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Comparison of Landsat Thematic Mapper and High Resolution Photography to Identify Change in Complex Coastal Wetlands

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ABSTRACT

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Landsat Thematic Mapper (TM) images were used to generate pre- and post-hurricane classifications of a complex wetland environment in southern Louisiana. Accuracies were estimated as 77% and 81.5% for the pre- and post-classifications that included water, emergent vegetation, floating vegetation, and mud flats. From the two classifications, areas of emergent vegetation loss were identified. The classifications and change map were compared to similar output generated from high resolution color infrared photography. The comparison showed spatial scale of the sensor was the most important factor in separation of classes in this type of wetland environment. Classifications derived by using the TM images provided good class separation when one class dominated more extensive areas (>30 m), but not when mixtures of wetland types were on the same order as the TM sensor spatial resolution. Boundary pixel mixtures were problematic, however problems also occurred in areas of fairly continuous canopies containing small pockets of water and floating vegetation, and in areas of degrading marsh. Both areas were predominately misclassified as emergent vegetation. In the case of change detection, loss of emergent vegetation occurring as small pockets was not identified, whereas loss of degraded marsh was identified but the spatial continuity and extent overemphasized. In combination, these misclassifications resulted in the TM change analysis overpredicting emergent vegetation loss by about 40%.

ADDITIONAL INDEX WORDS: *Louisiana, wetland classification, wetland change detection, remote sensing.*

INTRODUCTION

Numerous studies have shown that high spatial resolution photography can be used to classify and determine changes in coastal wetlands. Various classification schemes for mapping wetlands exist. Most schemes rely on photointerpretation, which becomes increasingly laborious as the number of classes and complexity of the wetlands increase. The National Wetland Inventory (NWI), as the largest producer of wetland maps, has been successful in producing high quality, very detailed classified maps of coastal wetlands (PETERS, 1994). The enormous investment in photographic acquisitions and photointerpretation, however, result in a turnaround of nearly 10 years for new map production (WILEN and FRAYER, 1990). The inability to provide timely monitoring of coastal wetlands, which are rapidly being altered by humans (*e.g.*, conversion, hydrologic modification) and nature (*e.g.*, sea level rise, storm impacts) has led to research using satellite remote sensing.

A number of studies that used multispectral imaging systems (MSS) onboard the early Landsat satellites had limited success in mapping expansive and homogeneous coastal marshes (*e.g.*, WEISMILLER *et al.*, 1977; KLEMAS *et al.*, 1980). The Landsat MSS sensor declined when the Landsat Thematic Mapper (TM) sensor with improved spectral and spatial resolutions became available (*e.g.*, HARDISKY *et al.*, 1986). Later, the launch of the SPOT XMS and panchromatic sensors provided improved spatial resolutions, but a more limited number of spectral bandwidths than on the TM sensor. More recently, programs such as the National Oceanic and Atmospheric Administration's Coastal Change and Analysis Program (C-CAP) have developed a coastal landcover classification method, including wetland classes, that is more conducive to the use of TM imagery (KLEMAS *et al.*, 1993).

In many cases, however, the general distribution of wetland classes is well known—only a binomial classification of wetland loss and gain provided on a regional basis is required. Even with a simple binomial classification scheme, problems can be acute in complex marsh systems exhibiting extremely convoluted and heterogeneous landscapes. In these cases, problems with the TM spatial resolution hamper the generation of a binomial land and water mask. A further complication is the limited availability of cloud-free TM imagery in subtropical areas such as the Gulf of Mexico. Finally, plant phenology (senescence and regrowth) and flood conditions can complicate the ability to discern marsh change by using the spectral reflectance of wetland features. This is particularly acute with seasonally or diurnally ephemeral features, such

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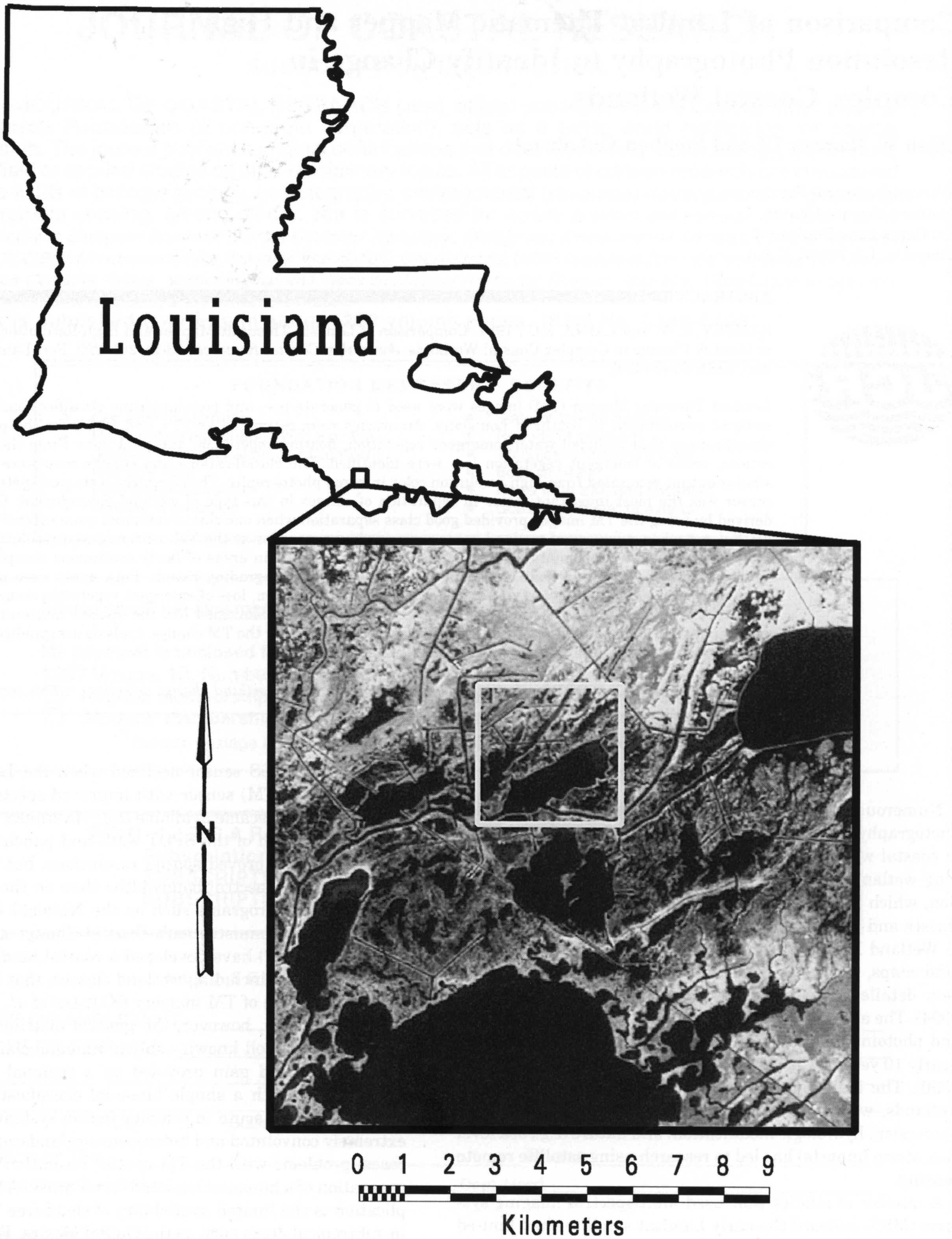

Figure 1. The TM scene shows the extent of the larger study area. The box centered in the TM scene locates the subset area used for detailed analyses and comparisons of high resolution photography and TM images.

as the presence and absence of floating vegetation, the flooding and exposure of tidal and inland mud flats, and the raising and lowering of water levels under the wetland canopy (JENSEN *et al.*, 1994). Radar images can alleviate problems of cloud contamination, but land and water delineation can be problematic due to the possibility of high radar returns from inland water areas experiencing wind roughening (RAMSEY *et al.*, 1994).

The objective of this research was to evaluate the ability of TM type sensors to detect change in complex and heterogeneous wetlands. In reaching this objective, we analyzed wetlands to open water change in a coastal Louisiana marsh and identified problems in the change prediction.

SITE DESCRIPTION

The study area was a coastal Louisiana marsh that has sustained severe loss of land (Figure 1). The area was particularly well suited because it also included a study examining the effects of marsh management (FOOTE *et al.*, 1993) and because the complexity of this particular landscape was even higher than the normally highly dissected and heterogeneous gulf coast marshes. Plant species in the study area were typical of the Gulf Coast, including those found in saline, brackish, intermediate, and fresh marshes (CHABRECK, 1970). Additionally, different species of floating aquatic vegetation proliferate at various times throughout the year. This area not only offered the chance to study marsh changes occurring in steady processes of conversion, waterlogging and salinity rise, but also the occurrence of Hurricane Andrew on 26 August 1992 offered the chance to study dramatic changes to the marsh impacted by severe winds and extreme high water.

METHODS

In carrying out the examination, first, pre- and post-hurricane sets of TM images of a 12.8- by 12.8-km study area in coastal Louisiana were classified and error analyses generated. Second, high resolution photography of a subset area (3.2- by 2.8-km) near the center of the study area was classified and a binomial change map generated. The classified pre- and post-hurricane photography and change map were then compared to the TM classifications and change map of the subset area.

Database Creation

In order to compare and verify changes in the marsh, a geographic database of imagery collected before and after the hurricane was created (Table 1). All raster data was rectified to a UTM projection and coordinate system by using a nearest neighbor resampling at a spatial resolution of 25 m by 25 m. Visual inspection and the reported root-mean-square error (RMS) indicated a <1 pixel registration accuracy between all raster data. Although, available TM imagery was limited, the compiled database provided a realistic scenario of imagery in subtropical areas.

Aerial photographic transparencies were scanned and entered into separate databases with a resolution of 1 m by 1 m (Table 1, October 1991 and 1992). Problems of nonuniform

Table 1. *Hurricane Andrew database.*

Date	Type	Resolution	Time*
November 1, 1990	TM	25 m	09:51:59
December 8, 1990	CIR	1:65,000	10:15:00
March 9, 1991	TM	25 m	09:53:38
July 31, 1991	TM	25 m	09:56:02
October 16, 1991	CIR**	1:12,000	15:28:00
October 5, 1992	TM	25 m	09:54:07
October 12, 1992	CIR**	1:12,000	14:06:00
January 23, 1993	TM	25 m	09:54:14
January 26–27, 1993	CIR	1:24,000	16:35:00

*All times are in Local Standard Time
**Coverage only includes Jug Lake Study Area
TM = Thematic Mapper Imagery
CIR = Color Infrared Photography

light exposure across the individual frames necessitated the use of high overlap (about 40%) when mosaicing the photography into individual scenes. Six frames were used to construct the pre- and post-hurricane mosaiced scenes (Figures 2a and 2b). The georeferencing of the mosaiced scenes followed two steps. First, the pre-hurricane scene was registered to the 1993 TM scene. Nearest neighbor resampling was used to create the georeferenced scene at an approximate 1 m by 1 m pixel resolution. Second, to ensure the best overlay possible, the pre-hurricane scene was then registered to the post-hurricane scene with a resulting RMS registration error of <1 pixel.

Classification

A K-means algorithm was used to classify the TM and photography images (PCI, 1993). To improve class separability, two TM images were combined in each classification; winter and spring (pre), and fall and winter (post) (Table 1). Instead of classifying each TM image separately (SCHRIEVER and CONGALTON, 1993; WOTLER *et al.*, 1995), all reflective bands for each pre- and post-hurricane set were combined into a single classification analysis. For example, 12 bands were entered into the classification algorithm for the pre-hurricane classification. Combining two dates of TM images was especially important in separation of emergent and floating vegetation in the pre-TM classification, and in separation of flooded marsh and open water in the post-TM classification. To further improve separation between classes a progressive classification scheme was used (Figure 3; JENSEN *et al.*, 1987). This method allowed the progressive separation of mixed clusters until no further spectral separation was possible. Even though the objective of all analyses was a binomial change map, more classes were produced to help detail and explain errors in the predicted changes. Final classes included water, emergent marsh, floating vegetation, and mud flats. Even with the use of progressive classification and multiple TM images, confusion still existed between classes. In these cases, final class determination was based on retaining the landscape pattern while minimizing the classification error. This was especially pertinent where the spatial resolution of the sensor integrated the landcover mixtures.

A geometric, stratified, random sampling technique was used to generate classification error estimates for the larger

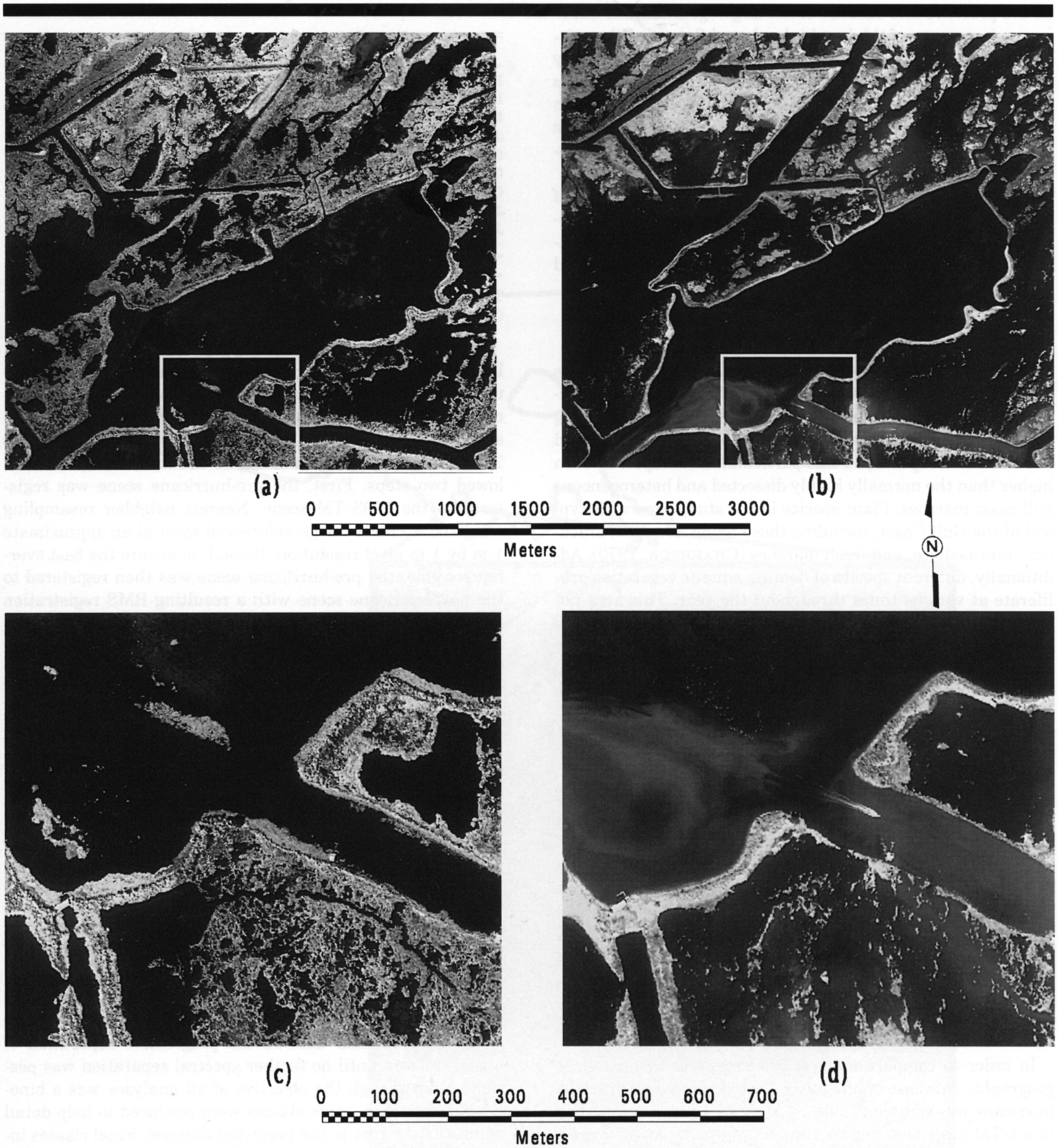

Figure 2. Mosaiced high resolution photography covering the subset area used for detailed analyses—(a) pre-hurricane and (b) post-hurricane. Full resolution inserts illustrate the highly dissected and heterogeneous marsh—(c) pre-hurricane and (d) post-hurricane.

study area (CONGALTON, 1988). Near concurrent photography was used as reference data (Table 1, December 1990 and January 1993). Two hundred samples were used for each error estimate, including at least 50 samples for each major class (CONGALTON, 1991). Omission and commission errors were used to describe classification results (CONGALTON, 1991; JANSSEN and VAN DER VEL, 1994).

Classification problems were examined in more detail by

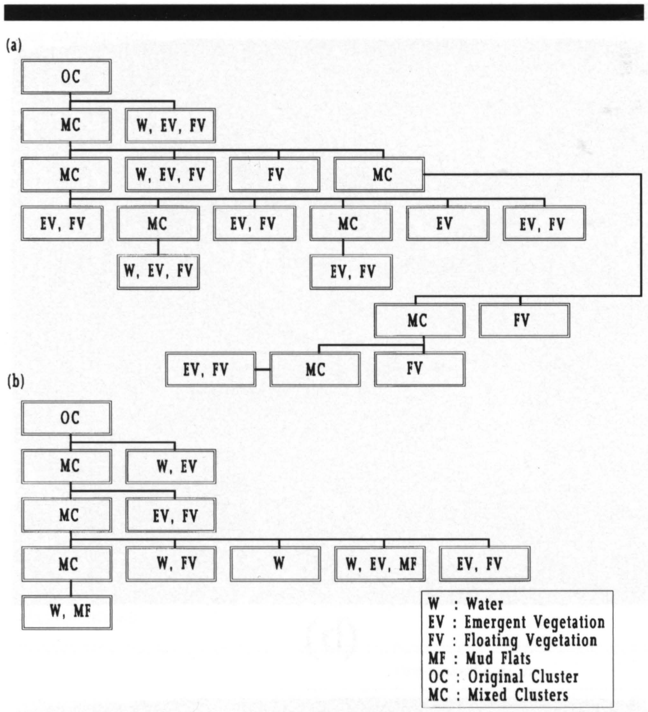

Figure 3. Examples of the progressive clustering procedure used in this study—(a) pre-hurricane photography classification of the subset area and (b) TM classification of the larger study area.

comparing classified photography and classified TM images. To generate the comparison, the classified TM images were subset to an area coincident with the classified photography and were resampled to the spatial resolution of the photography. Comparisons between the classifications and change analyses were produced by using a matrix analysis (PCI INC., 1993). Results from this analysis show in each spatial location (pixel) what classes co-occurred in the two images. Photographic classifications were considered accurate basemaps in the comparisons and were used to generate classification accuracy estimates. Prior to these analyses and comparisons, floating vegetation was aggregated into the water class and mud into the emergent vegetation class. Gain and loss of emergent vegetation was used to document the pre- and post-hurricane landcover changes. Gain occurred in areas of wrack deposits, where detached and dead grasses and debris were deposited onto emergent vegetation or open water areas by the hurricane. In the subset area, most losses occurred when scour or marsh compression caused by the hurricane removed the emergent vegetation, leaving open water (GUNTENSPERGEN *et al.*, 1995). Marsh losses due to interior pond formation or enlargement (DELAUNE *et al.*, 1994) were probably minor from 1990 to 1992, compared to the more drastic impacts immediately from the hurricane in the subset area.

RESULTS

TM Classifications

Overall accuracy of the pre-hurricane and post-hurricane classifications of the TM images was estimated at 77% and 81.5%, respectively, for the larger study area (Table 2). Pre- and post-classifications of the subset area are shown in Figures 4a and b. In both classifications, most omission errors were linked to the misclassification of emergent vegetation as floating vegetation and water. Commission errors in both classifications were dominated by misclassification of emergent vegetation as water. Additionally, in the pre-hurricane classification, floating vegetation was often misclassified as emergent vegetation and water. Mud flats were incorrectly classified as emergent vegetation in the pre- and post-classifications, as well as water in the post-classification. In both classifications, most confusion between classes was associated with areas of highly degraded marsh (mixture of emergent and floating vegetation and mud flats; *e.g.*, Figures 2c and d).

Table 2. *Geometric, stratified, random sample design.*

Pre hurricane classification

TM Classification	Color Infrared Photography (December 8, 1990) 1	2	3	4	Total
1 Water	53	13	10	3	79
2 Emergent Vegetation	0	86	2	0	88
3 Floating Vegetation	5	10	12	0	27
4 Mud Flats	0	3	0	3	6
Total	58	112	24	6	200
Percent Correct = 77.0			Estimated Kappa = 0.606		

Post hurricane classification

TM Classification	Color Infrared Photography (January 26–27, 1993) 1	2	3	4	Total
1 Water	86	17	0	1	104
2 Emergent Vegetation	2	76	1	0	79
3 Floating Vegetation	2	7	1	0	10
4 Mud Flats	3	4	0	0	7
Total	93	104	2	1	200
Percent Correct = 81.5			Estimated Kappa = 0.656		

Prior to determining emergent vegetation change, floating vegetation was combined into the water class and mud flats into the emergent vegetation class. The change analysis suggested that 1,619 ha of emergent vegetation was lost between late 1990 and early 1993. Most of the loss occurred in areas of highly fragmented marsh with unusually high concentrations of floating vegetation. These areas were predominately in the intermediate marsh areas, but an area of fragmented fresh marsh also experienced high loss. A gain of about 470 ha of emergent vegetation was estimated for the larger study area.

Photographic Classifications

Visual comparison of the original and classified photography covering the subset area indicated few misclassification errors (Figures 4c and d). Most errors were a result of confusion between floating and emergent vegetation in the pre-hurricane photography (Figures 2a and c). The small number of these misclassified pixels can be seen in the north-south bayou and in the southern area of Jug Lake (Figure 4c). Floating vegetation caused less problems in the post-hurri-

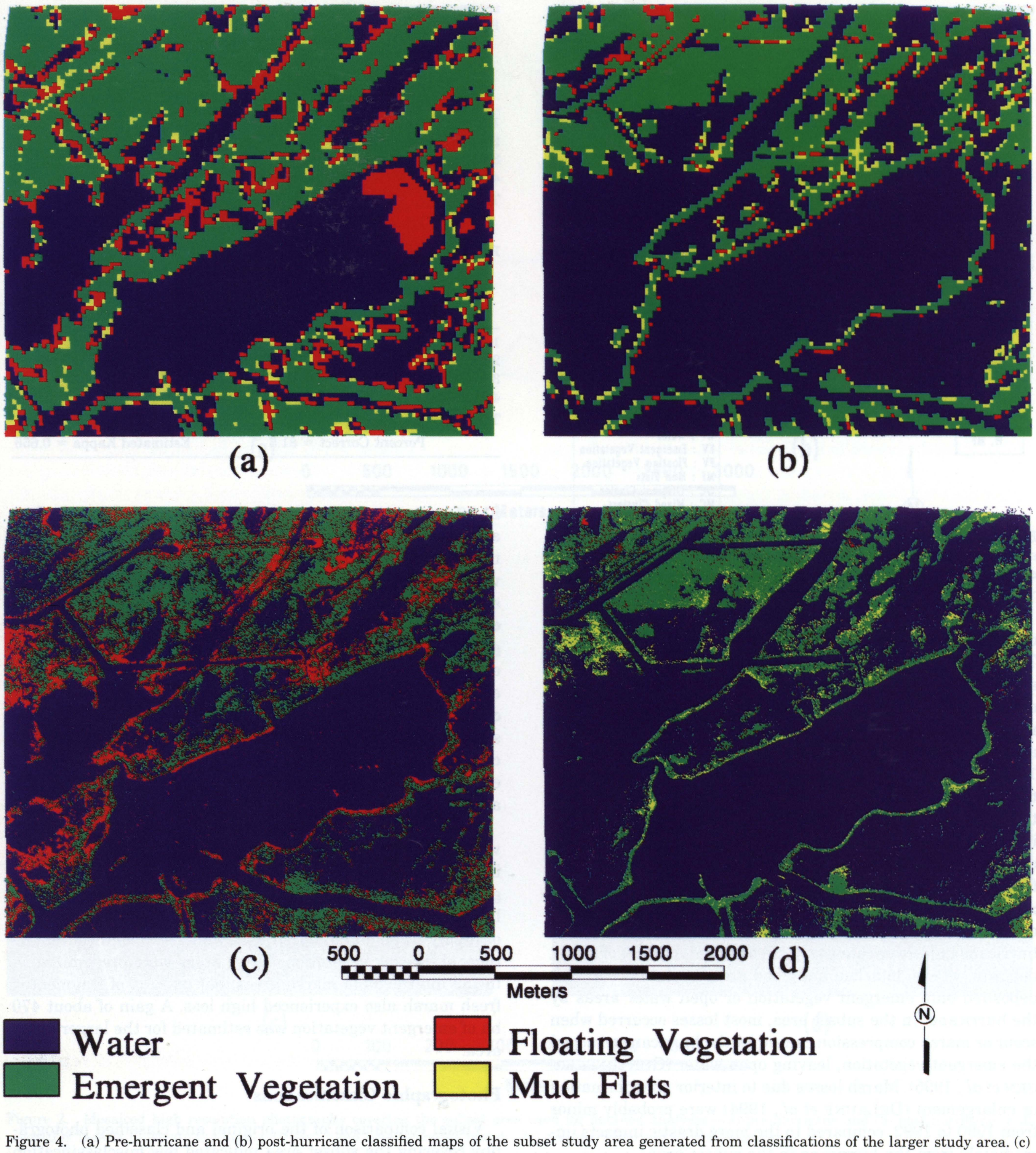

Figure 4. (a) Pre-hurricane and (b) post-hurricane classified maps of the subset study area generated from classifications of the larger study area. (c) Pre-hurricane and (d) post-hurricane classified maps of the subset area derived from the high resolution photography. Note: No mud flats were identified in the pre-hurricane photography.

Table 3a. *Pre-hurricane classified, and Photography and Thematic Mapper comparison.*

TM Classification	Photography Classification (October 16, 1991) 1	2	Total
1 Water	459.71	20.00	479.71
2 Emergent Vegetation	243.10	181.69	424.79
Total	702.81	201.69	904.50

Table 3b. *Post-hurricane classified photography and Thematic Mapper comparison.*

TM Classification	Photography Classification (October 12, 1992) 1	2	Total
1 Water	582.70	29.81	612.51
2 Emergent Vegetation	122.20	169.60	291.80
Total	704.90	199.41	904.31

Table 3c. *Comparison of pre-hurricane and post-hurricane photography classifications.*

Post-classification	Pre-classification 1	2	Total
1 Water	611.34	93.56	704.90
2 Emergent Vegetation	91.35	108.07	199.42
Total	702.69	201.63	904.32

Table 3d. *Comparison of pre-hurricane and post-hurricane Thematic Mapper classifications.*

Post-classification	Pre-classification 1	2	Total
1 Water	455.81	156.81	612.62
2 Emergent Vegetation	23.90	267.99	291.89
Total	479.71	424.80	904.51

*All values are in hectares

cane photography classification (Figure 4d). Most floating vegetation had been removed by the passage of the hurricane and had not regrown by the collection of the post-hurricane photography.

Comparison of Photography and TM Imagery Classifications

A pixel for pixel comparison of the pre-hurricane photography and TM classifications found a 71% overall accuracy (Table 3a, Figure 5a). Most omission errors were from incorrectly classifying water as emergent vegetation. Nearly 35% of the water on the classified photography was identified as emergent vegetation on the classified TM images. Even though nearly all of the water identified in the TM classification was water in the classified photography, over half of the emergent vegetation was water—dominating the commission errors. A comparison that included a floating vegetation class confirmed that about half of water incorrectly classified as emergent vegetation was associated with regions of floating vegetation. Overall, the TM classification overestimated the emergent vegetation area and underestimated the water areas.

There was about a 12% improvement in the overall classification percent accuracy in the post-hurricane comparison (Table 3b, Figure 5b). Most of the incorrectly classified water areas were associated with emergent vegetation and water boundaries. Omission errors were about the same percentagewise, but they differed greatly in magnitude. There was a 15% (30 ha) error in incorrectly identifying emergent vegetation as water and a 17.3% (122 ha) error in incorrectly classifying water as emergent vegetation. Commission errors were dominated by incorrectly classifying water as emergent vegetation on the classified TM images. Nearly 42% of the emergent vegetation on the classified TM image was water on the classified photography. Even though improved, the same pattern as in the before classification comparisons was shown in the after comparison. The classification generated by using TM images overestimated the emergent vegetation area and underestimated the water area.

Comparison of Photography and TM Change Detection Classifications

Change analysis was generated on the pre- and post-hurricane photography classified images by using matrix analysis (PCI INC., 1993). The analysis suggested 87% of the water and 54% of the pre-hurricane emergent vegetation areas remained unchanged (Table 3c, Figure 5c). Accordingly, there was a 46% gain and a 46% loss in emergent vegetation as related to before hurricane conditions. Comparison to changes derived from the pre- and post-hurricane TM images showed 95% of the water and 63% of the pre-hurricane emergent vegetation areas remained unchanged (Table 3d, Figure 5d). Consequently, there was an associated 8% gain and 37% loss of emergent vegetation.

The comparison seems to indicate that the emergent vegetation loss generated from the photography was higher than the loss derived from the TM images; however, closer inspection shows the emergent vegetation loss obtained from the classified TM images was about 1.7 times higher. The percentages are reversed because the emergent vegetation area predicted in the pre- and post-hurricane TM classifications was higher than in the photography classifications. This is especially pertinent in the pre-classification where emergent vegetation in the TM classification was about 2.1 times that identified in the photography classification. In the post-classifications, emergent vegetation classification ratio of the TM to photography had decreased to about 1.5 times.

To further examine the spatial distribution and misclassification of loss, a matrix analysis was performed on the photography and TM change maps (Table 4, Figure 6). Sixteen classes were output from the analysis, but for simplicity of depiction, classes were grouped into coocurring emergent vegetation, water, loss, gain, areas of loss generated in the photography but not in the TM change analysis, and similarly loss in the TM not occurring in the photography change analysis. All other matrix elements were set to gray.

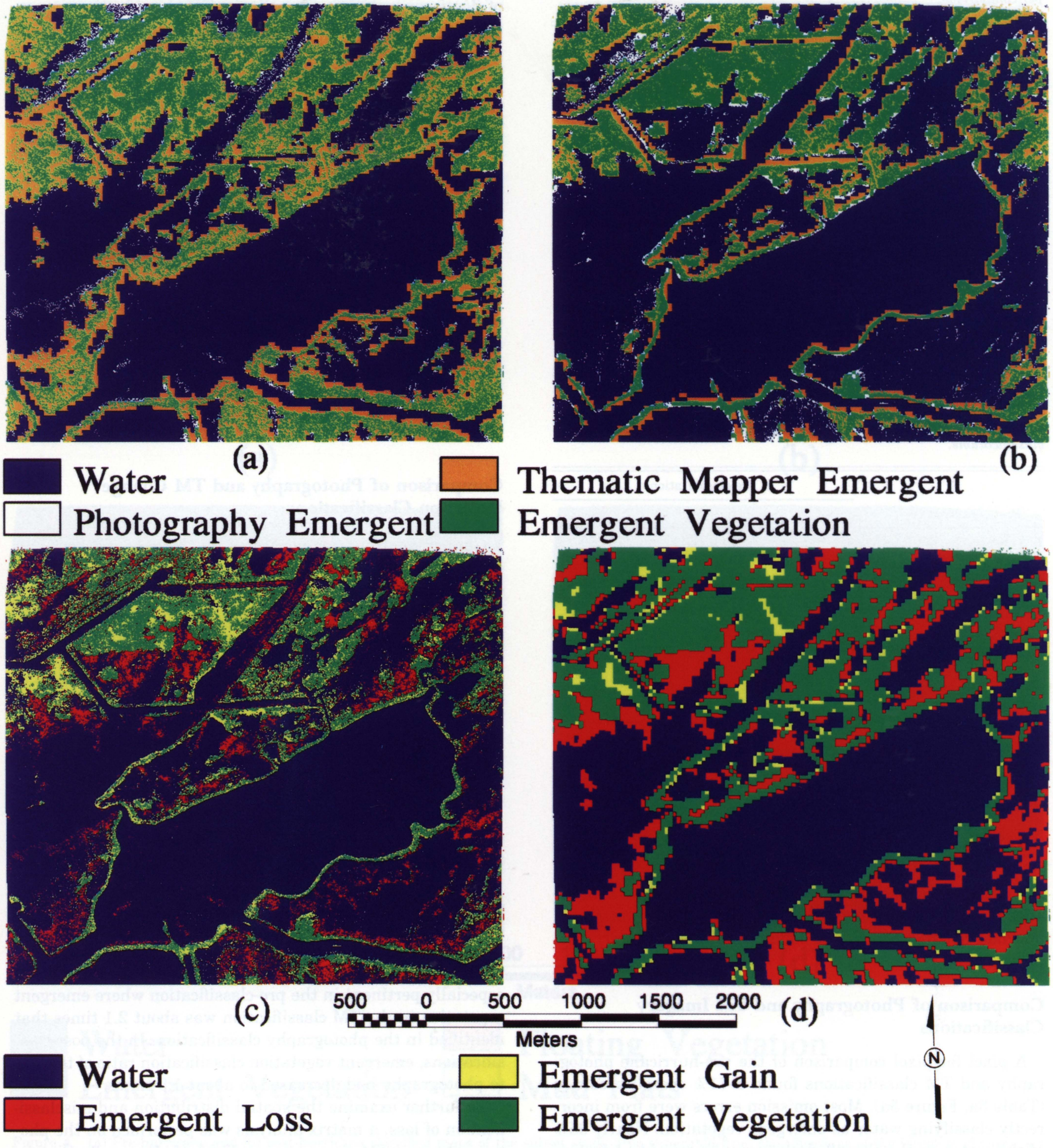

Figure 5. Comparison of the (a) pre-hurricane and (b) post-hurricane TM and photography classifications of the subset area. Change maps generated from the (c) photography and (d) TM analyses.

Table 4. *Comparison of photography and Thematic Mapper change maps.*

TM Change Map	Photography Change Map 1	2	3	4	Total
1 Water	432.94	11.99	7.41	3.42	455.76
2 Emergent Loss	94.66	43.11	9.65	9.33	156.75
3 Emergent Gain	11.84	1.57	7.49	3.00	23.90
4 Emergent	71.90	36.89	66.79	92.32	267.90
Total	611.34	93.56	91.34	108.07	904.31

*All values are in hectares

Overall, 64% of the water, loss, gain, and emergent vegetation classes were in agreement in the TM and photography classifications. Disagreements in the photography water class were mostly associated with misclassification of water as loss or emergent vegetation in the TM classes. About half of the photography loss was classified as loss in the TM classification while nearly an equal percentage was misclassified as emergent vegetation and a smaller percentage as water. Only a small percent of the gain was correctly identified in the TM classification while emergent vegetation was correctly identified about 85% of time. Almost all of the TM water class agreed with the photography water class. Nearly 28% of the TM loss class was correctly identified, while over 60% was confused with water. A comparison that included a floating vegetation class confirmed that about 28% of the TM loss class was associated with regions of floating vegetation. Almost half of the gain in the TM change classification was water. Only about a third of the TM gain class cooccurred with the photography gain class. Emergent vegetation in the TM classification was distributed between all photography classes, with about 35% correctly identified and about half split between the water and gain classes.

Areas of loss accounted for in the photography but not in the TM analysis were distributed in small pockets (<30 m), and because of the scale of the TM sensor, were incorporated in the emergent marsh class. These areas probably madeup most of the misclassification of loss as emergent vegetation in the TM change analysis. Losses identified in the TM but not in the photography analyses mostly were located in areas that before the hurricane had been dominated by extensive flats of floating vegetation, mud, and scattered emergent vegetation (Figures 2c and d). These misclassified losses often enclosed areas of coaggreement of loss in both the photography and TM analyses (Figure 6). To further examine the spatial codistribution of the TM and photography loss classes in these more extensive areas, a spread function was used (PCI Inc., 1993).

In one-pixel increments, areas of concurring loss (red areas in Figure 6) were enlarged, and cooccurrence between the enlarged area and the TM loss, emergent vegetation, and water classes calculated (Figure 7). Initially, the cooccurrence of TM and photography losses was about 43 ha of the nearly 157 ha predicted in the TM loss class (Table 3). With the enlargement of these concurring loss areas by three pixels, an additional 70 ha of TM loss was accounted for along with <15 ha confusion with water and emergent marsh. In total, nearly 113 ha of the 157 ha predicted in the TM loss class was accounted for with minimum overlap with other classes. These results suggest that—in more extensive areas of loss—the spatial pattern of loss predicted from the TM classifications was similar to nearly half the predicted losses from the photography analyses; however, areas of predicted TM loss were enlarged and continuous.

DISCUSSION

The use of progressive classification and multiple TM images alleviated many of the problems of classification associated with wetland ephemeral features, such as floating and flooded vegetation and exposed and flooded mud flats. Estimates of error indicated a 77 to 81% moderate overall accuracy of the pre- and post-hurricane classifications of the larger study area. However, confusion still existed between emergent vegetation, floating vegetation, water and mud flats. Areas of confusion seemed to be isolated to more persistent areas of floating vegetation in inland lakes or canals, to mud flats exposed in one image but not in the other, and to boundary pixels and areas of highly degraded marsh. The estimated error in misclassifying emergent vegetation as floating vegetation, water, and mud flats totaled about 19–28%, respectively for the pre- and post-hurricane TM classifications (Table 2).

Assessment of emergent vegetation change between the pre- and post-classifications predicted the loss of 1,619 ha of emergent vegetation in the larger study area. However, of the loss, 22% was associated with the change of mud areas in the pre-hurricane to water in the post-hurricane classification. Because of changing water levels, inclusion of the mud flats class in either the water or vegetation class is subject to whomever is performing the analysis. In the case of this study, most of the mud class was generated from classification of the pre-hurricane TM images, and therefore, probably not related to marsh scour from storm activity. If the total loss was adjusted by the loss associated with the mud class, a final emergent vegetation loss for the larger study area would be 1,260 ha.

Separation of emergent and floating vegetation was enhanced by combining the moderate spectral resolution of the TM sensor with multidate analysis; however in this study, it was the spatial resolution that was most important. For example, in the classification of the single date, low spectral but high spatial resolution photography of nearly all classes in the subset area were correctly identified. Misclassification of floating vegetation in the TM classifications, however, occurred in areas where floating vegetation and water occupied small gaps in the otherwise continuous emergent vegetation canopy, or where clumps of emergent vegetation were scattered throughout extensive mats of floating vegetation and mud (Figure 2c). In both cases, the tendency was to classify these mixed pixels as emergent vegetation. In the former case, this meant the gaps were not detected, and thus, the appearance of small openings in the canopy were not identified in the change analysis. In the latter case, because the mats of floating vegetation mixed with emergent vegetation were removed by the hurricane, change analysis determined

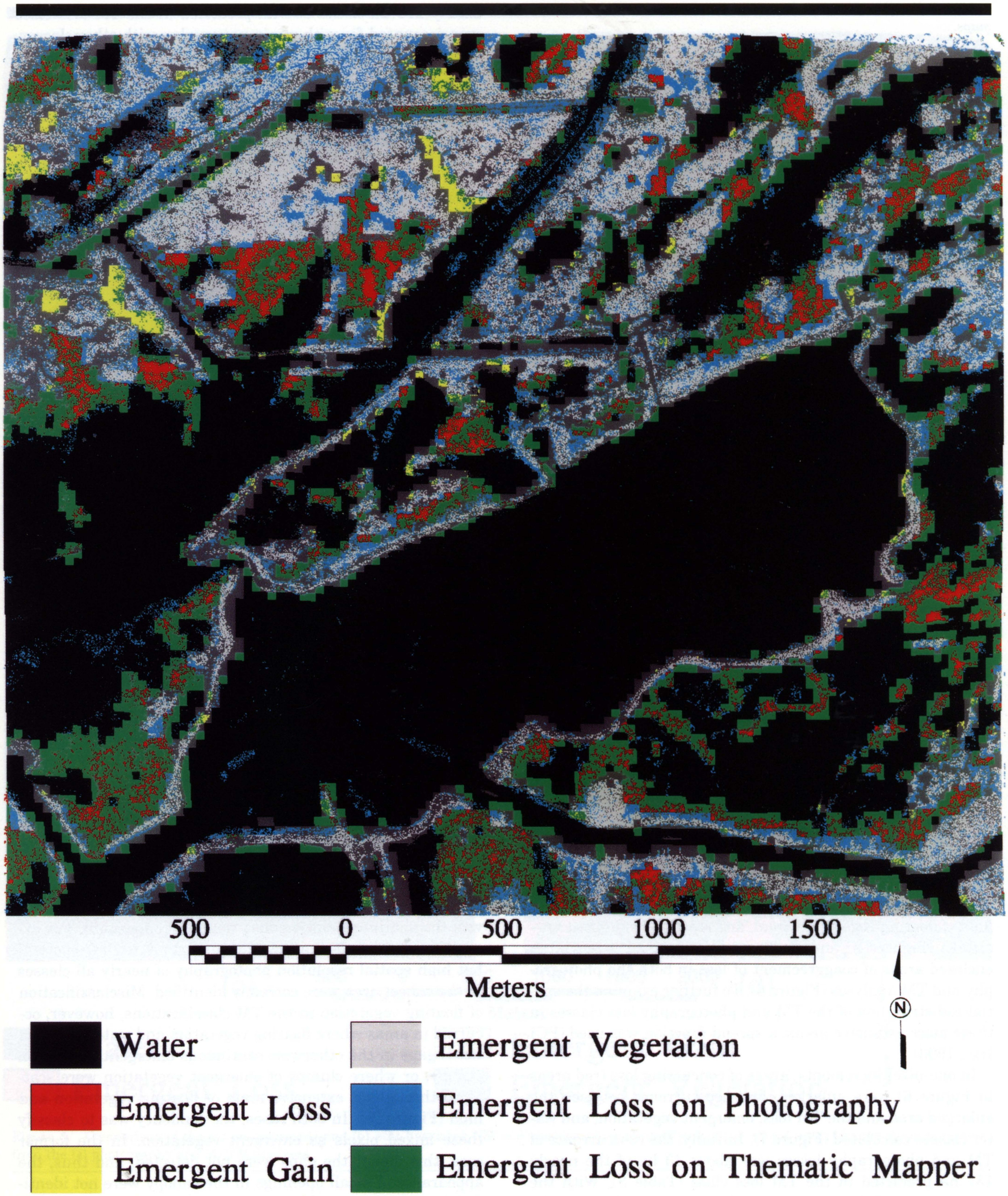

Figure 6. A map of the subset area detailing the correspondence between the photography and TM analyses of emergent vegetation loss. Only areas of coagreement of water, emergent vegetation, loss, gain, and areas of nonagreement of loss are shown.

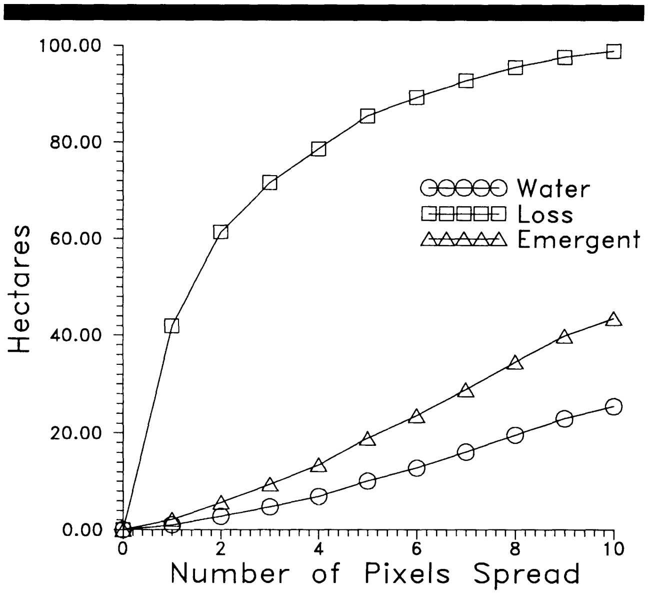

Figure 7. The results of a spread function applied to areas of concurring loss on both the photography and TM change analyses (red areas in Figure 6). Each line depicts the area of overlap at one-pixel increments of each landcover class.

large areas of loss (Figure 2d). This type of loss in the TM change classification was spatially correlated with loss in the photography classification. Even though spatially coincident, the area of loss in the TM classification was more continuous and extensive. This led to an over estimation of emergent loss in the TM versus the photography change classification.

Misclassification due to boundary pixels (mixtures of emergent vegetation and water) was apparent in all TM classifications. This type of misclassification mainly occurred on lake and canal boundaries; however, islands, or clumps of emergent vegetation, smaller than the spatial resolution of the TM sensor were also the areas of confusion. The extent of misclassification related to boundary pixels was roughly estimated by comparing the pre- and post-classifications in the subset area. In the pre-hurricane TM classification, about 50% (120 ha) of the water misclassified as emergent vegetation was related to floating vegetation and mud flats, while an equal amount was related to boundary pixels. In the post-hurricane TM classification, nearly all the misclassified water was related to boundary pixels (122 ha). Even though the land to water ratio changed between the before and after classifications, in both classifications, errors related to boundary pixels included about 13% of the total subset area.

Error analyses suggested a difference in the type of misclassifications associated with the larger study area and subset area. In the larger study area classifications, the tendency was to misclassify the emergent vegetation as water, while in the subset classifications, the opposite was true. Possibly the differences between the larger study area and the subset area could explain part of the discrepancy. The subset area typified regions exhibiting more highly degraded marsh including more floating vegetation than in the overall study area. The cause could also be that the number of points sampled was not adequate for describing the misclassification in these marshes. For an accurate assessment of error, 1% of the population should be sampled; requiring >2,600 pixels in this case (CONGALTON, 1988). In this study, a practical limit was used of at least 50 samples per each major class, emergent vegetation and water (CONGALTON, 1991). Still, reasons for the apparent discrepancy are unclear. However, the results from the subset error analyses should be more reliable. Further, most of the change occurred in marsh areas typified by the subset area. This suggests that results from the subset analysis can be used for estimating the types and magnitude of misclassifications influencing the change detection estimates.

For the larger study area, change analysis suggested there was a 470 ha gain (wrack deposits) and a 1,619 ha loss of emergent vegetation. In the subset area, the predicted loss related to the TM analysis was about 157 ha, while that associated with the photography analysis predicted about 94 ha loss of emergent vegetation. Using the ratio of photography to TM loss (about 60%), the loss predicted for the larger study area can be lowered to a final loss of about 971 ha. Finally, while the TM analysis predicted about a 24 ha gain in the subset area, the photography analysis predicted a gain about equal to the loss. The long term stability of these gain areas is not known.

CONCLUSION

This study examined the problems of using TM imagery to produce a binomial change map of a highly dissected and heterogeneous marsh. The use of multidate TM imagery and progressive classification improved the ability to identify and separate classes, especially when separating floating and emergent vegetation and identifying and separating flooded emergent vegetation from water. The use of a direct comparison between classified high resolution photography and TM images, however, elucidated the remaining problems in using TM imagery to detect wetland change in complex marshes. The direct comparison showed that combining multiple TM images and progressive clustering provided good separation of classes when one class dominated more extensive areas (>30 m), but not in areas where the mixtures of vegetation types and water were on the order of the TM spatial resolution. Part of these misclassifications were related to areas of an otherwise continuous emergent vegetation canopy but with scattered pockets (<3 m) of water and floating vegetation. The rest were associated with highly degraded marsh. TM change analysis identified the location of these degraded marshes, but over emphasize the continuity and spatial extent. Further, about half of the misclassifications were related to boundary pixel mixtures. In effect, the coarse spatial resolution of the TM sensor was the primary cause of the remaining misclassifications. In aggregate, these misclassifications resulted in an overprediction of emergent vegetation loss. By using a direct comparison of losses predicted in the photography and TM change analyses, an estimate of the overprediction was obtained. Using the overprediction estimate resulted in a 40% reduction in the initial emergent vegetation loss estimate.

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LITERATURE CITED

CHABRECK, R.H., 1970. Marsh Zones and Vegetative Types in the Louisiana Coastal Marshes. Louisiana State University, Baton Rouge, PhD Dissertation. 112p.

CONGALTON, R.G., 1988. A comparison of sampling schemes used in generating error matrices for assessing the accuracy of maps generated from remotely sensed data. *Photogrammetric Engineering and Remote Sensing,* 54(5), 593–600.

CONGALTON, R.G., 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment,* 37, 35–47.

DELAUNE, R.D.; NYMAN, J.A., and PATRICK, W.H., JR., 1994. Peat collapse, ponding and wetland loss in a rapidly submerging coastal marsh. *Journal of Coastal Research,* 10(4), 1021–1030.

FOOTE, A.L.; BURKETT, V., and WILLIAMS, S.J., 1993. Natural resource problem solving: an interdisciplinary approach in coastal Louisiana. Proceedings, 8th Symposium on Coastal and Ocean Management Sponsored by the American Shore and Beach Preservation Association/ASCE in New Orleans, Louisiana held on July 19-23.

GUNTENSPERGEN, G.R.; CAHOON, D.R.; GRACE, J.; STEYER, G.D.; FOURNET, S.; TOWNSON, M.A., and FOOTE, A.L., 1995. Disturbance and recovery of the Louisiana coastal marsh landscape from the impacts of Hurricane Andrew. *Journal of Coastal Research,* (18), 324–339.

HARDISKY, M.A.; GROSS, M.F., and KLEMAS V., 1986. Remote sensing of coastal wetlands. *BioScience,* 36(7), 453460.

JANSSEN, L.L.F. and VAN DER VEL, F.J.M., 1994. Accuracy assessment of satellite derived land-cover data: a review. *Photogrammetric Engineering and Remote Sensing,* 60(4), 419–426.

JENSEN, J.R.; RAMSEY E.W., III; MACKEY, H.E.; CHRISTENSEN, E.S., and SHARITZ, R.R., 1987. Inland wetland change detection using aircraft MSS data. *Photogrammetric Engineering and Remote Sensing,* 53(5), 521–528.

JENSEN, J.R.; COWEN, D.J.; ALTHAUSEN, J.D.; NARUMALANI, S., and WEATHERBEE, O., 1994. An evaluation of the coastwatch change detection protocol in South Carolina. *Photogrammetric Engineering and Remote Sensing,* 59(6), 1039–1046.

KLEMAS, V.V.; BARTLETT, D.S., and MURILLO, M., 1980. Remote sensing of coastal environment and resources. Proceedings of the 14th International Symposium on Remote Sensing of Environment.

KLEMAS, V.V.; DOBSON, J.E.; FERGUSON, R.L., and HADDAD, K.D., 1993. A coastal land cover classification system for the NOAA Coastwatch Change Analysis Project. *Journal of Coastal Research,* 9(3), 862–872.

PCI INC., 1993. Using PCI Software, Version 5.2 EASI/PACE. (Richmond Hill, Ontario, Canada: PCI Inc.)

PETERS, D.D., 1994. Use of aerial photography for mapping wetlands in the United States: National Wetlands Inventory. *Proceedings of the First International Airborne Remote Sensing Conference and Exhibition* (Strasbourg, France on 11–15 September, 1994).

RAMSEY III, E.W.; LAINE, S.C.; WERLE, D.; TITTLEY, B., and LAPP, D., 1994. Monitoring Hurricane Andrew damage and recovery of the Coastal Louisiana marsh using satellite remote sensing data. Proceedings of the Coastal Zone Canada '94 Conference held in Halifax, Canada on 10–15 September 1994.

SCHRIEVER, J.R. and CONGALTON, R.G., 1993. Mapping forest cover-types in New Hampshire using multi-temporal Landsat Thematic Mapper data. *Proceedings of the 1993 ACSM/ASPRS Annual Convention and Exposition* (February 15–18 in New Orleans, Louisiana), Vol. II, pp. 333–342.

WEISMILLER, R.A.; KRISTOF, S.J.; SCHOLZ, D.K.; ANUTA, P.E., and MOMIN, S.A., 1977. Change detection in coastal zone environments. *Photogrammetric Engineering and Remote Sensing,* 43(12), 1533–1539.

WILEN, B.O. and FRAYER, W.E., 1990. Status and trends of U.S. wetlands and deepwater habitats. *Forest Ecology and Management,* 33/34, 181–192.

WOLTER, P.T.; MLADENOFF, D.J.; HOST, G.E., and CROW, T.R., 1995. Improved forest classification in the northern lake states using multi-temporal Landsat imagery. *Photogrammetric Engineering and Remote Sensing,* 61(9) 1129–1143.