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MEASUREMENT OF SEASONAL AND YEARLY AQUATIC MACROPHYTE CHANGES IN A RESERVIOR USING MULTIDATE AERIAL PHOTOGRAPHY AND SPOT DIGITAL REMOTE SENSOR DATA (U)

by

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Measurement of Seasonal and Yearly Aquatic Macrophyte Changes in a Reservoir Using Multidate SPOT Panchromatic Data

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INTRODUCTION

Wetlands assimilate pollutants, provide flood control, and serve as breeding, nursery, and feeding grounds for fish and wildlife (Odum, 1989). Information on wetland distribution and condition are essential for their effective protection and management (Norton and Slonecker, 1990; Dobson and Bright, 1991). Unfortunately, wetlands present challenges to effective evaluation and quantification. For example, inland wetlands are found in diverse geographic areas ranging from small tributary streams, shrub/scrub and marsh communities, to open water lacustrine environments (Cowardin et al., 1979). In addition, the type and spatial distribution of wetlands can change dramatically between season, especially when non-persistent species are present (Mackey, 1990).

There are four alternatives for collecting aquatic macrophyte wetland information, including: 1) *in situ* field investigation, ideally using global positioning systems (Shirer, 1991), 2) interpreting aerial photography (Wilen, 1990), 3) analyzing high resolution aircraft multispectral scanner (MSS) data (Jensen et al., 1984; 1986), and 4) digital analysis of satellite remote sensor data. Jensen et al. (1991) reviewed these alternatives in detail and provided a case study on the use of a) multidate color and color-infrared aerial photography, and b) a single year of SPOT remote sensor data. This study builds on the initial work by demonstrating the use of multiple season and multiple year SPOT panchromatic satellite digital data for aquatic macrophyte inventory and analysis in Par Pond on the Savannah River Site, South Carolina.

AQUATIC MACROPHYTE CONDITIONS IN PAR POND, SOUTH CAROLINA

The Par Pond Study Area

The Savannah River Site (SRS) is a 777 km^2 federal facility located in South Carolina. Par Pond, which is approximately 1,000 hectares in size, was constructed in 1958 as a recirculating cooling lake. The water level is relatively stable, fluctuating only 0.1 m each year. Natural invasion of wetland has occurred over the reservoir's 33-year history with much of the shoreline now characterized by extensive beds of persistent and non-persistent aquatic macrophytes (Table 1). These beds often exceed 20 to 40 meters in width with several beds being > 100 m wide.

Cattail beds exist (persist) year-round in Par Pond and generally occupy the shallow water (< 1 m in depth) adjacent to the lake shoreline. Their phenological cycle is illustrated diagrammatically in Figure 1. They green-up in early to mid-April and often have a full, green canopy by late May. Cattails senesce in late September or early October, remaining brown through the winter months (Mackey, 1990).

Waterlilies and other non-persistent species do not live through the winter. They appear at the outer-most edge of the cattails by late early May and reach full emergence 6 to 8 weeks later. The waterlily beds persist until about late-October to mid-November (Figure 1). Thus, the best time of year to estimate the areal extent of these beds is later in the growing season in the southeastern United States. These phenological or seasonal patterns dictate the appropriate times for remote sensing data acquisition.

Table 1. Common Persistent and Non-persistent Emergent Aquatic Macrophytes Found Along the Shoreline of Par Pond

Persistent	
Cattails	*Typha latifolia*
Spikerushes	*Eleocharis* spp.
Pickerelweed	*Pontederia cordata*
Maidencane	*Panicum* spp.
Non-Persistent	
Waterlilies	*Nymphaea odorata*
Watershield	*Brasenia schreberi*
Lotus	*Nellumbo lutea*

In situ Data Collection in Par Pond.

The *in situ* data collection was performed in the spring and fall of 1988 - 1991 at 48 transects situated around the perimeter of Par Pond (Figure 2). At each transect, the width of the cattails and waterlilies were measured using a surveyor's tape. In addition, the depth at the transect marker pole and the depth at the furthest extent of the waterlilies was measured .

ANALYSIS OF MULTIDATE SPOT DATA TO INVENTORY AQUATIC MACROPHYTES IN PAR POND

The goal of this analysis was to determine 1) if there was a significant difference between aquatic macrophyte information derived from SPOT multispectral (XS) and panchromatic (PAN) data versus *in situ* data, and 2) the utility of such data for seasonal and multi-year change detection.

SPOT multispectral and panchromatic data were acquired on 17 April 1988, 25 October 1988, 26 April 1989, and 4 October 1989 (Table 2). All SPOT imagery were rectified using 3rd order polynomials to the 1:48,000 scale Savannah River Site Topographic Map. Each multispectral and panchromatic scene was resampled to 5 x 5 m using a nearest neighbor resampling algorithm with an x,y root mean square error (RMSE) of 1.0 pixel for the panchromatic data (± 10 meters) and +0.5 m for XS data (±10 m). The extraction of the aquatic macrophyte information from the rectified SPOT data required several innovative image processing functions.

Table 2. SPOT Data Used to Estimate the Growth of Cattails and Waterlilies in Par Pond

Year	Date	Sensor	Band	Spatial Resolution
1988	17 April	HRV2	Pan	10 x 10 m
1988		HRV1	XS	20 x 20 m
1988	25 Oct	HRV1	Pan	10 x 10 m
1988		HRV2	XS	20 x 20 m
1989	26 April	HRV2	Pan	10 x 10 m
1989		HRV1	XS	20 x 20 m
1989	4 Oct	HRV1	Pan	10 x 10 m
1989		HRV2	XS	20 x 20 m

The Creation of a Land/Water Mask

When trying to extract wetland information from a SPOT scene it is useful to exclude all upland vegetation from further investigation. A mask was produced in the following manner (Figure 3). First, a 3-band (24-bit) color composite image of the study area was converted into an 8-bit pseudo-color composite using a 24 to 8-bit data compression algorithm. This single image was then viewed at 3x magnification on the CRT screen and used to perform 'heads-up', manual digitizing of the shoreline of the lake. All upland regions were then recoded to a value of "0" and all lake regions (including the wetland) to a value of "1". This binary mask was then applied to the original 24-bit SPOT XS dataset yielding a file with all the upland masked out to a value of "0". This same mask was also applied to the PAN data. Thus, all dates and bands of SPOT data included exactly the same geographic area which is important when comparing the hectares of wetland in different seasons and years. With the data rectified and masked, the next step was the wetland classification.

Wetland Classification Using Panchromatic Data

Seasonal aquatic macrophyte change detection can be performed by producing a classification map from each date of multispectral data and applying an appropriate change detection algorithm (Jensen, 1986). The accuracy of this method is dependent upon geometric registration of each date of imagery and very accurate wetland classification of each image. To get away from performing standard statistical pattern recognition on the poorer spatial resolution XS data (20 x 20 m), a more elegant solution was found using just the PAN data. The method was based on the fact that cattails are present throughout the year while waterlilies are present only from May to October . The procedure involved the merging of the PAN data (17 April 1988, 25 October 1988, 26 April 1989 and 4 October 1989) into a single, four-band dataset which could then be analyzed in a number of ways.

One very powerful analog (visual) presentation of the data was produced when the 17 April 1988 image was displayed in the green image plane and the 25 October 1988 image displayed in the red image plane. The stable cattails present on both dates were revealed in shades of yellow, while the emergent waterlilies present after April 1988 and still present in October 1988 were seen in shades of red. Image differencing of the April and October images in each year [(i.e. $BV_{ijkout} = BV_{ijkOct} - BV_{ijkApr}$) rescaled to 8-bits (values from 0 to 255)] yielded maps showing the exact location of the waterlilies in 1988 and 1989. By identifying all pixels which were aquatic macrophytes at any time during the year (i.e. present on both April and October images), and then subtracting the waterlilies information from this file, it was possible to produce a map showing both the cattail and the waterlily distribution for 1988 and 1989 (Figures 4 and Figure 5). These techniques work well for years when the growing season is normal (i.e. spring does not arrive early causing some waterlilies to appear) and thermal effluent is not introduced into the reservoir. When such conditions exist, the analyst must a) obtain the spring image earlier in the growing season, or b) analyze the spring image using careful density slicing techniques to reduce the total amount of aquatic macrophytes present in the spring image. This preprocessed image can then be differenced with the fall image to obtain good results.

In Situ Versus Remote Sensing Derived Measurements

The location of each of the 48 *in situ* transects was identified in the rectified classification maps and the number of pixels of cattails and waterlilies found along each transect were quantified. Using this information it was possible to determine the correlation between *in situ* and SPOT aquatic macrophyte data. Figure 6a is a scattergram of the width of cattail beds found along the 48 *in situ* transects in 1988 versus the information extracted from the SPOT PAN April-October, 1988 dataset. The fit was a good fit with an r of .856, accounting for 73% of the variance ($r^2 = .732$). The correlation is was even better for the waterlilies (Figure 6b) which yielded an r of .925, accounting for 85% of the variance ($r^2 = .855$). Figure 6c depicts a scattergram of the cattail widths found along the 48 *in situ* transects measured in 1989 versus the information extracted from the SPOT PAN April-October, 1989 dataset. The also had a good fit, with an r of .895, accounting for 80% of the variance ($r^2 = .802$). Again, the correlation was better for the waterlilies (Figure 6d) which yielded an r of .953, accounting for 91% of the variance ($r^2 = .908$).

The upland mask previously discussed may not be completely accurate at the land/water interface and may be responsible for some of the error in the remote sensing cattail measurement . Also, beds smaller than 20 m are generally underestimated because of the spatial resolution of the SPOT PAN sensor system. Jensen et al. (1991) obtained slightly better results for the same study area analyzing high spatial resolution color-infrared aerial photography. The advantage of aerial photography, however, is offset by the cost incurred. In South Carolina, inland wetland information derived from analysis of SPOT data are encouraging and appear to be a realistic alternative, especially if many lakes are to be studied.

Because the 1988 and 1989 SPOT data were registered to a common map projection, it was possible to perform multi-year 1988 versus 1989 aquatic macrophyte change detection (Figure 7). The image differencing revealed that there was 192 ha of cattails present during the 1988 growing season and 179 ha in 1989. Interestingly, there were 150 ha of waterlilies in 1988 and only 126 ha in 1989. Thus, while cattail distribution remained relatively constant, waterlily distribution declined and must be carefully monitored. Initial evaluation of 1990 and 1991 field data suggests that the waterlilies hectares continued to decline.

Conclusions

Aquatic macrophytes (cattails and waterlilies) in a South Carolina freshwater reservoir were inventoried using multidate SPOT panchromatic data and found to be highly correlated with *in situ* measurements. Digital change detection was used to monitor seasonal and yearly changes in the aquatic macrophyte type and distribution. SPOT Image Corporation is considering the use of a 5 x 5 m spatial resolution data on future high resolution visible (HRV) sensors. Such data will allow smaller beds to be more accurately inventoried.

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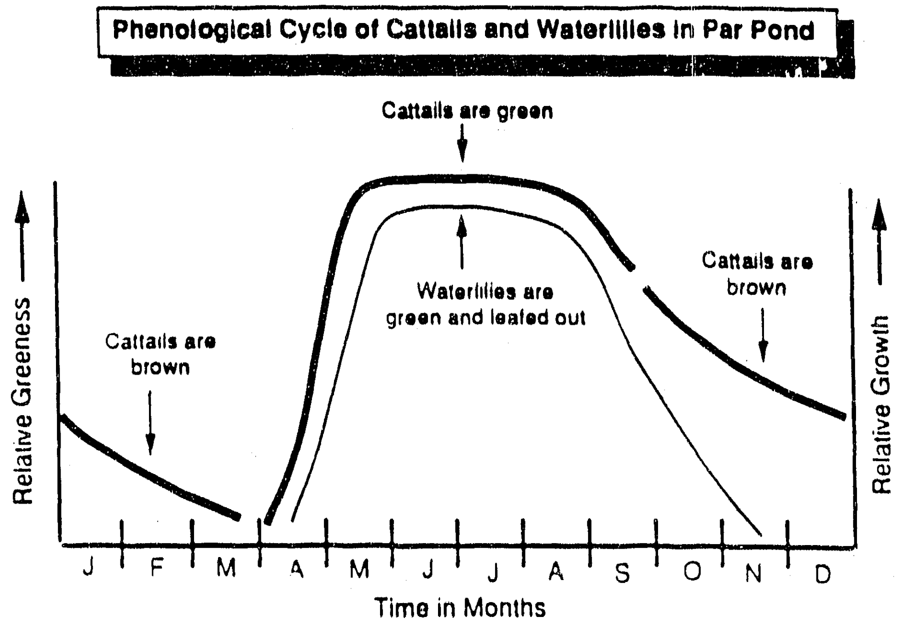

Figure 1. The phenological cycle of cattails and waterlilies in Par Pond, South Carolina.

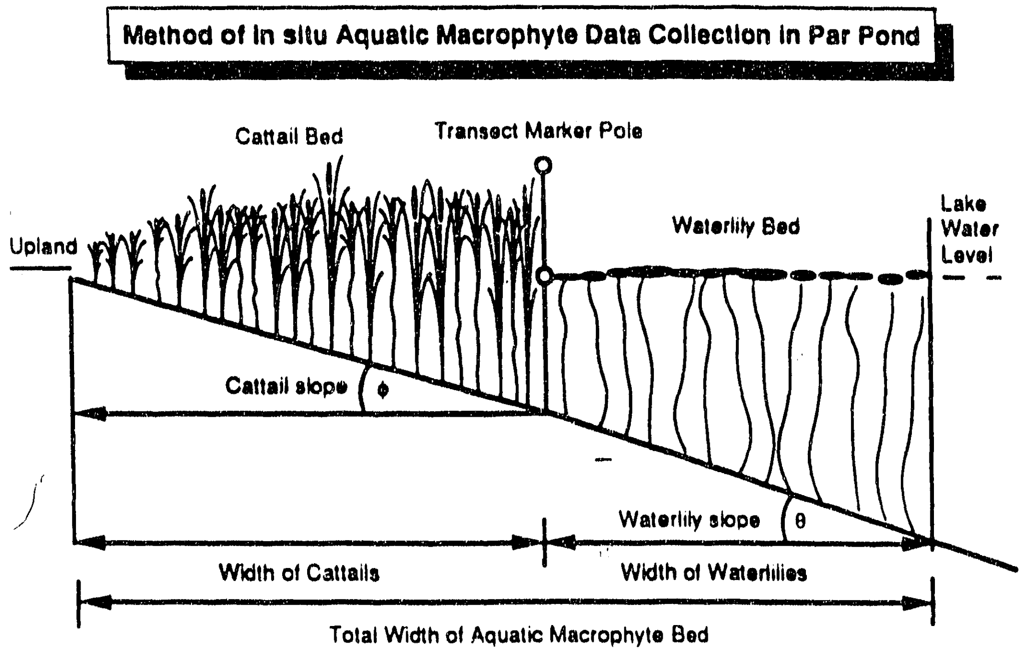

Figure 2. The method of *in situ* aquatic macrophyte data collection in Par Pond, South Carolina.

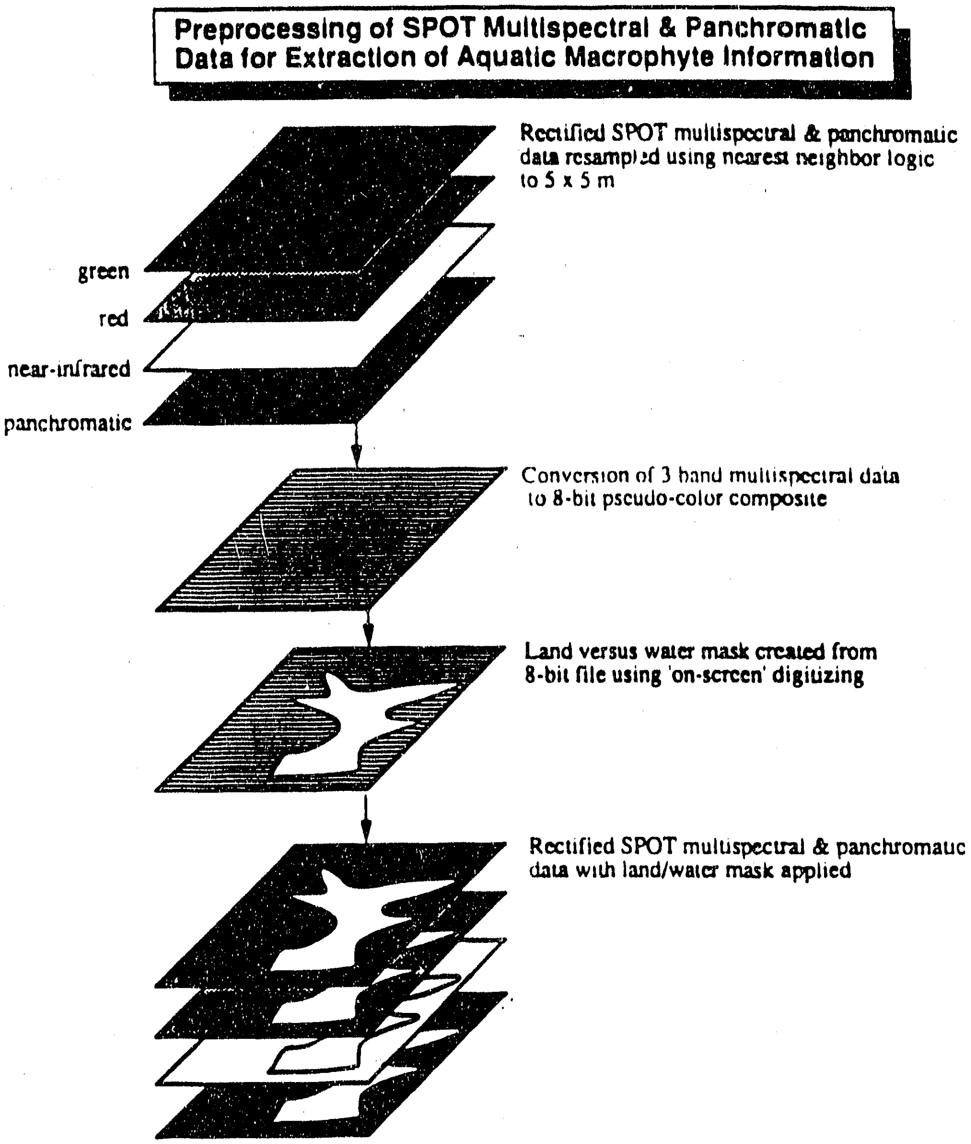

Figure 3. The methodology for creating a land/water mask by preprocessing SPOT multispectral and panchromatic data for the extraction of aquatic macrophyte information in Par Pond, South Carolina.

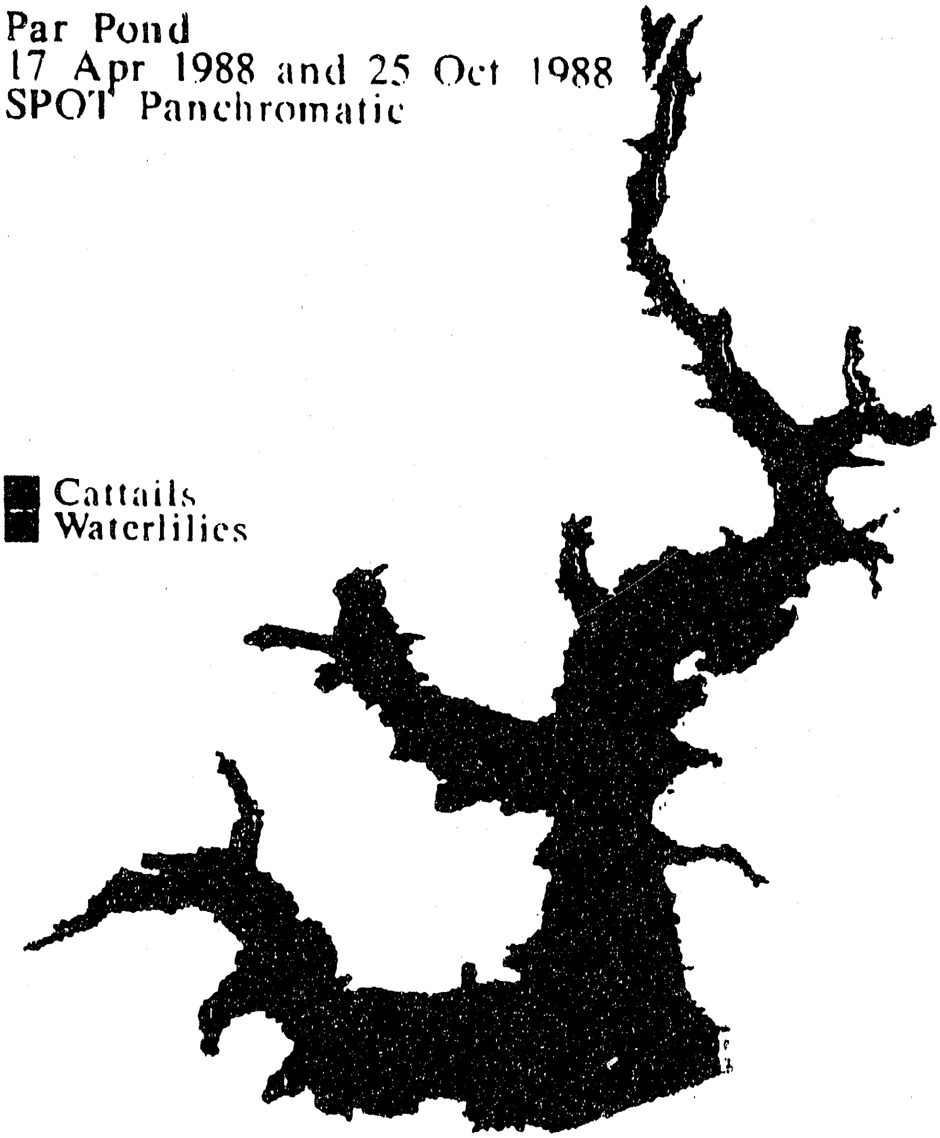

Figure 4. The spatial distribution of cattails and waterlilies in Par Pond in 1988 produced using panchromatic SPOT data obtained on 17 April 1988 and 25 October 1988).

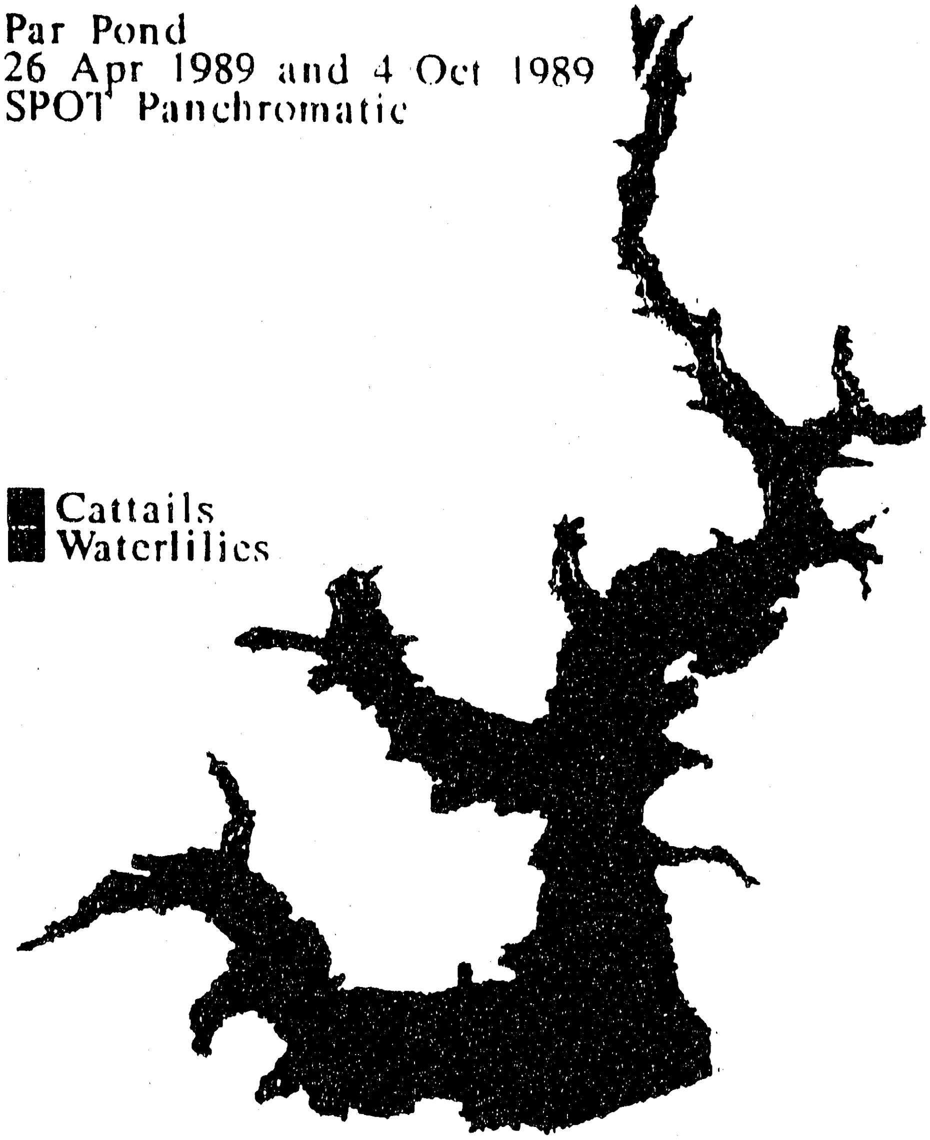

Figure 5 The spatial distribution of cattails and waterlilies in Par Pond in 1989 produced using panchromatic SPOT data obtained on 26 April 1989 and 4 October 1989).

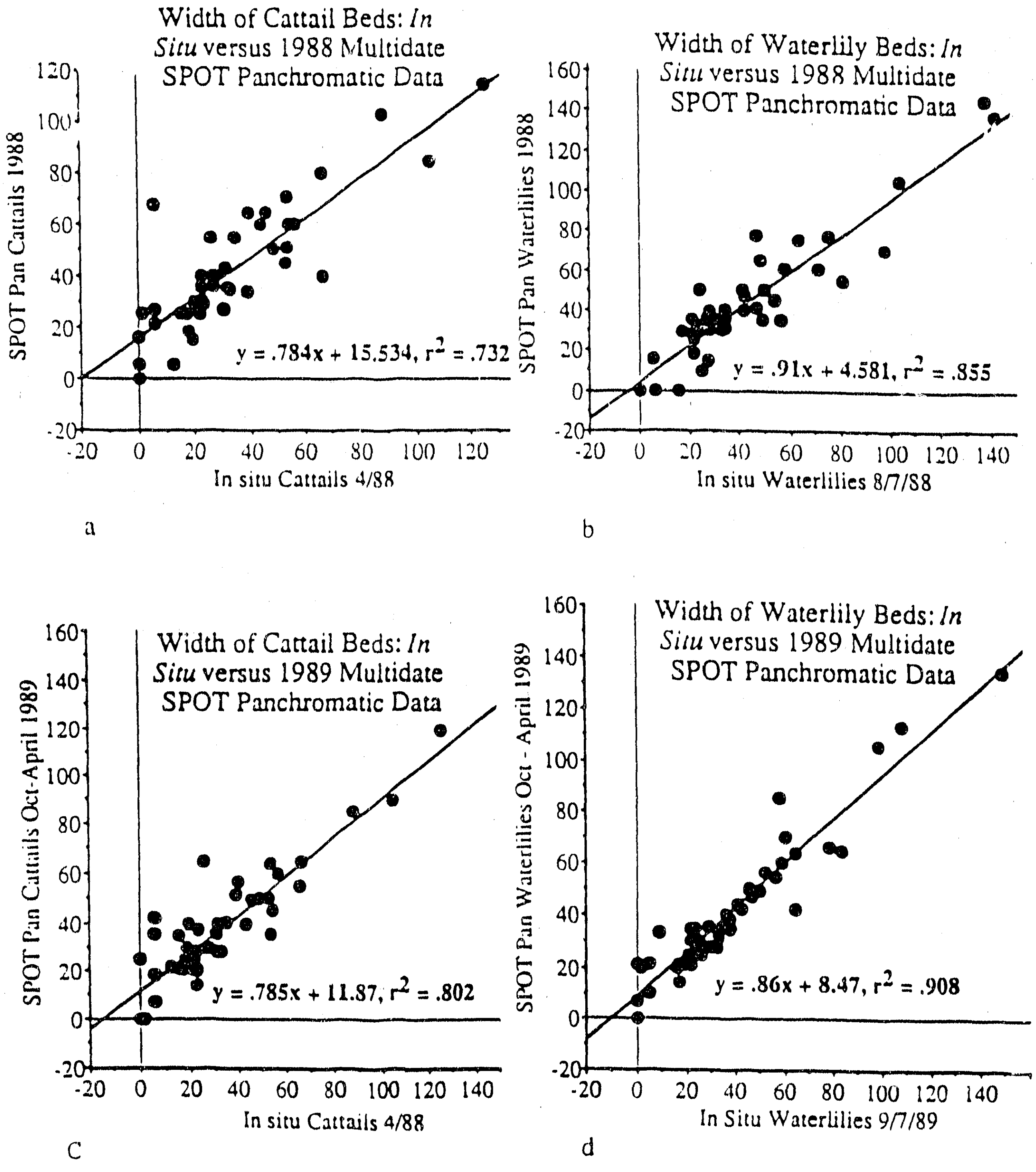

Figure 6a. A scattergram showing the relationship between cattail beds measured *in situ* versus the same beds measured using SPOT multidate panchromatic imagery in 1988. (6b) Scattergram of waterlily beds measured *in situ* versus the beds measured using SPOT multidate panchromatic imagery in 1988. (6c) Scattergram of cattail beds measured *in situ* versus the beds measured using SPOT multidate panchromatic imagery in 1989. (6d) Scattergram of waterlily beds measured *in situ* versus the beds measured using SPOT multidate panchromatic imagery in 1989.

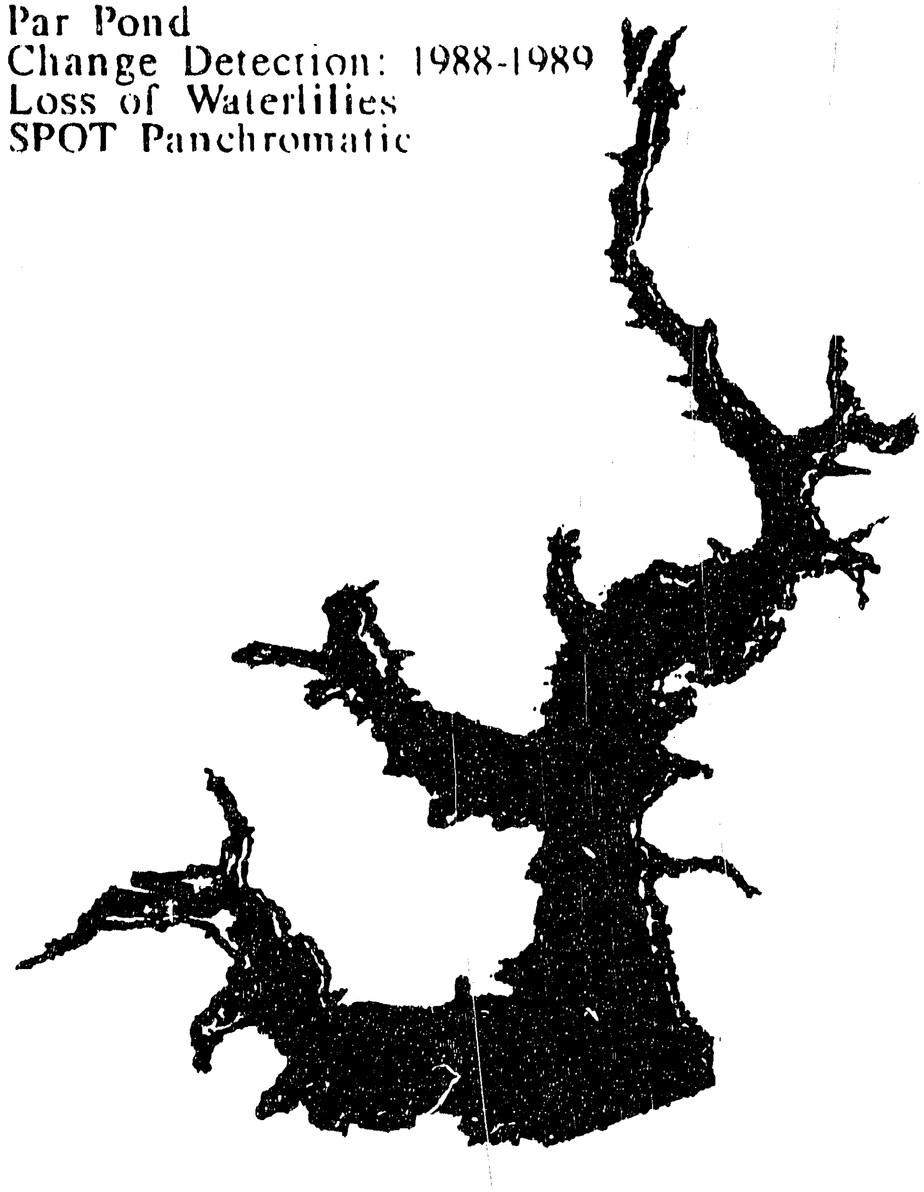

Figure 7. Waterlilies lost between 1988 and 1989 in Par Pond, South Carolina using multiple year SPOT panchromatic data.

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