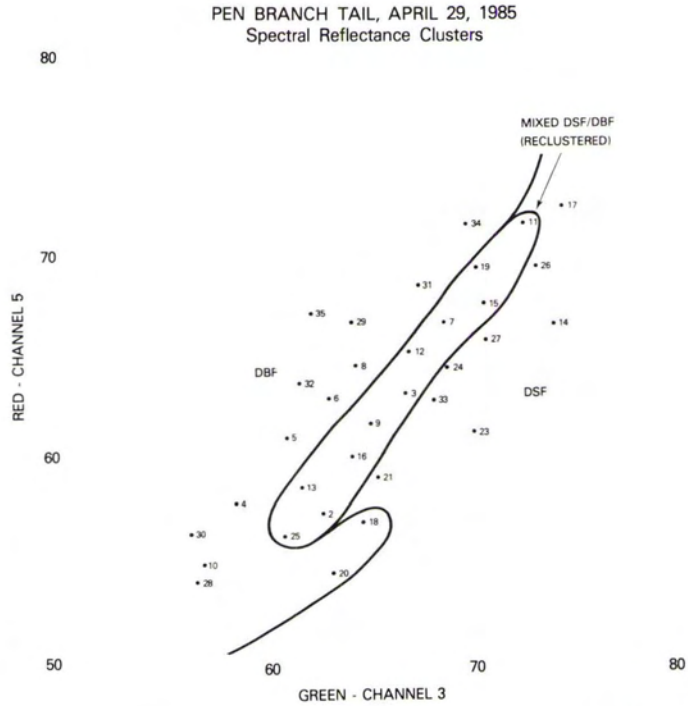

FIG. 4. The result of reclustering on the eight mixed clusters identified in Figure 3. Twenty-four of the 35 new clusters were easily identified as being DSF or DBF. Eleven were still mixed, but the total number of mixed pixels was significantly reduced.

est (DSF) was relatively straightforward. First, as shown in Figure 3, there were eight mixed clusters (#7, 11, 18, 22, 28, 31, 32, and 37). To understand the spectral characteristics of these mixed clusters, all pixels in the cluster classification map assigned to these clusters were re-examined. These (and only these) pixels in the original four-band MSS data set were then clustered again, yielding 35 new clusters (Figure 4). Twenty-four of the 35 new clusters were easily labeled as DBF or DSF; i.e., there was no question as to which class they should belong. Eleven were still mixed, but the total number of mixed DBF or DSF cluster pixels was significantly reduced. The process was repeated on the second generation mixed clusters (#2, 3, 7, 9, 11, 12, 13, 15, 16, 19, and 25), yielding 47 new clusters (Figure 5). This procedure allowed the remaining DBF and DSF clusters to be separated. The two new cluster sets were "recoded" to numbers greater than the original 50 clusters extracted from the 29 April 1985 data. The pixels associated with the more recent clusters were then overlaid onto the original 50-cluster map with the most recently derived clusters taking precedence. The iterative clustering improved the discrimination between the DBF and DSF clusters using the 29 April 1985 imagery.

The classification maps of the 31 March 1981 and 29 April 1985 data sets are shown in Plate 4. The dark green area is Stave Island, which is composed of Deciduous Bottomland Forest (DBF). The upland areas of the 1981 and 1985 classification maps were "masked out" by overlaying a digitized boundary onto both classification maps. The overall accuracy of wetland classification using multispectral aircraft MSS data on this and other deltas in the vicinity was 82 to 86 percent (Jensen *et al.*, 1984, 1986a; Christensen *et al.*, 1986).

The two classification maps were then compared pixel-by-pixel to document the change taking place from 1981 to 1985. The Transition Deciduous Swamp Forest (T-DSF) present in 1981 (red) and 1985 (yellow) is shown in Plate 5a. Areas that did not change are shown in black. The changes from healthy Deciduous Swamp Forest (DSF) to Transition-DSF (yellow), Emergent Marsh (cyan), or to Open Water (dark blue) are shown in Plate 5b. The statistics associated with these changes are summarized in Table 4.

Comparison of the 1981 and 1985 classified images showed expansion of the Pen Branch tail (Plate 5). No lengthening of the tail was observed, but it did increase in width. Increase in the T-DSF vegetation accounted for most of the change. Ap-

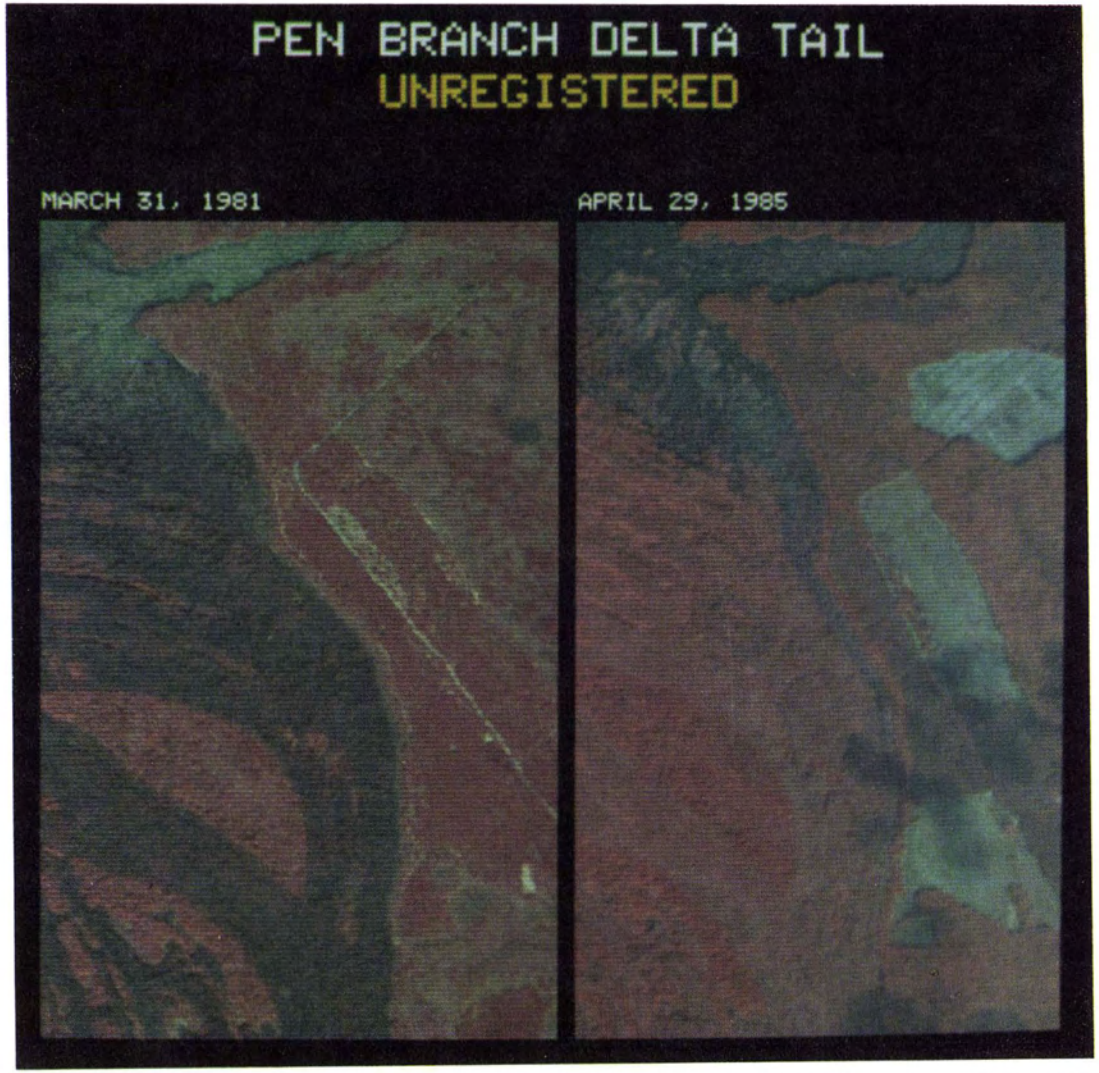

PLATE 2. Unregistered subsets of the 31 March 1981 and 29 April 1985 aircraft MSS imagery. The color-infrared color composites depict a 375 ha area on each date.

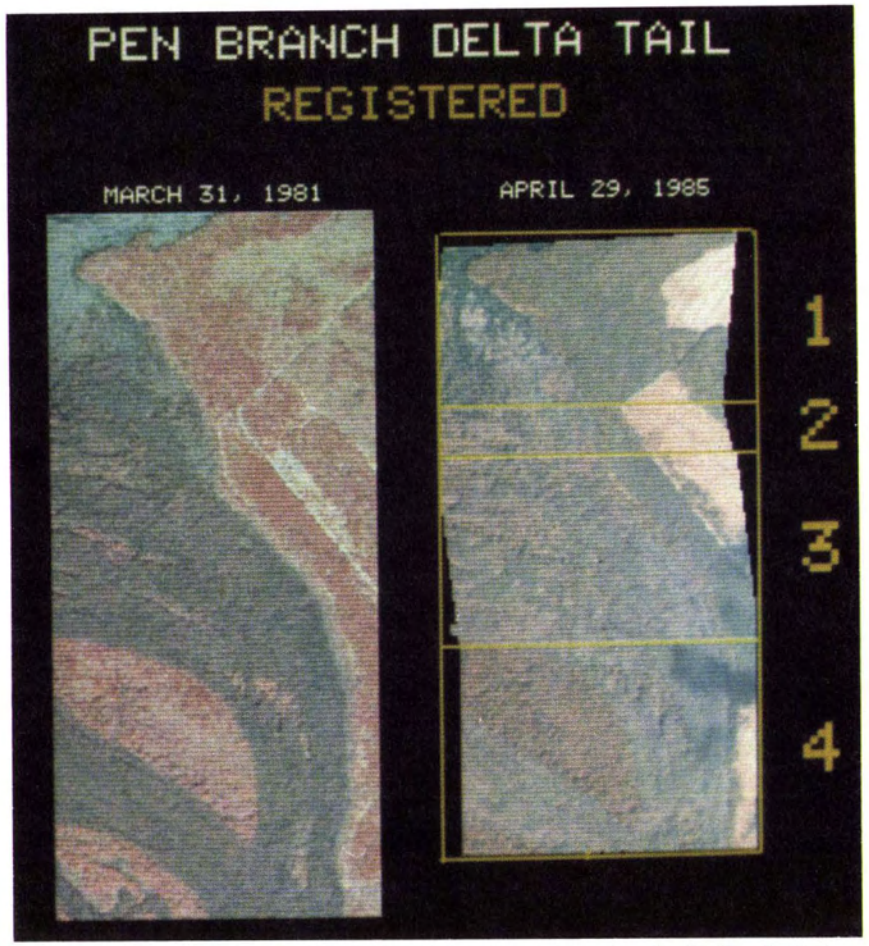

PLATE 3. The 29 April 1985 aircraft MSS data were registered to the 31 March 1981 data using a piecewise-linear image-to-image registration procedure. The 29 April 1985 subscene was divided into four parts based on observable geometric distortions. The four parts were then individually rectified to the 1981 MSS data and mosaicked together.

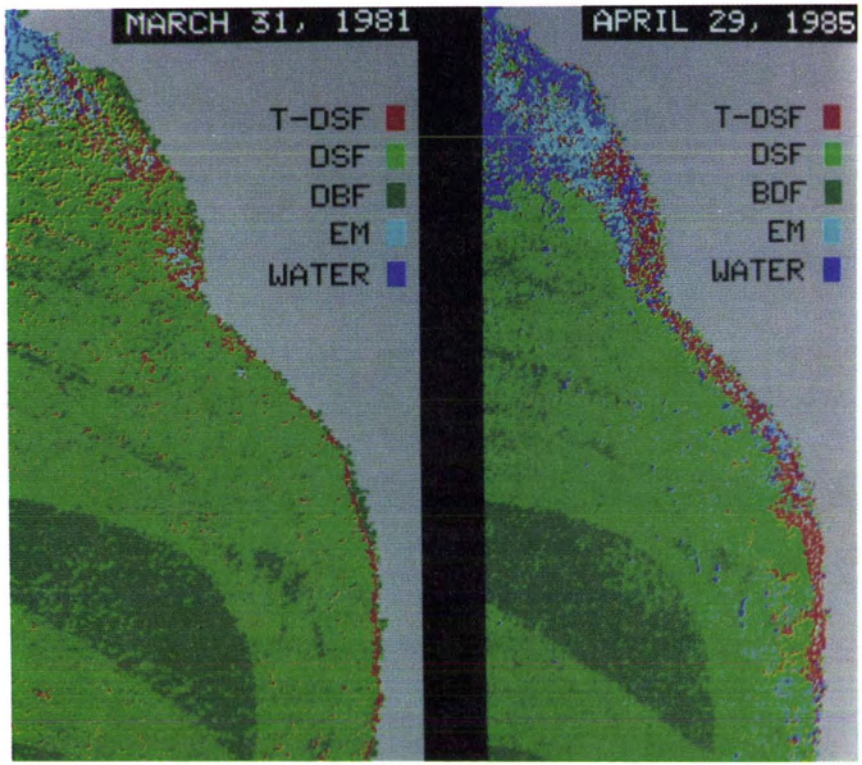

PLATE 4. Classification maps derived from unsupervised classifications of the 31 March 1981 (Plate 4a) and 29 April 1985 aircraft MSS data (Plate 4b). The classes are Transition Deciduous Swamp Forest (T-DSF) composed of sparse cypress-tupelo, Deciduous Swamp Forest (DSF), Deciduous Bottomland Forest (DBF), Emergent Marsh (EM), and Water. The species associated with the wetland classes are summarized in Table 3.

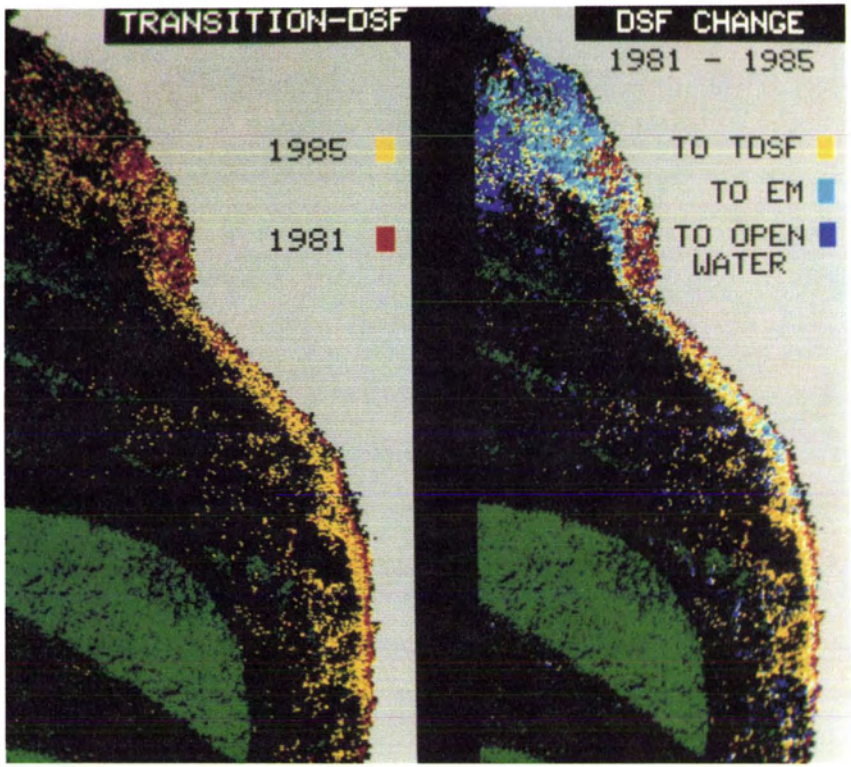

PLATE 5. Change between the 31 March 1981 and 29 April 1985 wetland vegetation maps as determined through a post-classification comparison. The sparse cypress-tupelo class (Transition-DSF) existed in 1981 (red in Plate 5a). However, it had expanded greatly by 1985 (yellow in Plate 5a). The transition from indigenous Deciduous Swamp Forest (DSF) to the sparse Deciduous Swamp Forest (T-DSF) or to other land cover (Emergent Marsh or Open Water) is shown in Plate 5b. All areas not experiencing change from 1981 to 1985 are shown in black. The change statistics are summarized in Table 4.

TABLE 4. PEN BRANCH TAIL WETLAND CHANGE ANALYSIS USING 31 MARCH 1981 AND 29 APRIL 1985 AIRCRAFT MSS IMAGERY

Change Class	Hectares
Deciduous Swamp Forest (DSF) to Emergent Marsh (EM)	3.64
Deciduous Swamp Forest (DSF) to Transition-DSF	12.14
Deciduous Swamp Forest (DSF) to Open Water	9.30
Transition-DSF to Emergent Marsh (EM)	2.42
Transition-DSF to Open Water	1.21
Transition-DSF—No Change	5.66

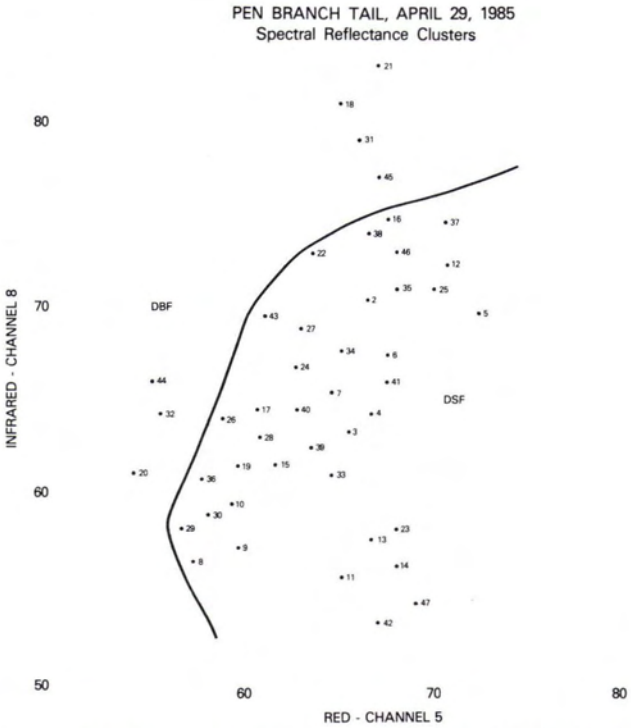

FIG. 5. The result of reclustering on the 11 clusters identified in Figure 4. After this iteration, all clusters were accurately labeled as being Deciduous Swamp Forest (DSF) or Deciduous Bottomland Forest (DBF).

proximately 12.14 ha (30 ac) of Deciduous Swamp Forest changed to T-DSF. In addition, 16.57 ha (41 ac) of swamp forest (both DSF and T-DSF) were lost to other land-cover types; DSF to EM (3.64 ha), DSF to Open Water (9.30 ha), T-DSF to EM (2.42 ha), and T-DSF to Open Water (1.21 ha). Basically, as the canopy opened, 6.06 ha (15 ac) of Emergent Marsh invaded and 10.51 ha (26 ac) of Open Water became visible. Most of the Deciduous Swamp Forest (DSF) mortality occurred near the delta where water temperatures were highest and inundation most persistent, especially under flood conditions. Only 5.66 ha (14 ac) of the Transition Deciduous Swamp Forest (T-DSF) present in 1981 survived until 1985.

CONCLUSIONS

High resolution aircraft MSS data can be used to conduct detailed change detection mapping of wetland vegetation in the southeastern United States. However, considerable attention must be given to image registration, classification, and change detection algorithm implementation. In this study, the aircraft MSS data were registered image-to-image to within approximately 2.26 pixels using a piecewise linear methodology. This was just adequate. The ideal approach is to use image-to-map rectification if sufficient ground control points can be located both in the imagery and the map. Even if sufficient points are available, however, it may still be necessary to use a piecewise linear approach to minimize the geometric effects introduced by random platform movement.

Jensen *et al.* (1984) found that various wetland types could be discriminated in the southeastern United States only by using spring imagery. Nevertheless, even using high resolution 31 March 1981 and 29 April 1985 spring imagery did not insure excellent results because the 30-day difference between these dates in the growing season introduced enough phenological change to make the analysis quite complex. This complexity made it necessary to use iterative clustering techniques to adequately discriminate and label the various wetland clusters of interest on the 29 April 1985 imagery where healthy Deciduous Swamp Forest (DSF) could not be discriminated from Deciduous Bottomland Forest (DBF). In addition, a Transition Deciduous Swamp Forest (T-DSF) class composed of sparse-canopy Deciduous Swamp Forest (DSF) was identified on each date and substantiated by field work. The individual classification maps were then evaluated using post-clasification comparison techniques to produce wetland change detection maps and associated statistics. Such information was useful in monitoring the effects of industrial activities on wetlands.

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