Measurement of Seasonal and Yearly Cattail and Waterlily Changes Using Multidate SPOT Panchromatic Data

Abstract
Freshwater lakes and reservoirs in the southeastern United States often produce large beds of persistent and non-persistent aquatic macrophytes. Multiple date SPOT panchromatic data (10- by 10-m spatial resolution) obtained in April and October of 1988 through 1990 were analyzed using digital image processing techniques to inventory the spatial distribution of cattail and waterlily beds in a freshwater reservoir located on the Savannah River Site in South Carolina. The remote sensing derived wetland information was highly correlated with in situ *cattail and waterlily measurements (correlation coefficients ranging from 0.86 to 0.95) made at 48 transects during the 1988 and 1989 growing seasons. In addition, the creation of a multiple date color composite using October 1988, 1989, and 1990 SPOT panchromatic data proved to be a very effective method to visually identify the change in aquatic macrophyte distribution through time. These remote sensing techniques should be applicable to other southeastern lakes and reservoirs, which have large beds of cattails and waterlilies with similar phenological cycles and lake hydrology.*

Introduction
Wetlands are recognized as a valuable natural resource (Podolsky and Conkling, 1991). They 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 is essential for their effective protection and management (Norton and Slonecker, 1990; Dobson and Bright, 1991). Unfortunately, wetlands present challenges to effective monitoring 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 seasons, especially when non-persistent species are present (Mackey, 1990). For these reasons, remote sensing is often used to obtain important information on the spatial distribution and biophysical condition of wetlands (Jensen *et al.*, 1991a; Roughgarden *et al.*, 1991).

There are four alternatives when collecting wetland information using remote sensing technology, including the use of (1) global positioning systems (GPS), (2) aerial photography, (3) aircraft multispectral scanner data, and (4) satellite derived remote sensor data. Each of these alternatives has advantages and disadvantages.

- *In situ field investigation using global positioning systems* (GPS). This method can provide detailed wetland information if the GPS data are differentially corrected and government "selective availability" is off (Shirer, 1991). Unfortunately, even when using GPS units, it is still difficult to traverse the exact perimeter of all the wetlands by foot, boat, or helicopter to prepare a regional, planimetrically accurate inventory.
- *Interpretation of color and color infrared aerial photography.* Numerous organizations and individuals have demonstrated that aerial photography can be used to accurately map inland wetlands (Edwards and Brown, 1960; Welch *et al.*, 1988; Wilen, 1990; Dahl and Johnson, 1991). Aerial photography can be acquired on demand when cloud cover conditions are ideal. However, wetlands may not be accurately inventoried using aerial photography when (a) certain film and film filter combinations are used (Dahl and Johnson, 1991), (b) relief displacement is present in the scene which can cause inaccurate area estimates, and (c) significant vignetting is present which can cause photointerpretation inconsistencies. Metric aerial photography may also be expensive to acquire when large regions must be inventoried (Nohara, 1991). Furthermore, the interpreted data must be transferred to a planimetric basemap and subsequently digitized into a geographic information system (GIS) to be of quantitative value (Jensen *et al.*,1991b).
- *Analysis of high resolution aircraft multispectral scanner* (MSS)*data.* Such data can provide accurate inland wetland information over small geographic areas on demand. However, the data are expensive to acquire, must undergo substantial radiometric and geometric preprocessing, and the areal coverage is limited (Jensen *et al.*, 1984; 1986)
- *Digital analysis of satellite remote sensor data.* Satellite imagery such as that acquired by the Landsat Thematic Mapper (30- by 30-m spatial resolution), SPOT multispectral (20- by 20-m) and panchromatic (10- by 10-m) sensor systems can be analyzed to yield inland wetland information (Gao and Coleman, 1990; Jensen *et al.*,1990; 1991a; Podolsky and Conkling, 1991). While the spatial resolution of such data is not as good as the aforementioned data types, the radiometric and geometric attributes of the datasets are conducive to regional wetland inventories if a more coarse minimum mapping unit is acceptable. Satellite sensor systems which provide pointable, off-nadir viewing (e.g., SPOT) increase the probability of obtaining cloud-free imagery.

Jensen *et al.* (1990; 1991b; 1992) reviewed these inland wetland remote sensing alternatives and provided detailed

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case studies on the use of (a) multi-date color and color-infrared aerial photography, and (b) a single year of SPOT remote sensor data. This research builds on these initial studies 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. It is believed that the methods described are applicable to many freshwater lakes and reservoirs in the southeastern United States which have similar aquatic macrophyte vegetation.

Aquatic Macrophyte Conditions in Par Pond, South Carolina

The Par Pond Study Area

The Savannah River Site (SRS) is a 777 km² Department of Energy (DOE) facility located in South Carolina (Figure 1). Par Pond was constructed in 1958 as a recirculating cooling reservoir and occupies approximately 1,000 hectares. The water level was maintained at a constant elevation, fluctuating about ± 0.1 m each year from 1958 to July, 1991. Natural invasion of freshwater wetland species has occurred over the 33-year history with much of the shoreline characterized by extensive beds of persistent and non-persistent aquatic macrophytes (Table 1). These beds often exceeded 20 to 40 metres in width, with several beds being greater than 100 metres wide. *In situ* studies have shown that two species of aquatic macrophytes dominate the shoreline of the lake, cattails (*Typha latifolia*) and waterlilies (*Nymphaea odorata*).

Cattail beds persist year-round in Par Pond and are generally found in shallow water (≤ 1.0 m in depth) adjacent to the shore. The phenological cycle of cattails is illustrated diagrammatically in Figure 2. They begin "greening-up" in early April and often have a full, green canopy by late May (Workman and McLeod, 1990). Cattails senesce in late September to early October, yet they are physically present and appear brown through the winter months (Gao and Coleman, 1990; Mackey, 1990). Conversely, waterlilies and other non-persistent species do not live through the winter. They appear at the outer-most edge of the cattails in early May and reach full emergence six to eight weeks later. The waterlily beds usually persist above water until early November (Figure 2), at which time they disappear.

The phenological cycles of cattails and waterlilies dictate the most appropriate times for remote sensing data acquisition. The spatial distribution of cattails is best derived from remotely sensed data acquired in the early spring (April or early May), when the waterlilies have not yet developed. Conversely, waterlilies do not reach their full development until the summer, thus dictating late summer or early fall as a better period for remote sensing data acquisition and measurement.

Table 1. Common Persistent and Non-persistent Emergent Aquatic Macrophytes Found in Par Pond (Workman and McLeod, 1990)

Persistent	
Cattails	*Typha latifolia*
Spikerushes	*Elocharis* spp.
Pickerelweed	*Pontederia cordata*
Maidencane	*Panicum* spp.
Non-Persistent	
Waterlilies	*Nymphaea odorata*
Watershield	*Brasenia schreberi*
Lotus	*Nelumbo 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. The outer-most edge of the cattails was identified with a marker pole (Figure 3). The widths of the cattail and waterlily beds were measured using a surveyor's tape. The elevation of the shore point, the depth at the marker pole, and the depth at the furthest extent of the waterlilies in 1988 was also measured. These measurements

Figure 1. The location of Par Pond on the Savannah River Site in South Carolina.

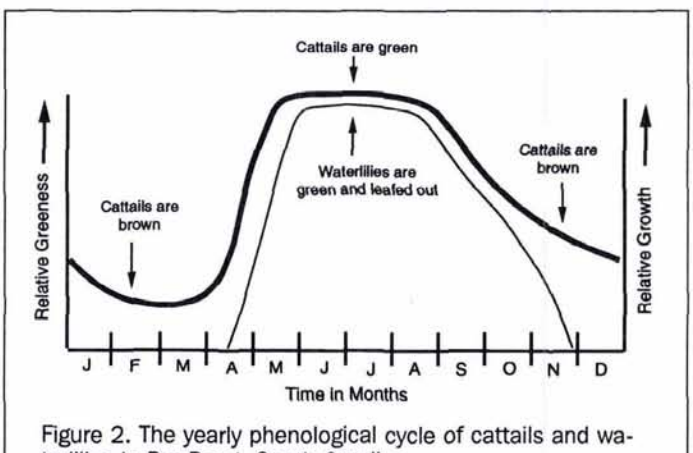


Figure 2. The yearly phenological cycle of cattails and waterlilies in Par Pond, South Carolina.

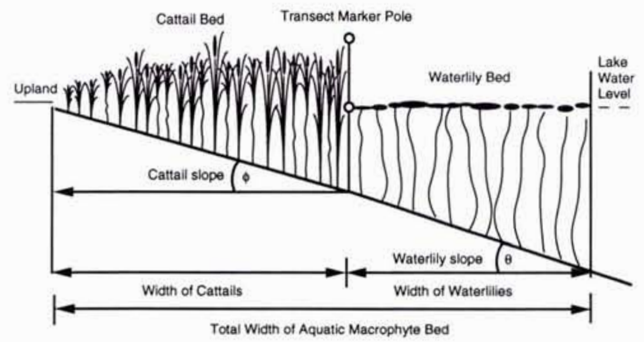


Figure 3. The method of *in situ* aquatic macrophyte data collection in Par Pond, South Carolina.

made at the 48 transects were used to assess the accuracy of the remote sensing derived inland wetland classifications as per criteria specified in Lunetta *et al.* (1991).

Analysis of Multidate SPOT Data to Inventory Aquatic Macrophytes in Par Pond

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

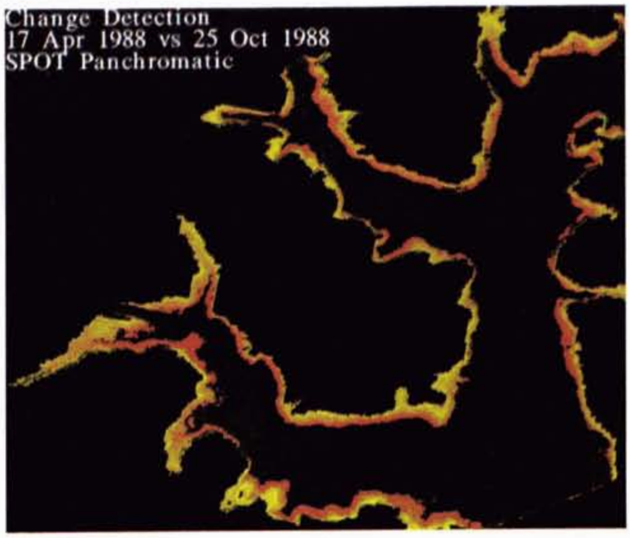
SPOT multispectral and panchromatic data were acquired on 17 April 1988, 25 October 1988, 26 April 1989, 04 October 1989, 04 April 1990, and 16 October 1990 (Table 2). All SPOT imagery was rectified using third-order polynomials to the 1:48,000-scale Savannah River Site Topographic Map (1989). Each multispectral and panchromatic scene was resampled to 5 by 5 m using a nearest neighbor resampling algorithm with an *x, y* root-mean-square error (RMSE) of ± 1.0 pixel. The extraction of the aquatic macrophyte information from the rectified SPOT data required several innovative image processing functions.

The Creation of a Land/Water Mask

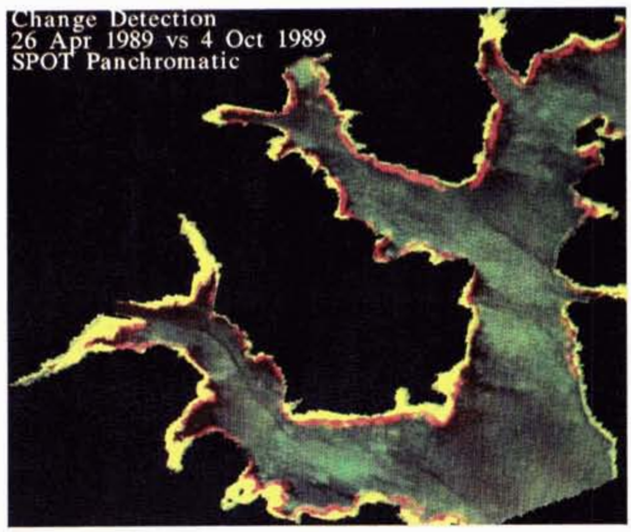
When extracting wetland information from a SPOT scene, it is useful to exclude all upland vegetation from further investigation by creating a land/water mask (Figure 4). The land/water interface is identified best using a color-infrared, color composite rather than the panchromatic data. Therefore, a SPOT three-band (24-bit) rectified 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 (Jensen, 1986). This image was then viewed at 3× magnification on the CRT screen and used to manually digitize the shoreline of the lake. All upland regions were recoded to a value of "0" and all lake regions (including the wetland) to a value of "1." This binary mask was applied to the original, rectified 24-bit SPOT multispectral (XS) dataset, yielding a file

TABLE 2. SPOT DATA USED TO MEASURE THE GROWTH OF CATTAILS AND WATERLILIES IN PAR POND

Year	Date	Sensor	Band	Spatial Resolution
1988	17 April	HRV 2	Pan	10 × 10 m
1988		HRV 1	XS	20 × 20 m
1988	25 Oct	HRV 1	Pan	10 × 10 m
1988		HRV 2	XS	20 × 20 m
1989	26 April	HRV 2	Pan	10 × 10 m
1989		HRV 1	XS	20 × 20 m
1989	4 Oct	HRV 1	Pan	10 × 10 m
1989		HRV 2	XS	20 × 20 m
1990	4 April	HRV 1	Pan	10 × 10 m
1990	16 Oct	HRV 1	Pan	10 × 10 m



(a)



(b)

Plate 1. (a) A color composite of the spatial distribution of cattail and waterlily beds in Par Pond in 1988. The image was produced by placing the panchromatic SPOT data obtained on 17 April 1988 and 25 October 1988 in the green and red image planes, respectively. (b) A color composite depicting the spatial distribution of cattail and waterlilly beds in Par Pond in 1989. The image was produced by placing the panchromatic SPOT data obtained on 26 April 1989 and 4 October 1989 in the green and red image planes, resepectively.

with all the upland masked out to a value of "0." This same mask was also applied to the panchromatic 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; Jensen *et al.*, 1991b). The accuracy of this method, however, is dependent upon (a) the quality of the geometric registration of each date of imagery, and (b) accurate wetland classification of each image. It is known that the poorer spatial resolution SPOT multispectral data (20 by 20 m) would not detect most beds less than 40 m wide (Podolsky and Conkling, 1991). Therefore, a more rigorous solution was found using just the SPOT panchromatic data. The method was based on the fact that cattails are present throughout the year while waterlilies are present only from late May to November. The procedure involved the merging of the panchromatic data into a six-channel, multitemporal remote sensing dataset (17 April 1988, 25 October 1988, 26 April 1989, 4 October 1989, 4 April 1990, and 16 October 1990) which was analyzed in a number of ways.

First, a powerful visual (analog) presentation of the seasonal nature of the aquatic macrophytes in Par Pond was produced when the April image of a single year was placed in the green image plane and the October image was placed in the red image plane. Examples of this method using 1988 and 1989 data are presented in Plates 1a and 1b. The stable cattails present on both dates are revealed in shades of yellow, while the emergent waterlilies present after April and still present in October are shown in shades of red.

Second, image subtraction (differencing) was used to quantitatively inventory the amount and spatial distribution of cattails and waterlilies in 1988 and 1989. The total amount of aquatic macrophytes present in the lake throughout the year was determined by thresholding the October image so that only the aquatic macrophytes were visible (remember that in October *both* cattail and waterlily are present). Image differencing of the April and October images in each year (i.e., $BV^{ijkout} = BV^{ijkOct} - BV^{ijkApr}$) rescaled to eight bits (values from 0 to 255) yielded maps showing the location of the waterlilies. The waterlily information was then subtracted from the October image to map the spatial distribution of the cattails. An example of the 1988 distribution of cattails and waterlilies is shown in Figure 5. These techniques are effective when the growing season is normal (i.e., when spring does not arrive early, causing some waterlilies to appear) and thermal effluent is not introduced into the reservoir. If spring arrives early, the analyst should obtain the spring image as early in the growing season as possible.

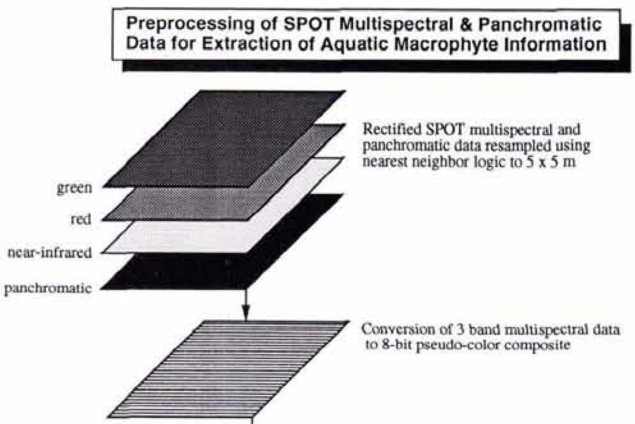


Figure 4. The methodology used to create a land/water mask for the extraction of aquatic macrophyte information from SPOT panchromatic data.

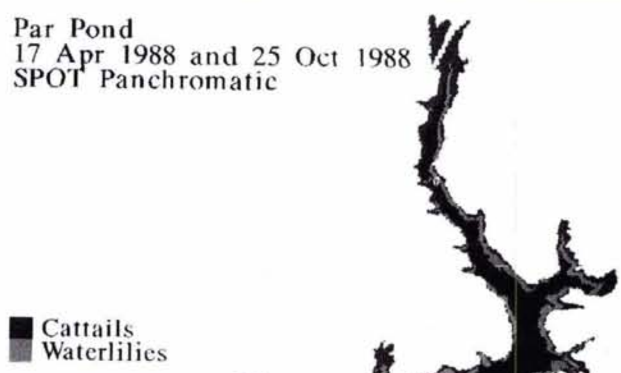


Figure 5. The spatial distribution of cattail and waterlily beds in Par Pond in 1988 produced using the multiple data 1988 SPOT panchromatic data shown in Plate 1a.

In Situ Versus Remote Sensing Derived Measurements for the 1988 and 1989 Growing Seasons

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. A product moment correlation coefficient (**r**) of 0.856 accounted for 73 percent of the variance ($\mathbf{r}^2$ = 0.732) and was significant at the 0.001 level of confidence. The correlation was even better for the waterlilies (Figure 6b) which yielded an **r** of 0.925, accounting for 85 percent of the variance ($\mathbf{r}^2$ = 0.855). 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. These data also had a good fit, with an **r** of 0.895, accounting for 80 percent of the variance ($\mathbf{r}^2$ = 0.802). Again, the correlation was better for the waterlilies (Figure 6d) which yielded an **r** of 0.953, accounting for 91% of the variance ($\mathbf{r}^2$ = 0.908).

Jensen *et al.* (1991b; 1992) obtained slightly better results for the same study area analyzing high spatial resolution color-infrared aerial photography. 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 using SPOT data. Also, beds smaller than 20 m were expected to be underestimated because of the spatial resolution of the SPOT panchromatic sensor system.

Monitoring Multiple Year Changes in Aquatic Macrophyte Distribution Using SPOT Panchromatic Data

Because the 1988 and 1989 SPOT data were registered to a common map projection, it was possible to perform multi-year aquatic macrophyte change detection. A complete

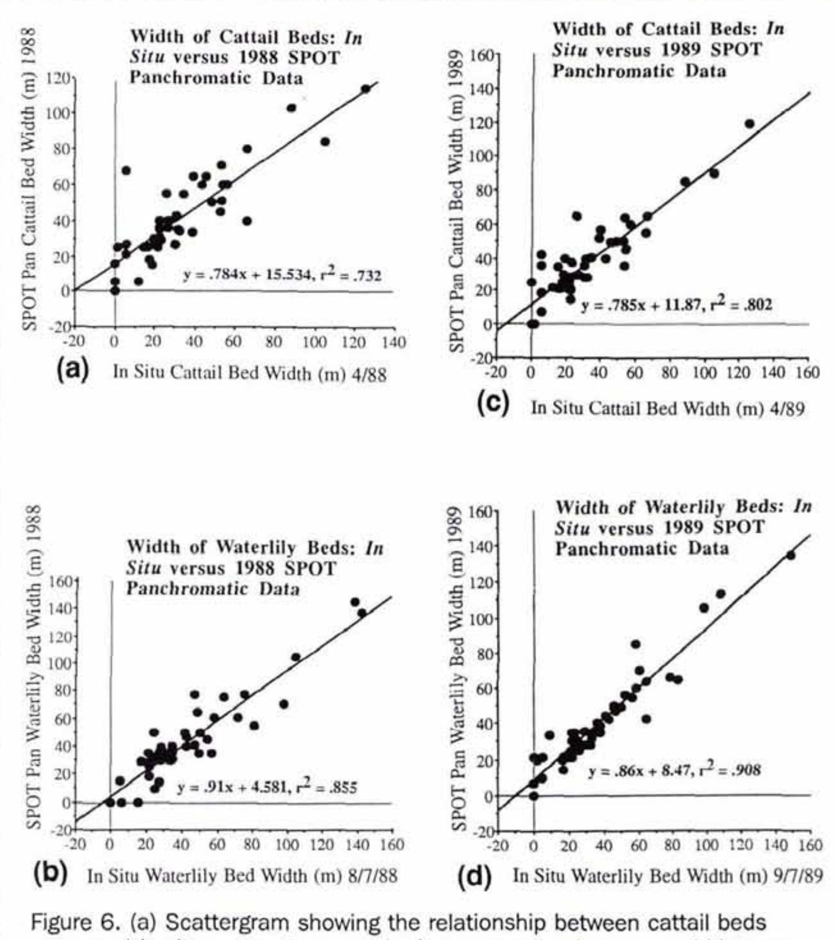


Figure 6. (a) Scattergram showing the relationship between cattail beds measured *in situ* versus the same beds measured using SPOT multidate panchromatic imagery in 1988. (b) Scattergram of waterlily beds measured *in situ* versus beds measured using SPOT multidate panchromatic imagery in 1988. (c)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

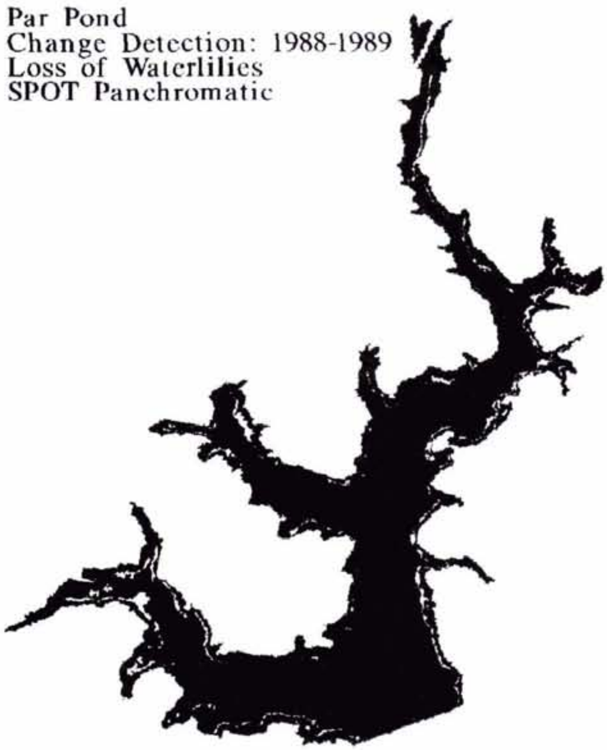


Figure 7. The spatial distribution of waterlily beds which were lost from 1988 to 1989 monitored using SPOT panchromatic data.

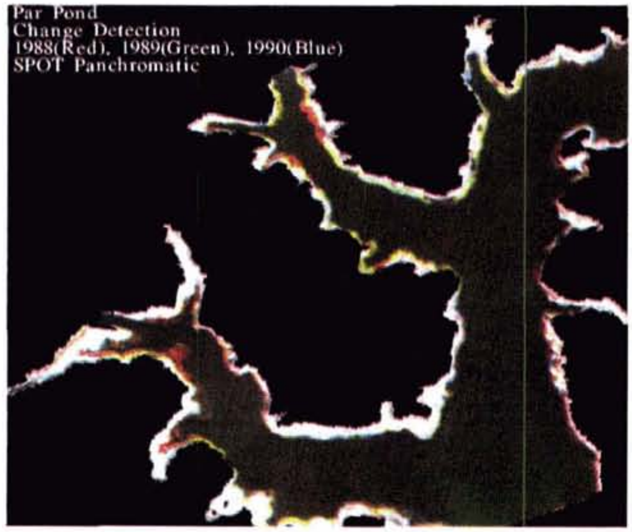


Plate 2. A multiyear color composite of SPOT panchromatic data. The October 1988, 1989, and 1990 images were placed in the red, green, and blue image planes, respectively. Aquatic macrophytes which were present in 1988 but lost in 1989 are shown in shades of red. Macrophytes which were present in both 1988 and 1989 but lost in 1990 appear in shades of yellow. Aquatic macrophytes present in all three years are white.

analysis using image differencing revealed that there were 192 ha of cattails present during the 1988 growing season and 179 ha in 1989. There were 150 ha of waterlilies in 1988 and only 126 ha in 1989. The spatial distribution of the waterlilies lost between 1988 and 1989 is shown in Figure 7.

Based on the success of analyzing the 1988 and 1989 SPOT data, a decision was made to identify the change in aquatic macrophyte distribution from 1988 to 1990. After much experimentation, an effective method of visualizing this information was selected. The October 1988, 1989, and 1990 SPOT panchromatic images were histogram equalized and placed in the red, green, and blue image planes, respectively (Plate 2). The aquatic macrophyte beds which were present only in 1988 are depicted in shades of red. Those macrophytes present in 1988 and 1989, but gone in 1990, are shown in shades of yellow. Areas in white represent aquatic macrophytes which were stable from 1988 through 1990. This multi-temporal display of SPOT panchromatic data is an excellent way of visually identifying the spatial distribution of aquatic macrophyte beds which change through time.

Summary

This study demonstrated how cattails and waterlilies found in a South Carolina freshwater reservoir in 1988 and 1989 were inventoried using multidate SPOT panchromatic data. The remote sensing derived information were 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 hectare distribution. Placement of October 1988, 1989, and 1990 panchromatic data into a single color composite (red, green, and blue image planes, respectively) was particularly useful when visually analyzing the data to identify yearly changes in aquatic macrophyte distribution. The current methodology based on 10-m panchromatic data should not be used to identify aquatic macrophyte beds less than 20 m in width. The President of *SPOT* Image Inc., Theodore Nanz, says "SPOT plans to go to five-metre resolution when it launches its privately funded satellite at the turn of the century" (Stephens, 1991). Such panchromatic data should allow beds smaller than 10 m in width to be inventoried accurately.

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