

A Semiautomated Approach for Monitoring Landscape Changes in Texas Seagrass Beds from Aerial Photography

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ABSTRACT

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In support of the Texas Seagrass Monitoring Program, remote sensing research is underway to evaluate automated methods for monitoring landscape changes in seagrass beds related to human and/or natural disturbances. This paper discusses the integration of high resolution aerial color film photography, color space transformation, pixel threshold models, and geographic information system technology to detect, assess, and monitor 1-m ground feature changes and disturbance areas within a Texas, United States, shallow seagrass bed over 3 site years. The procedure entails transforming digitized, aerial color film transparencies from red, green, and blue color space to intensity, hue, and saturation color space; analyzing the saturation and/or intensity imagery and their histograms to identify bare areas; and developing threshold models to separate bare areas from vegetated areas employing the results obtained in the previous step. Maps created with this semiautomated approach had classification accuracies ranging from 75% to 100%. We used geographic information system tools to quantify landscape feature changes occurring at the shallow test site for 3 consecutive years. The overall findings indicate that the semiautomated approach described in this study can be used as an efficient protocol to accurately map changes in bare and vegetated areas within this Texas seagrass bed, and suggest that the techniques would have high potential for other similar seagrass areas.

ADDITIONAL INDEX WORDS: *Color space transformation, threshold models, geographic information system, seagrass monitoring.*

INTRODUCTION

Coastal seagrass beds have long been recognized as important nursery habitats for estuarine fisheries and wildlife; providing food for fish, waterfowl, and sea turtles; contributing large amounts of organic matter to estuarine and marine food webs; participating in nutrient cycling processes; and acting as stabilizing agents in coastal sedimentation and erosion processes (Dennison *et al.*, 1993; Phillips, 1984; Pulich and Calnan, 1999; Thayer, Kenworthy, and Fonseca, 1984; Zie-man, 1982). Both natural and anthropogenic disturbances to seagrass beds can negatively affect the ecology of coastal environments, such that resource managers now use changes in seagrass habitat as a critical indicator of estuarine ecosystem health (Dennison *et al.*, 1993; Orth and Moore, 1983; Short and Wyllie-Echeverria, 1996).

The Seagrass Conservation Plan for Texas included a proposal to establish a seagrass habitat monitoring program for

Texas coastal waters (Pulich and Calnan, 1999). The proposal recommended monitoring of key habitat indices such as landscape disturbance features to detect ecosystem stress occurring before actual loss of seagrasses. In 2000, the Texas Parks and Wildlife Department (TPWD) also initiated a management program to protect sensitive seagrass beds in the Redfish Bay area of the Coastal Bend of Texas (McEachron *et al.*, 2002). As part of the program, TPWD established the Redfish Bay, Texas, Scientific Area, a “no-motor zone” where boaters and fishermen voluntarily restrict use of gasoline engines to prevent propeller scarring of shallow grass beds. To assess motorboat impacts and subsequent recovery particularly of turtlegrass (*Thalassia testudinum*) beds in this Scientific Area, research staff at TPWD designed and instituted a landscape monitoring protocol for the Terminal Flats site based on aerial remote sensing data (Pulich and Calnan, 1999).

In support of the Texas Seagrass Monitoring Program, remote sensing research is underway at various institutions to evaluate methods for documenting landscape changes in seagrass beds related to human and/or natural disturbances. Over the years, remote sensing imagery has gained acceptance within the scientific community as a cost-effective tool to provide wide-area estimates of seagrass beds. Analysts

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*Trade names are included for the benefit of the reader and do not imply endorsement of or preference for the product listed by the United States Department of Agriculture.

have extensively employed manual photointerpretation analysis of aerial photography for quantitative seagrass mapping purposes (Ferguson, Wood, and Graham, 1993; Orth and Moore, 1983; Pulich, Blair, and White, 1997; Ward, Markon, and Douglas, 1997). In recent years, the trend has shifted to using digitized aerial photographs (Finkbeiner, Stevenson, and Seaman, 2001; Kurz *et al.*, 2000; Moore, Wilcox, and Orth, 2000), airborne electronic imagery (Garono *et al.*, 2004; Lanthrop, Montesano, and Haag, 2006; Su *et al.*, 2006), and satellite imagery (Ackleson and Klemas, 1987) to study seagrass beds. Investigators have employed various techniques to analyze the data, and they have obtained mixed results from these studies, suggesting that no optimal procedure yet exists for mapping seagrass beds with remotely sensed data.

Remotely sensed imagery subjected to color space transformation has helped investigators to identify land-cover features not readily apparent in conventional color images (Andreadis, Glavas, and Tsalides, 1995). Compared with the red, green, and blue color (RGB) space used to display images on computer monitors, the intensity, hue, and saturation (IHS) color space corresponds more to the human visual system. This transformation results in a decorrelation of color features. Intensity represents the brightness of a color, and its values range from 0 to 1, with 0 and 1 equaling black and white, respectively. Hue describes the major wavelength of light contributing to a color. Terms used to characterize hue include red, green, orange, blue, and magenta. Its values range from 0° to 360°, with red, green, and blue having values of 0°, 120°, and 240°, respectively. Saturation represents the purity of a color in reference to gray. Its values range from 0 to 1 with 1 representing a pure color.

Analysts can use pixel thresholding, a computer technique employed to group image pixels into classes using cutoff values, to create binary masks for extracting important or non-essential features from remotely sensed imagery. Integration of geographic information systems (GIS), a collection of computer hardware and software used to store, retrieve, and analyze various types of geographic data, and remote sensing technologies has also provided new and useful information related to seagrasses (Dobson *et al.*, 1995; Finkl and DaPrato, 1994; Klemas, 2001; Robbins, 1997). This paper discusses the integration of high resolution aerial color photography, color space transformation, pixel threshold models, and geographic information system technology to detect, assess, and monitor 1-m ground feature changes and bare disturbance areas within a Texas seagrass bed over 3 years. Earlier attempts using standard classification procedures of high resolution color photography of this area did not provide the information needed to meet the goals of the monitoring program, leading to the exploration of the semiautomated technique presented in this study. This paper expands on the preliminary report published by Pulich, Fletcher, and Hardegree (2006).

MATERIALS AND METHODS

Study Area

Redfish Bay, Texas (Figure 1), supports extensive seagrass meadows containing the five species of seagrasses found on the Texas Gulf coast: *Halodule wrightii*, *Ruppia maritima*,

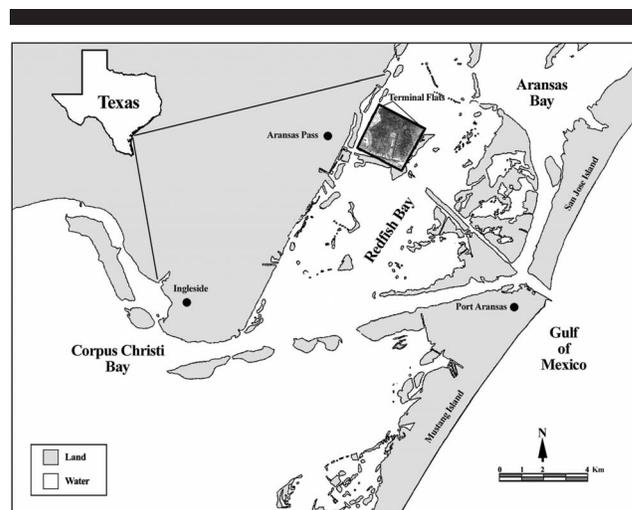


Figure 1. Location of the Terminal Flats site in Redfish Bay, Texas.

Thalassia testudinum, *Syringodium filiforme*, and *Halophila engelmannii* (Pulich, Blair, and White, 1997). Much seagrass restoration and management work since 1999 has been focused on the shallow Terminal Flats site near Aransas Pass, Texas (Figure 1), because propeller scarring has caused a major reduction in seagrass acreage in this region (Dunton and Schonberg, 2002; McEachron *et al.*, 2002). Seagrasses grow at the shallow Terminal Flats site in water of 0.2 m to less than 0.6 m depth mean sea level (MSL). The region also represents the largest percentage and extent of *Thalassia* occurring this far north on the Texas coast. Wide-scale remote sensing monitoring techniques are considered critical to management and protection of these *Thalassia* beds.

Acquisition of Aerial Photography

Between 1000–1130 hours Central Standard Time on 14 December 2001, 6 December 2002, and 18 December 2003, United States Department of Agriculture-Agricultural Research Service (ARS) personnel acquired aerial photography of the Terminal Flats site at a scale of 1:9600 (2918.4 m above ground level). They obtained the photography with a large format mapping camera mounted in a hole in the belly of a fixed-winged aircraft. ARS personnel used Aerocolor Kodak 2427 (22.9 × 22.9 cm) film for each date. The mapping camera employed for these missions had a 30.48 cm focal length lens.

Late fall was appropriate for obtaining the photographs because seagrass biomass was still relatively high and detritus (wrack) was moderate, while water levels were low. Tides were slightly above winter period low water conditions. Sky and water conditions all 3 years were clear and calm, respectively, after cold fronts had passed through a day or two earlier.

Artificial Ground Control Targets

Some areas within the study site did not have prominent natural and/or man-made features to use as ground control

points, which were needed for georeferencing the photography to a known coordinate system. Prior to each photomission, artificial ground control targets were placed at strategic locations within the seagrass bed. These white plastic targets, 1.2 by 1.2 m in size, were anchored with poles and floated on the water surface; 10 to 12 such targets were highly visible in each photograph. A ground crew recorded the coordinates of these targets with a handheld differential global positioning system accurate to ± 1 m.

Film Processing, Scanning, and Georeferencing

The exposed film was sent to a commercial laboratory for processing. Positive transparencies were used to assess the study site. For each year, a representative transparency of the study site was selected and digitized at 1100 dpi with a flatbed scanner and Adobe Photoshop Software (version 6.0). During scanning, neither the brightness/contrast nor exposure time was adjusted on the scanner. The digitized files were saved in the tagged image file format (TIFF; 8-bit radiometric resolution for each channel) and were imported into the ERDAS imagine software (version 8.6) for further analyses.

The digitized transparencies were georeferenced to the Universal Transverse Mercator Coordinate System (Spheroid: GRS 1980; zone number: 14N; datum: North American Datum 1983), using the coordinates of the artificial ground control targets and employing some additional coordinates of land features located on a rectified United States Geological Survey Digital Orthophoto Quadrangle of the study site and the surrounding area. A second-order polynomial and the nearest neighbor resampling technique were employed in the georeferencing process, and the imagery was resampled to a pixel resolution of 0.3048 m, meeting the specifications of the Seagrass Habitat Monitoring Program. The geometric correction tool of ERDAS was used to georeference the imagery.

Image Processing

The primary area of interest was extracted for further analysis with the area of interest (AOI) tool of the ERDAS software. In preliminary analyses, the authors observed that deepwater channels could have similar image responses to seagrasses, leading to a reduction in the overall accuracies of the thematic maps. Seagrasses do not grow in these deepwater channels; therefore, water channels and terrestrial features within the AOI were masked out (Figure 2A). In this study, the primary submerged land cover types of interest were bare (*i.e.*, $\leq 10\%$ vegetative cover) and vegetated bottom areas. In attempts to increase classification accuracies, other researchers have also masked out land and deepwater features from coastal imagery (Ackleson and Klemas, 1987; Ferguson and Korfmacher, 1997; Maeder *et al.*, 2002; Su *et al.*, 2006; Zainal, Dalby, and Robinson, 1993).

Extraction of Bare Bottom Areas

The AOI subsample image for each of the 3 years was transformed from red, green, and blue color space (Figure 2A) to intensity, hue, and saturation color space (Figure 2B) with

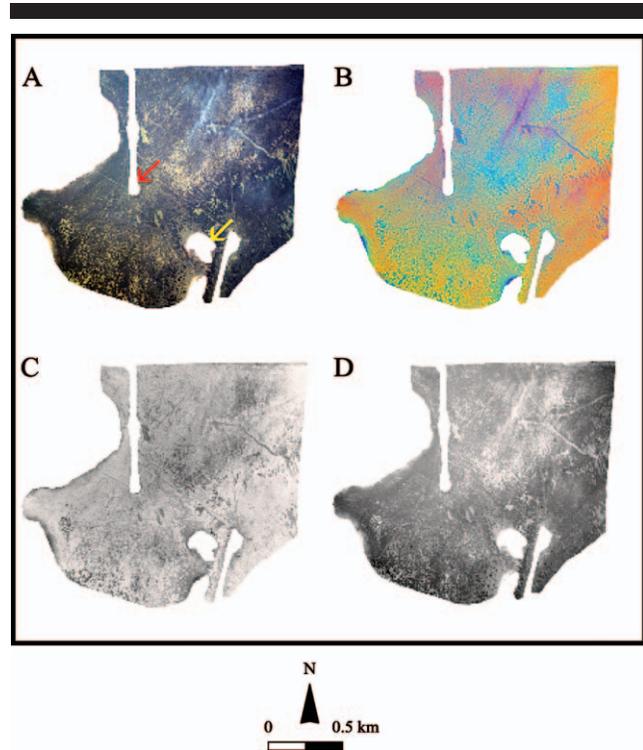


Figure 2. A) Color photograph of the area of interest (AOI) for the Terminal Flats study site (December 2001); yellow and red arrows point to an island and a deep water channel masked out of the image, respectively; B) intensity, hue, and saturation color composite image of the AOI; C) grayscale saturation image of the AOI (December 2001); and D) grayscale intensity image of the AOI (December 2001).

the RGB to IHS tool of the ERDAS software. Prominent bare areas were readily separated in the saturation image (see example for 2001 in Figure 2C); they appeared in dark gray to black tones. This image was used as the primary image to extract bare areas.

The saturation values range from 0 to 1 and are reported in real number format (*i.e.*, 0.726). To simplify the extraction procedure, the image data were rescaled to a range of 0 to 255 (8-bit) prior to further analysis. The rescale option of the ERDAS software was used to complete the task.

The inquire cursor of the ERDAS software was employed to position the cursor on bare areas in the saturation image. These values were recorded. Then, the numerical data in the saturation image histogram was assessed, and the values close to the selected cursor values were recorded as potential threshold values. Based on this information, a preliminary threshold value was determined.

A threshold model was developed, which required the following input for execution (in order): (1) a saturation image and an AOI file, (2) the threshold equation (input file \leq numeric value), and (3) an output name for the new file. For step two, if a value of 160 was chosen as the threshold value for bare areas, then in the conditional model, image values ≤ 160 were assigned a value of 1 and image values > 160 were given a value of 0. For step three, the thematic output data

Table 1. Error matrixes for the 2001 Terminal Flats thematic map.

Classified	Bare	Vegetated	Total	User's Accuracy (%)
Reference Data: 20 May 2002				
Bare	13	3	16	81.2
Vegetated	0	18	18	100
Total	13	21	34	
Producer's accuracy (%)	100	85.7		
Overall accuracy (%)	91.2			
Reference Data: 6 June 2002				
Bare	10	3	13	76.9
Vegetated	1	11	12	91.7
Total	11	14	25	
Producer's accuracy (%)	90.9	78.6		
Overall accuracy (%)	84.0			

type has to be selected. The output image was recoded (Recode module of ERDAS) to display bare, vegetative, and background areas in different colors.

For each date, the thematic map and digitized aerial color photograph were opened in the same viewer. The former was overlaid on top of the latter, resulting in the digitized aerial color photograph not being seen by the analysts. The attributes editor of the thematic image was opened, and the opacities of the bare and vegetative areas colors were changed to 0.3 and 0, respectively, causing partial transparency of the bare areas and full transparency of the vegetative areas. If the selected threshold value was too high or too low based on qualitative assessment of the thematic image and the digitized aerial photograph, then a new threshold value was selected, and the above steps were repeated until a satisfactory threshold value was obtained. The final thematic image was subjected to a 3 by 3 majority filter to remove "salt and pepper" pixels within the image. The neighborhood option of the software was used to complete this task.

Some bare areas were not extracted using the saturation image alone. Therefore, the intensity image (Figure 2D) was employed as the secondary image to extract some of these areas (2003 data only). The same procedures employed for the saturation image were used to extract bare areas from the intensity image. On the intensity image, bare areas appeared in lighter gray tones (Figure 2D); therefore, the \geq symbol was used in the model equation to extract the bare areas. After the thematic image was created using the intensity image, it was multiplied by the thematic image developed with the saturation image to devise a final bare area image. Before multiplying these images, they were recoded so that bare areas and vegetative areas had a value of 0 and 1, respectively. The recoding allowed bare areas to have priority over vegetative areas in portions of the maps with conflicting results. This image was overlaid on top of the digitized aerial color photograph to check the accuracy of the bare areas. The same filtering procedure described above was employed to create the final thematic image. The following final threshold values were used for December 2001: saturation 160; for December 2002: saturation 155; and for December 2003: saturation 70 and intensity 160.

Table 2. Error matrixes for the 2002 Terminal Flats thematic map.

Classified	Bare	Vegetated	Total	User's Accuracy (%)
Reference Data: 10 December 2002				
Bare	9	1	10	90.0
Vegetated	0	31	31	100
Total	9	32	41	
Producer's accuracy (%)	100	96.9		
Overall accuracy (%)	97.6			
Reference Data: 11 March 2003				
Bare	6	1	7	85.7
Vegetated	2	33	35	94.3
Total	8	34	42	
Producer's accuracy (%)	75.0	97.0		
Overall accuracy (%)	92.8			

Accuracy Assessment

For the 2001 photo of the study site, ground-truth data were acquired on 20 May 2002 and 6 June 2002; for the 2002 study site photo, ground-truth data were obtained on 10 December 2002 and 11 March 2003. Ground-truth data were not obtained for the 2003 photo of the study area; it was qualitatively assessed based on visual field observations to determine the general accuracy of the map. Ground-truth points were randomly selected for each survey date, and field measurements subsequently made using differential GPS. Error matrixes consisting of user's, producer's, and overall accuracies were used to evaluate the accuracy of the maps (Congalton and Green, 1999). User's accuracy described the reliability of the map as a predictive device. Producer's accuracy indicated the probability that the representative sample would be correctly classified. Overall accuracy explained the total percentage of correctly classified land cover types. To account for the effects of registration errors on map accuracy, a 3 by 3 pixel area (*ca.* 1×1 m) was assessed as the sampling unit when comparing GPS point data to the classified thematic maps.

GIS Analysis

The ERDAS GIS tool matrix option was employed to assess the changes occurring in the seagrass bed thematic images between the 3 years.

RESULTS AND DISCUSSION

Accuracy Assessment

Error matrix analyses of the 2001 and 2002 bare and vegetative thematic maps are summarized in Tables 1 and 2, respectively. For the combined years, overall accuracies ranged from 84.0% to 97.6%, user's accuracy ranged from 76.9% to 100%, and producer's accuracy ranged from 75.0% to 100%. The best accuracies were achieved when the ground-truth data were obtained closer to the image acquisition date (*e.g.*, December 2002). In general, most observed map errors occurred at GPS points where (1) very sparse seagrass stands were misclassified as bare or vice versa or (2) drifting macroalgae aggregations had covered up or washed away from

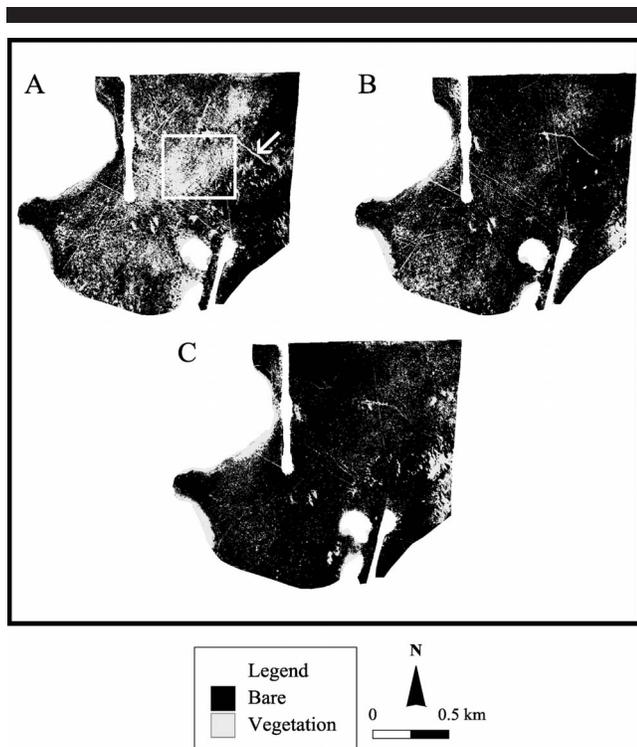


Figure 3. Thematic maps of the Terminal Flats seagrass bed showing bare and vegetative areas for A) 2001, B) 2002, and C) 2003. Arrow points to a prominent pipeline scar. Rectangle encloses an area consisting primarily of bare substrate in 2001.

a bare area. The ground-truth data for the 2001 photoimage had been collected between 5 to 6 months after the image acquisition. Therefore, some bare areas in December 2001 could have become vegetated with either seagrass or macroalgae by the time ground-truth was performed, and vice versa, for some vegetated areas that later became bare due to presence of drifting macroalgae on the photography date. Other investigators have also postulated that substantial time between image acquisition and ground-truthing may have contributed to error obtained in their studies (Lanthrop, Montesano, and Haag, 2006; Luczkovich *et al.*, 1993). To achieve the highest accuracies, Congalton and Green (1999) have recommended that ground-truth data must be obtained as close as possible to the date of image acquisition.

Change Analysis

Thematic maps of bare and vegetative areas within the seagrass bed for 2001, 2002, and 2003 are illustrated in Figures 3A, 3B, and 3C, respectively. A variety of bare areas are identifiable: fine-scale linear features (boat propeller scars) and larger, rounded to amoeboid, bare patches. The white arrow in Figure 3 points to a prominent pipeline scar that is known to be over 50 years old. Over time, scattered vegetative growth has occurred temporarily in this scar (Figures 3B and 3C). The white square in Figure 3 encloses an area consisting primarily of bare sediment in 2001. By 2002 and 2003, vegetation had filled in this area, as well as nearby bare ar-

Table 3. Hectares of bare and vegetative areas mapped at Terminal Flats seagrass bed for 3 site years.

Year	Bare (ha)	Vegetative (ha)
2001	67.7	141.3
2002	28.8	180.3
2003	24.6	184.5

eas. For both cases, observations indicate much of this change in vegetation was due to drift macroalgae.

An overall reduction in bare area occurred from 2001 to 2003 with many more bare areas present in 2001 compared with 2002 and 2003 (Table 3). Between 2001 and 2002, more area shifted from bare to vegetation than from vegetation to bare (Table 4). The same trend was evident between 2002 and 2003 (Table 4). The bare to vegetative change was substantially greater between 2001 and 2002 (57.5% to 24.6%) compared with 2002 to 2003 (14.6% to 8.8%) (Table 4; Figure 4). Between 2001 and 2002, these changes from bare to vegetation primarily occurred in the central section of the study site (Figure 4A). Many of the bare areas in this central section (both linear scars and ovoid patches) were revegetated with *Halodule wrightii* or filled in with macroalgae.

Shifts from bare to vegetation between 2002 and 2003 mainly appeared in the southwestern section of the study site (Figure 4B), where large accumulations of macroalgae were found. On the change detection maps (Figure 4), the light gray tone represents areas where loss of vegetation occurred. Several of these bare areas appeared in the far eastern section of the seagrass bed for 3 consecutive years (Figure 4). The impact of propeller scarring to the central and northern sections of the seagrass bed was easily seen on all the thematic maps. Aside from propeller scars, resource managers have speculated why other vegetation losses or gains have occurred at this site during the 3-year period. Deposition of drift macroalgae and wrack due to currents and hydraulic conditions, and possibly erosion and scour from winter storms or tropical weather systems, are considered highly probable.

General Perspective

The integrated approach employed in this study showed promise as a tool to monitor landscape changes occurring in a typical seagrass bed located in shallow water. Since the technique was not tested on deepwater seagrass beds (where seagrasses occur more than one to several meters below the water surface), the method's accuracy and applicability in those situations has not been validated. However, we would expect deep water classification results to be analogous to the

Table 4. Changes between bare and vegetative categories at Terminal Flats.

Year	Class	Area (ha)
2001–2002	Vegetation to bare	12.4
	Bare to vegetation	51.4
2002–2003	Vegetation to bare	14.1
	Bare to vegetation	18.3

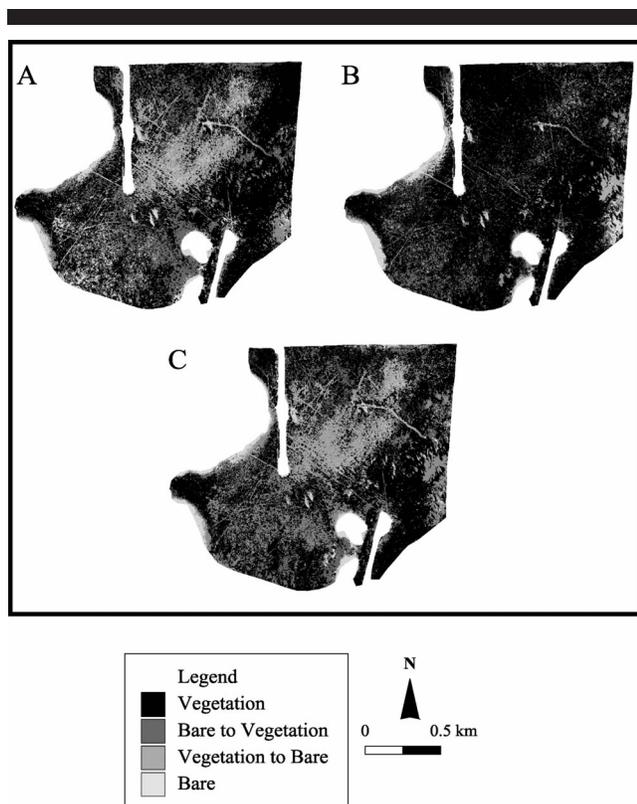


Figure 4. Change detection maps of the Terminal Flats seagrass bed: A) 2001 to 2002, B) 2002 to 2003, and C) 2001 to 2003.

present shallow water case as long as the analysis is conducted for a uniform depth of deep water seagrass. Using this approach on mixed areas with variable depths of seagrass may be problematic because the investigator could have difficulty in finding one distinct threshold value that consistently separates bare areas from vegetation at all depths. Thus, we would suggest that bathymetry data be used to first separate seagrass growing deeper than 1 m into several uniform depth zones (perhaps at 1-m intervals), and the analysis then be applied separately on the bare and vegetated features within individual depth zones.

Using this 1:9600 scale approach on areas larger than the 1:9600 photoframe (which is *ca.* 4.84 sq. km or 484 ha) would be quite cumbersome because it would involve classifying a series of 1:9600 photos and then mosaicing them together. There would be the problem with uneven lighting in the photos created by vignetting. This would cause the investigator to have difficulty in assessing bare areas properly in the thresholding phase, leading to over- or underestimation of bare and vegetated features. However, we suggest a simpler approach that could be used for larger area mapping. This approach would involve acquiring 1:24,000 scale photos. Although ground feature resolution would not be as fine as with 1:9600 scale photos, the technique should produce similar bare area and vegetation data over four times larger photo footprints than 1:9600 photos, and with less tediousness. Future studies will involve extending and refining the image

processing techniques (including comparison of 1:24,000 scale *vs.* 1:9600 scale photoanalysis), evaluating other geographic areas using the integrated approach (*i.e.*, seagrass beds sub-meter to several meters below water surface), and comparing the procedure's accuracy to that of much more expensive electronic imagery (*e.g.*, multispectral imagery).

CONCLUSIONS

The Seagrass Habitat Monitoring Program for Texas coastal waters has recommended the monitoring of landscape-scale disturbances in Texas seagrass beds. In support of the Texas Seagrass Monitoring Program, remote sensing research has been underway to evaluate automated, image analysis methods for documenting landscape feature changes in seagrass beds related to human and/or natural disturbances. Standard photointerpretation and manual classification procedures on high resolution color photography were not practical for providing the necessary information needed to meet the goals of the monitoring program, leading the authors to explore the digital techniques presented in this study.

The semiautomated method employed for this project encompassed the integration of high resolution aerial color photography, color space transformation, pixel thresholding models, and GIS technology to evaluate change dynamics of bare areas within seagrass beds over time. Map accuracies (*i.e.*, user's accuracy, producer's accuracy, and overall accuracy) ranging from 75% to 100% were obtained with this procedure. We were able to follow and monitor fine-scale changes in the same Texas seagrass bed site (approximately 209 ha) for 3 site years.

The overall findings show that the integration of high resolution digital color photography, RGB color space transformation, pixel threshold models, and GIS technology was successful for mapping changes in bare and vegetated areas within this Texas seagrass bed. When using this semiautomated approach, the analyst has more ability to determine the cut-off point between bare and vegetative areas, instead of relying completely on the computer. The integrated high resolution approach has shown great promise for assessing areas approximately the size of the one used in this study (209 ha) and should be beneficial to others interested in monitoring high resolution landscape changes in seagrass beds having similar characteristics.

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