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Use of Archive Aerial Photography for Monitoring Black Mangrove Populations

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ABSTRACT

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A study was conducted on the South Texas Gulf Coast to evaluate archive aerial color-infrared (CIR) photography combined with supervised image analysis techniques to quantify changes in black mangrove [*Avicennia germinans* (L.) L.] populations over a 26-year period. Archive CIR film from two study sites (sites 1 and 2) was studied. Photographs of site 1 from 1976, 1988, and 2002 showed that black mangrove populations made up 16.2%, 21.1%, and 29.4% of the study site, respectively. Photographs of site 2 from 1976 and 2002 showed that black mangrove populations made up 0.4% and 2.7% of the study site, respectively. Over the 26-year period, black mangrove had increases in cover of 77% and 467% on sites 1 and 2, respectively. These results indicate that aerial photographs coupled with image analysis techniques can be useful tools to monitor and quantify black mangrove populations over time.

ADDITIONAL INDEX WORDS: Avicennia germinans, *remote sensing, color-infrared aerial photography, supervised image analysis, change detection, Texas Gulf Coast.*

INTRODUCTION

Mangroves are salt-tolerant shrubs or trees that are widely distributed in estuaries and intertidal zones in the tropics and subtropics (Field *et al.*, 1998; Sherrod and McMillan, 1985). There are many benefits to mangrove communities, such as serving as breeding grounds to many fish, shellfish, birds, and other wildlife. They also provide a natural barrier that helps to prevent shoreline erosion, providing protection to inland areas during hurricanes and tidal waves (Badola and Hussain, 2005; Ewel, Ong, and Twilley, 1998; Quarto, 2005; Stutzenbaker, 1999).

Because mangrove communities are often inaccessible, it is difficult to determine their distribution and abundance by ground surveys. Remote sensing techniques provide a timely, cost-effective means to obtain reliable data over inaccessible areas (Tueller, 1982). Aerial photography has been used extensively to document the distribution and extent of mangrove communities in several areas of the world (Chauvaud, Bouchon, and Maniere, 1998; Kairo, Kivyatu, and Koedam, 2002; Manson, Loneragan, and Phinn, 2003; Reark, 1975; Ross, 1975; Sherrod and McMillan, 1981).

Everitt and Judd (1989) and Everitt *et al.* (2007) have demonstrated the value of color-infrared (CIR) aerial photography coupled with image analysis techniques to distinguish and map black mangrove populations along the South Texas Gulf Coast. Remotely sensed imagery is a valuable tool for measuring changes in landscape features. Computer image classification maps developed from imagery obtained on two or more dates are useful to assess temporal changes in landscape cover types during known time intervals (Lunetta and Elvidge, 1999; Jensen, 2005). The objective of this study was to demonstrate the use of archive CIR aerial photography for measuring changes in black mangrove populations along the South Texas Gulf Coast.

MATERIALS AND METHODS

This study was conducted on South Padre Island, Texas, along the extreme southern portion of the Texas Gulf Coast (Figure 1). This area has several populations of black mangrove. Two different black mangrove populations served as study sites, designated as sites 1 (26°5′ N, 97°10′ W) and 2 (26°8′ N, 97°10′ W). The two sites were approximately 5.5 km apart. Color-infrared aerial photography and computer image analysis techniques were used for this study. Kodak CIR (0.50 μm to 0.90 μm) type 2443 film was used for the aerial photography. Photography was obtained with a large format (23 × 23 cm) mapping camera. The camera had an aperture setting of f11 at 1/250 seconds and a 305-mm lens equipped with a Wratten 15 orange (minus blue) filter.

Aerial photography of site 1 was obtained 23 January 1976, 4 November 1988, and 16 October 2002. For site 2, aerial photography was acquired on 23 January 1976 and 16 October 2002. Aerial photography was obtained with either a Cessna

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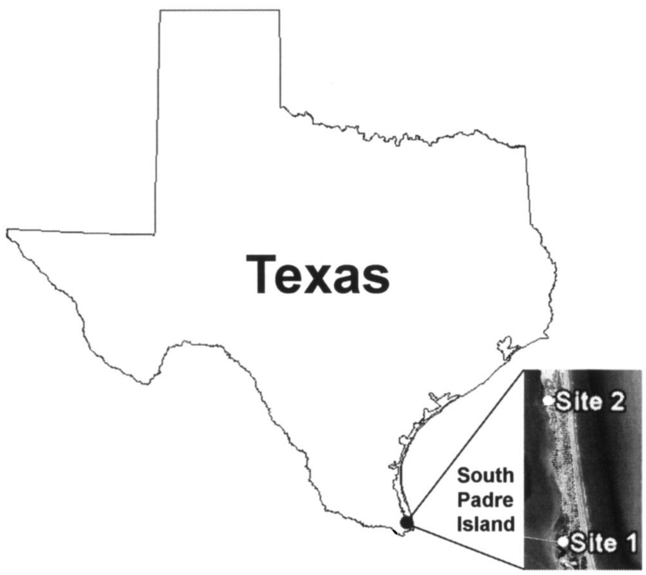

Figure 1. Location of study area.

206 or Cessna 404 airplane equipped with a camera port in the floor. The camera was maintained in a nadir position during image acquisition. All photography was acquired at an altitude above ground level of approximately 3050 m and had a scale of 1:10,000. Photography was acquired between 1300 and 1500 Central Standard Time.

The CIR photographic transparencies of each of the study sites for each date the imagery was acquired were scanned at 600 dots per inch and had a pixel resolution of 1.0 m. Small subset images of sites 1 and 2 were extracted from the scanned images. The extracted images were rectified to previously georeferenced CIR photographs of each study site (Everitt *et al.*, 2007). The extracted images were rectified to the georeferenced photographs of each study site using an image-to-image registration process (Erdas, 2008). The root mean square (RMS) errors for registered images of site 1 for 1976, 1988, and 2002 were 1.5 m, 2.5 m, and 2.6 m, respectively. For site 2, the RMS errors for the registered images for 1976 and 2002 were 3.2 m and 1.1 m, respectively.

The extracted CIR photograph of each site for each acquisition date was subjected to a supervised image analysis technique. Five subsamples were selected from each surface type on each site to be used as training sites. For site 1, the 1976 photograph had three surface types that included black mangrove, soil/algae/roads, and water. The 1988 and 2002 photographs of site 1 had four surface types that included black mangrove, soil/algae/roads, mixed vegetation, and water. The soil/algae/roads class in the 2002 photograph also included shallow water puddles from higher tide levels. For site 2, the 1976 photograph had three surface types including black mangrove, soil/algae, and water, whereas the 2002 photograph of site 2 had four surface types that included black mangrove, soil/algae, mixed vegetation, and water. The algae flats were composed of filamentous blue-green algae (Cyanobacteria). The algae flats, shallow water, soil, and roads were merged into one class. Mixed vegetation consisted of grasses, sedges, broad-leaved herbs, and woody plants. The woody species were ornamentals that included Texas sabal palm [*Sabal texana* (O. F. Cook) Becc.], natal plum (*Carissa grandiflora* A. DC.), and sea grape [*Coccoloba uvifera* (L.) L.]. The maximum likelihood classifier was used to classify the photographs (Erdas, 2008). Accuracy assessments and extensive ground surveys were made on the study sites in previous research studies (Everitt and Judd, 1989; Everitt *et al.*, 2007, 2008). Additional ground surveys were made during the current study to confirm film signatures among the surface types.

RESULTS AND DISCUSSION

Figures 2A, 2C, and 2E show CIR photographs of site 1 for January 1976, November 1988, and October 2002, respectively. The arrow on Figure 2A points to the dark red image tone of black mangrove. Black mangrove has a similar tonal response in all three images. Dry soil and roads have variable gray to white image tones, whereas wet soil (including shallow water puddles) and algae have light blue to dark gray image responses. The shallow water puddles are present in the 2002 photograph only. Deeper water generally has a dark blue color, whereas mixed vegetation generally has a light red to pink tonal response. Mixed vegetation occurred in only the November 1988 and October 2002 photographs (in road median).

Figures 2B, 2D, and 2F show the supervised classified image maps of the CIR photographs for January 1976, November 1988, and October 2002, respectively. In 1976, black mangrove made up 16.2% (4.4 ha) of the study site, whereas in the 1988 photograph its cover was 21.1% (5.6 ha), an increase of 27.1% over the 12-year period (Table 1). In the 2002 photograph, black mangrove made up 29.4% (7.7 ha) of the study site, an increase of 38.9% from the the 1988 photograph. For the overall 26-year period from 1976 to 2002, black mangrove had an increase in cover of 76.6%. The supervised classification generally did a good job in identifying black mangrove. However, there was some misclassification in the 1988 and 2002 photos where some of the mixed vegetation in the road median was misclassified as black mangrove. This was attributed to ornamental woody species having a similar CIR image tonal response to black mangrove. Soil/algae/roads made up 62.3% (16.8 ha) of the study site in 1976, whereas in 2002 they comprised 46.2% (12.2 ha) of the area, a decrease of 27.6% over the 26-year period. The area occupied by water was relatively stable over the 26-year period. Mixed vegetation was not present in the 1976 photograph, but its cover remained stable from 1988 to 2002.

For study site 2, black mangrove had a cover of 0.4% (0.06 ha) in the 1976 photograph compared with 2.7% (0.34 ha) in the 2002 photograph, an increase of 467% over the 26-year period (Table 2; imagery and classification maps not shown). Soil/algae had a 27.7% decrease in area from 1976 to 2002. The large increase in water in the 2002 photograph was due to the higher tide levels. Some individual black mangrove plants could not be identified by the supervised classification in the 2002 photograph because of the higher tide. Consequently, the area occupied by black mangrove in the 2002 photograph would be slightly higher than that reported in Table 2.

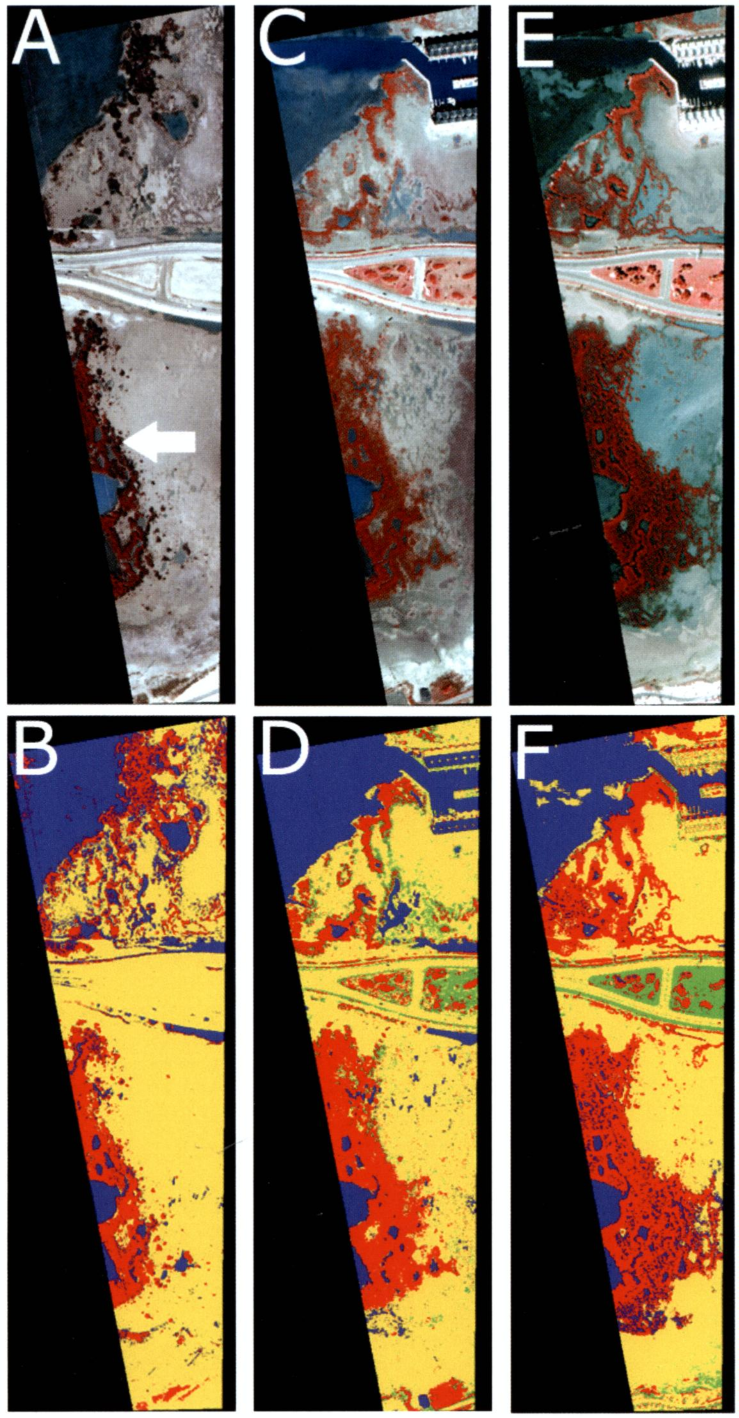

Figure 2. Color-infrared aerial photographs (A, C, and E) of the site 1 black mangrove study area on South Padre Island, Texas. Photographs were acquired on 23 January 1976 (A), 04 November 1988 (C), and 16 October 2002 (E). The arrow on print A points to black mangrove. The computer classifications for images A, C, and E are shown in B, D, and F, respectively. Color codes are: red = black mangrove; yellow = soil, algae, and roads; green = mixed vegetation; and blue = water.

Although it was not possible to conduct accuracy assessments on the supervised classified maps in this study, recent previous studies have shown that black mangrove can be mapped with both aerial and satellite imagery at relatively high accuracy. Everitt *et al.* (2007) used CIR aerial photographic and videographic imagery to distinguish black mangrove on the same two study sites used in the current study and reported that accuracy assessments performed on unsuper-

Table 1. *Percentage classification and percentage change of black mangrove and associated surface types derived from supervised image analysis of color-infrared aerial photographs from 1976, 1988, and 2002 of the study site 1 on South Padre Island, Texas.*

Cover Type	January 23, 1976 Area %	January 23, 1976 Area Ha	November 4, 1988 Area %	November 4, 1988 Area Ha	% Change[1]	October 16, 2002 Area %	October 16, 2002 Area Ha	% Change[2]	Overall % Change[3]
Mangrove	16.2	4.4	21.1	5.6	27.1	29.4	7.7	38.9	76.6
Soil/algae	62.3[4]	16.8[4]	53.0[4]	14.0[4]	−16.9	46.2[5]	12.2[5]	−12.9	−27.6
Mixed vegetation			5.4	1.4		5.1	1.3	−4.4	
Water	21.5	5.8	20.5	5.4	−6.9	19.3	5.1	−5.8	−12.4

[1] Change from 1976 to 1988.
[2] Change from 1988 to 2002.
[3] Change from 1976 to 2002.
[4] Includes roads.
[5] Includes roads and shallow water.

vised classification maps had producer's and user's accuracies for black mangrove ranging from 79% to 100%. Everitt *et al.* (2008) performed an accuracy assessment on a QuickBird satellite supervised classification map of the site 1 study area used in this study and reported producer's and user's accuracies for black mangrove of 82% and 96%, respectively.

It is anticipated that black mangrove populations may have been larger in both the 1988 and 2002 photographs if not for severe freezes in 1983 and 1989. Lonard and Judd (1985, 1991) noted extensive damage to black mangrove populations on South Padre Island from severe freezing temperatures in both December 1983 and 1989. They reported that many individual plants were killed to their bases. Sherrod, Hockaday, and McMillan (1986) reported that many black mangrove plants on South Padre Island that were damaged by the 1983 freeze had resprouted from the basal 0.3 m by August 1984. By June 1985, most of the plants that had resprouted were flowering.

CONCLUSIONS

Our results indicate that CIR aerial photography and image analysis techniques are useful tools for measuring the spread or contraction of black mangrove populations over time. The aerial photographs provide a record that can be stored and examined for comparative purposes over time. The spatially registered imagery can be entered into a geographic information system and enable resource managers to perform various applications such as integrating the imagery with soil maps and areas of wildlife and fishery habitat.

These findings should be of interest to coastal zone resource managers interested in mapping and monitoring mangroves and other ecological surface types. It is estimated that there are 17 million ha of mangrove habitats along the shorelines of the world (Valiela, Bowen, and York, 2001). Unfortunately, mangrove wetlands are being cleared for other land-use activities such as settlements and agriculture. Since the early 1980s, mangroves have declined at an annual areal rate of 2.1% (Valiela, Bowen, and York, 2001). Historical aerial photographs and satellite imagery could be used in conjunction with more current imagery to determine losses of mangrove habitat, particularly in developing areas of the world where most mangroves occur.

Table 2. *Percentage classification and percentage change of black mangrove and associated surface types derived from supervised image analysis of color-infrared aerial photographs from 1976 and 2002 of the study site 2 on South Padre Island, Texas.*

Cover Type	January 23, 1976 Area %	January 23, 1976 Area Ha	October 16, 2002 Area %	October 16, 2002 Area Ha	% Change
Mangrove	0.4	0.06	2.7	0.34	466.7
Soil/algae	91.2	11.82	68.7	8.54	−27.7
Mixed vegetation			7.8	0.97	
Water	8.4	1.08	20.8	2.59	139.4

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