Subtropical Plant Science, 62:44-55.2010.

Factors Affecting the Spatial Distribution of Black Mangrove on the Dredged-Material or "Spoil" Islands in the Lower Laguna Madre of Texas

Violet Yeager,[1] Kenneth R. Summy,[2] Frank W. Judd,[2] Robert I. Lonard,[2] Ruben A. Mazariegos,[2] James H. Everitt,[3] Michael R. Heep[2] and Thomas Whelan III[2]

[1] Tulane University, New Orleans, LA
[2] The University of Texas – Pan American, Edinburg, TX
[3] Agricultural Research Service, U. S. Department of Agriculture, Weslaco, TX

ABSTRACT

Research was conducted to evaluate the spatial distribution of black mangrove (*Avicennia germinans*) on the dredged-material or "spoil" islands of the Lower Laguna Madre of Texas. Aerial color-infrared (CIR) photographs revealed the presence of black mangrove stands on many of the islands located south of the Arroyo Colorado (a distributary of the Rio Grande which empties into the Laguna Madre), but failed to detect significant mangrove stands on islands located north of the Arroyo. Analysis of CIR photographs and supervised image classifications for individual islands suggested a concentration of black mangrove along western shorelines and relatively low interior areas of islands, although relatively small and localized mangrove stands were clearly evident along eastern shorelines at several locations. These observations were consistent with ground surveys which indicated significantly higher mangrove densities along western vs eastern shorelines of selected islands (0.6 and 0.1 plants/ m^2, respectively; $P < 0.05$), but no difference between ratios of small to large plants in stands located along western vs eastern shorelines (1.6 and 1.4, respectively; $P>0.05$). The most plausible explanation for these trends is that wave action caused by prevailing southeasterly winds during most of the year may impede or prevent the establishment of black mangrove propagules (germinated 'seeds') along eastern shorelines of islands which otherwise constitute suitable habitat for *A. germinans*. If this interpretation is correct, development of planting strategies designed to facilitate establishment of black mangrove stands along shorelines subject to turbulent wave action will be a requisite to the use of this important native plant species for erosion prevention and mitigation on spoil islands in the Lower Laguna Madre.

Additional Key Words: Avicennia germinans, spoil islands, erosion prevention and mitigation.

The dredged-material or "spoil" islands of the Lower Laguna Madre of Texas were created in 1947 when the Gulf Intracoastal Waterway (GIWW) was dredged along the Gulf and Atlantic coasts of the United States. Although these artificial islands are composed of sediment removed from the floor of the Laguna Madre and were initially barren, most islands were eventually colonized by native plant species (Barko et al. 1977) and eventually assumed an important role as nesting and foraging habitat for colonial water birds and other coastal wildlife (Chaney et al. 1978). Elevated areas within the interior of larger islands support communities of plant species typical of those occurring on the Texas mainland (Fig. 1a). Shorelines and other areas with relatively low relief support communities of halophytes typical of those bordering tidal flats on both the mainland and barrier islands (Fig. 1b). One of these native halophytes, black mangrove (*Avicennia germinans*), has long been recognized as an important shoreline stabilizer (Britton and Morton 1989).

Extensive shoreline erosion caused by wind and wave action currently represents a serious threat to many of the spoil islands in the Lower Laguna Madre. During most of the year, prevailing southeasterly winds along the south Texas coast tend to generate waves which move in a westerly or northwesterly direction (Tunnell 2002). Hence, eastern shorelines of both the mainland and islands located in the Laguna Madre appear to be most susceptible to wave action, and eastern shorelines devoid of stabilizing vegetative cover appear to be at greatest risk of serious erosion

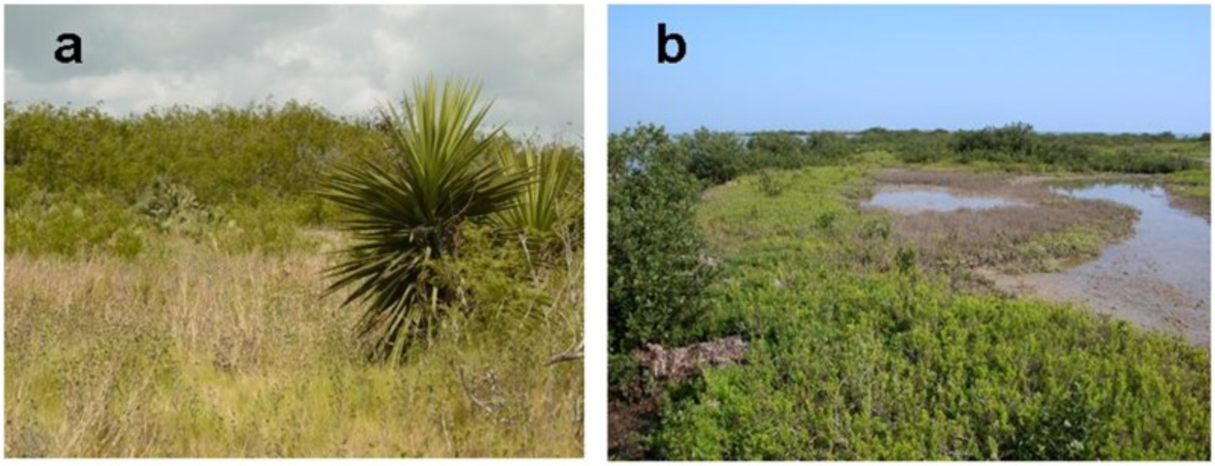

Fig. 1. Native vegetation occurring on the dredged-material or "spoil" islands of the Lower Laguna Madre includes honey mesquite, Prosopis glandulosa, Spanish dagger, Yucca treculeana, prickly pear cactus, Opuntia engelmanii, and other upland species typical of plant communities occurring on the mainland (a) and glasswort, Salicornia virginica, vidrillos, Batis maritima, and black mangrove, Avicennia germinans, and other halophyte species typical of those occurring around tidal flats on both the mainland and barrier islands (b).

(Fig. 2). Black mangrove exhibits certain characteristics which make it a prime candidate for use in the prevention and/or mitigation of shoreline erosion: 1) it is a native plant species which is otherwise adapted to normal weather conditions of southern Texas, 2) its high tolerance to salinity allows it to thrive in the hypersaline shoreline environment (Walsh 1974), and 3) once established at a given location, plants produce an abundance of long cable roots with pneumatophores or "air roots" (Fig. 3). Although the primary function of cable roots and pneumatophores is anchoring and gas exchange (Scholander et al. 1955; Britton and Morton 1989), both structures also tend to reduce the impact of wave action and trap sediment, thus contributing further to shoreline stability. Moreover, the presence of abundant pneumatophores may also facilitate the rooting of mangrove propagules (germinated 'seeds' which abscise from plants) in the immediate vicinity of parent plants, thus allowing established stands to increase in size (Fig. 3).

The native vegetation occurring on the mainland and barrier islands along the Lower Texas Coast has been studied extensively during the past three decades (Judd et al., 1977; Lonard and Judd 1980, 1981, 1997; Lonard et al. 1978; 1999; Richardson 2002; Summy et al. 2005). The flora of the spoil islands in the Lower Laguna Madre has been documented in several reports compiled by the U. S. Army Corps of Engineers (Barko et al. 1977; Chaney et al. 1978) and a comprehensive study conducted by Pan American University, now The University of Texas – Pan American (Heep 1982). The latter study documented the occurrence of black mangrove stands on a number of islands located south of the Arroyo Colorado (a distributary of the Rio Grande which empties into the Lower Laguna Madre), although the extent of mangrove stands during 1982 was apparently far lower than that reported in more recent aerial surveys of selected island chains (Mazariegos et al. 2005; Yeager et al. 2007).

During the past quarter century, commercial development of South Padre Island and other areas bordering the Lower Laguna Madre has accelerated considerably and has resulted in a considerable loss of native coastal habitat. The Lower Rio Grande Valley region has also experienced a series of natural catastrophes including two major freezes (during 1983 and 1989) and landfall of four major hurricanes (Hurricane Allen during 1981, Hurricane Gilbert during 1988, Hurricane Bret during 1999, and Hurricane Dolly during 2008) and several tropical storms of lesser magnitude. Moreover, the incessant effects of erosion caused by wind and wave action have seriously degraded the shorelines of many of the artificial islands bordering the GIWW, particularly along eastern shorelines where turbulence tends to be most intense (Fig. 2). Although the effects of many of these events on native plant communities on the Texas mainland and barrier island have been well

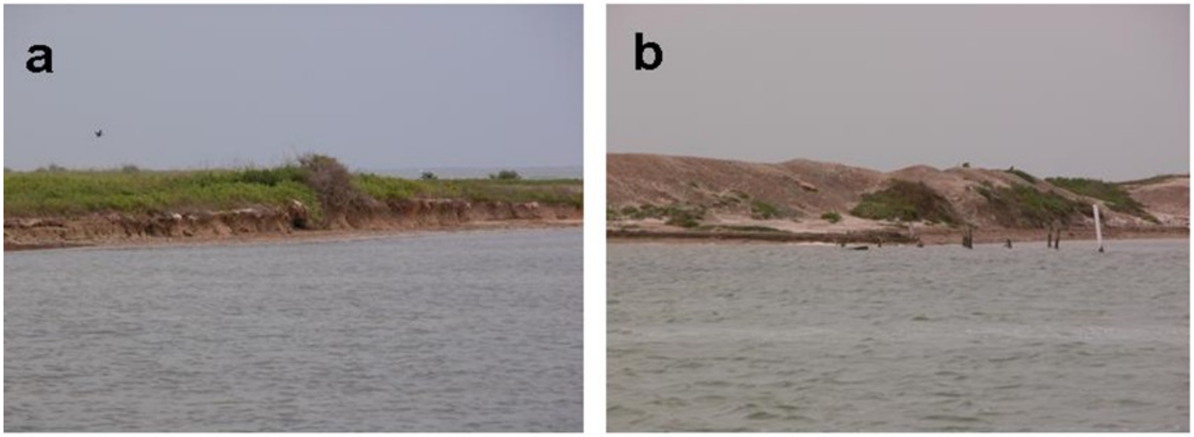

Fig. 2. Areas along shorelines of many spoil islands have been severely damaged by wave action generated by prevailing southeasterly winds during most of the year. Erosion tends to be particularly intense along shorelines devoid of stabilizing vegetation such as black mangrove (a,b).

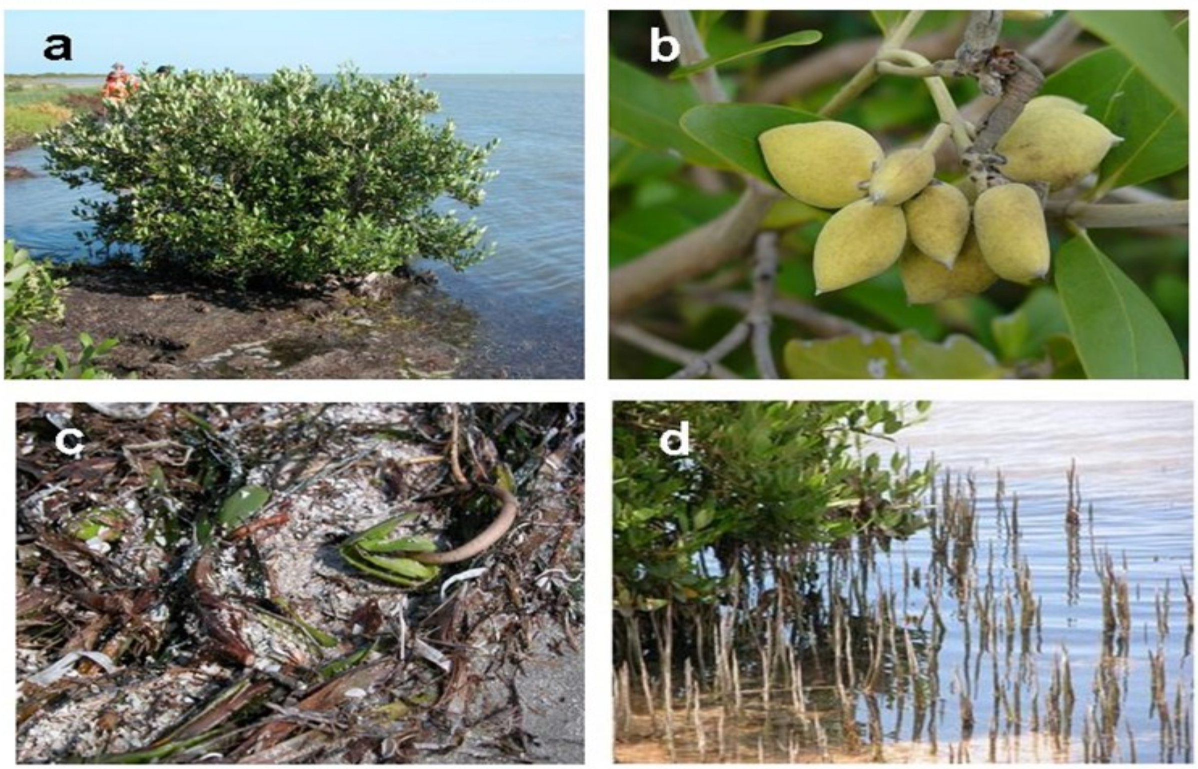

Fig. 3. Black mangrove plants (a) produce propagules which germinate on plants prior to abscission (b) and commonly root beneath parent plants (c). Once established, black mangrove plants produce "air roots" or pneumatophores (d) which provide oxygen to submerged root systems and comcomitantly break wave action and trap sediments, thus stabililizing shorelines.

documented (Judd and Sides 1983; Lonard and Judd 1985, 1993), the current distribution of black mangrove and extent of erosion occurring along shorelines of the spoil island chains of the Lower Laguna Madre is poorly understood at the present time. This lack of knowledge represents a major impediment to the use of black mangrove and other native plant species for erosion prevention and mitigation efforts designed to preserve these islands for future generations.

Our objectives in this study were to 1) evaluate spectral reflectance of black mangrove in relation to other plant species occurring in the shoreline environment of spoil islands, 2) develop thematic vegetation maps for representative spoil islands using existing remote sensing technology which has been shown to be effective in the detection of black mangrove and other coastal plant species (Everitt and Judd 1989; Everitt et al. 1991, 1996, 2007, 2008), and 3) conduct ground surveys designed to compare densities and size distribution of mangrove stands located along shorelines facing each of the four cardinal directions (N, E, S and W). When used in conjunction with published studies relating to the growth and reproduction of *A. germinans* (Amusan and Adeniyi 2005; Bhat and Suleiman 2004; Chen and Twilley 1998), these data are expected to clarify many factors relating to the spatial distribution of black mangrove stands within and among the spoil islands bordering the GIWW, and the effects of this important shoreline stabilizer on wave-caused erosion which currently threatens many, if not most, of these valuable islands.

MATERIALS AND METHODS

Study Area. The spoil islands of the Lower Laguna Madre include a group of islands oriented in an E-W direction near the Mansfield Pass and a chain of 70+ islands extending in a NW-SE direction parallel to the GIWW (Fig. 4a). This study focused on a group of islands located approximately eight kilometers south of the mouth of the Arroyo Colorado (Fig. 4b).

Spectral Reflectance Measurements. Spectral reflectance curves for black mangrove in relation to several other plant species, sand, and algal mats (cyanobacteria) were collected *in situ* using a FieldSpec® Dual VNIR spectroradiometer with sensitivity to electromagnetic radiation extending from the ultraviolet through the near-infrared region of the spectrum (350 – 1100 nm) in 10-nm increments (Analytical Spectral Devices, Inc., Boulder, CO). White reference samples were collected at frequent intervals using a Spectralon® reference plate and real-time measurements of percent reflectance were obtained using ViewSpec Pro® software (ASD, Boulder, CO). Spectral reflectance data for selected wavelengths (450nm, 550nm, 680nm, 850nm) were compared using the one-way analysis of variance (ANOVA) procedure in SYSTAT 10® and the Tukey HSD test for ad hoc comparisons (SPSS, Inc., Chicago, IL).

Aerial Survey. During June 2005, aerial photographs of the study area (1:10,000 scale) were acquired under clear, sunny conditions from a USDA-ARS aircraft equipped with a Fairchild KA-2 camera, 300-cm focal length lens and appropriate filters (Mazariegos et al. 2005; Everitt et al. 2007). Exposures were made on Kodak Aerochrome II color-infrared (CIR) film 1443 (23 x 23 cm) along a single flightline with 60% overlap between frames. CIR photographs were scanned at a density of 800 dpi (which provided a ground pixel resolution of 0.3 m) using an Epson Expression® 1600 scanner (Epson America, Inc., Long Beach, CA).

Image Classification and Accuracy Assessment. Digitized CIR images were separated into green, red and near-infrared (NIR) waveband images using Adobe Photoshop® 6.0 (Adobe Systems, Inc., San Jose, CA) which were then imported into Idrisi32® v.2 (Clark Laboratories, Worcester, MA) as TIFF images. Individual waveband images for each frame were used to develop 8-bit composite CIR images which were then subjected to an unsupervised image classification (Isocluster) designed to identify "natural spectral classes" in the imagery (Campbell 2007). The various information categories of the original image classification (n = 23) were reclassified into the following information classes: 1) water, 2) sand, 3) mud, 4) black mangrove, and 5) live vegetation other than black mangrove.

Accuracy assessments of image classifications were based on conventional error or confusion matrices (Congalton and Green 1999). Summaries were compiled for *overall accuracy* (i.e., percentage of total pixels that were classified correctly), *producer's accuracy* (percentage of pixels within a given column that were classified correctly), and user's accuracy (percentage of features of a given row that were classified correctly). The kappa statistic was used to evaluate the accuracy of the classification in relation to what would have presumably resulted from use of a random classifier (Congalton and Green 1999; Campbell 2007). Ground truth data for accuracy assessments included annotations made on photographic prints of each island during ground visits, examination of aerial CIR film and digital RGB images of each island taken at ground level.

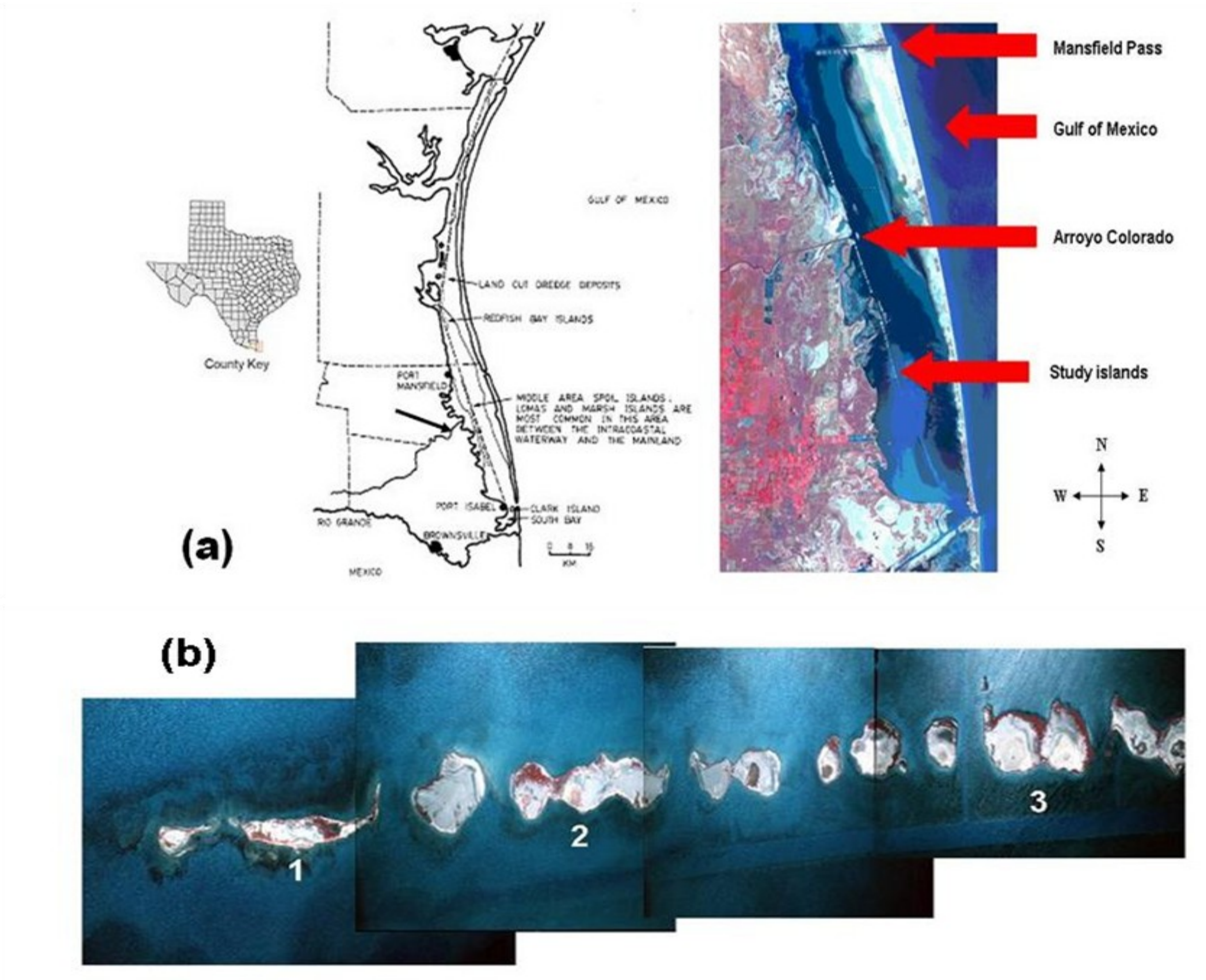

Fig. 4. The dredged-material or "spoil" islands of the Lower Laguna Madre consist of island chains oriented in an E-W direction near the Mansfield Pass in Willacy County, and 70+ islands oriented in a NE-SW direction along the Gulf IntraCoastal Waterway in Cameron and Willacy Counties (a). The present study was conducted on several islands located approximately 8 km south of the Arroyo Colorado (b).

Ground Surveys. Ground surveys were conducted on two representative islands to estimate densities and size distribution of mangrove plants located along shorelines within four directional quadrats – NE, NW, SE and SW – on each island (Fig. 5). Total numbers of black mangrove plants, recorded separately as large (height ≥ 1 m) and small (height <1m) plants, were enumerated within an area extending ± 1.0 m to either side of the shorelines of each quadrat. Transect data for each quadrat were converted to mangrove densities by dividing total numbers of plants per transect by the length (in m) for that particular transect (estimated by pacing). Mean densities of black mangrove plants and ratios of large to small plants along shorelines within quadrats were compared using one-way analysis of variance (ANOVA) and the Tukey HSD for ad hoc comparison of means.

RESULTS AND DISCUSSION

Aerial Photography. Visual interpretation of aerial CIR film acquired during the June, 2005 survey suggested two important trends relating to the distribution of black mangrove within the Lower Laguna Madre. First, the distribution and abundance of black mangrove appeared to be greatest on islands located south of the Arroyo Colorado, but relatively rare or absent on most of the islands located north of the Arroyo. Second, black mangrove appeared to be concentrated along western shorelines and interior

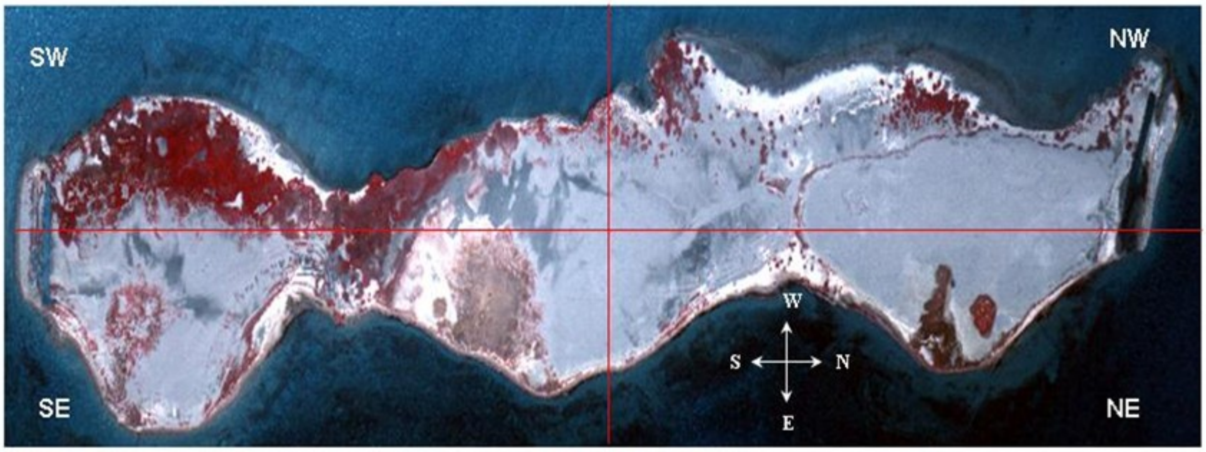

Fig. 5. Selected islands were partitioned into four sampling quadrants (NE, NW, SE and SW) using aerial color-infrared photographs, and densities of black mangrove along shorelines of each quadrat were estimated by ground sampling procedures. A dark red signature of black mangrove is evident along shorelines of the SW and NW quadrats.

areas of individual islands, and relatively rare or absent along eastern shorelines (Fig. 5).

Spectral Reflectance Curves. Spectral reflectance curves for black mangrove were substantially different in one or more waveband regions from those of typical halophyte species and from sand and cyanobacterial mats which are typical features in the spoil islands (Fig. 6). Percent reflectance of black mangrove foliage was significantly lower than all other features analyzed in the blue (450 nm) and red (680 nm) regions, was similar to most of the halophytes except vidrillos (*Batis maritima)* in the green (550 nm) region, and significantly higher than all other features in the NIR (850 nm) region (Fig. 7). These results are consistent with previous studies conducted within tidal flat areas of South Padre Island (e.g., Everitt et al. 2007) and suggest that black mangrove is distinguishable from other halophytes occurring on the spoil islands using aerial CIR film.

Image Classifications and Accuracy Assessment. Thematic maps developed from unsupervised image classifications of digitized CIR imagery are shown in Fig. 8. In each of these classifications, a concentration of black mangrove is evident along the western shorelines and areas with minimal elevation within the interior of islands. Accuracy assessments for this classification indicated an overall accuracy of 90.2% with *producer's* accuracy and *user's* accuracy for black mangrove of 91% and 86%, respectively (Table 1). The *kappa* statistic (K=0.87) indicated the classification was approximately 87% better than what would have been obtained using a random classifier (Congalton and Green 1999).

Ground Surveys. The sharp contrast between densities of black mangrove along eastern and western shorelines was evident in digital RGB images taken at ground level on Island 2 (Fig. 9; see also Fig. 4b) and in actual counts of large and small mangrove plants occurring along shoreline transects within each of four directional quadrats on two representative islands (Table 2). Although no significant differences in mangrove densities were evident in comparisons of northern and southern shorelines (Fig. 10a), plant densities along western shorelines were substantially higher than those along eastern shorelines (Fig.10b). However, ratios of small (<1.0-m) to large (>1.0-m) plants did not differ significantly in either N - S or E - W comparisons (Fig. 11). These results suggest that black mangrove 1) is clearly capable of growth and reproduction along eastern shorelines of spoil islands and 2) once established, dense stands may develop in this apparently-harsh physical environment (Fig. 12).

Conclusions. The contrast between relatively high densities of black mangrove along western shorelines and its relative rarity or absence along eastern shorelines of islands located south of the Arroyo Colorado is probably an effect of wave action generated by prevailing southeasterly winds during most of the year. If this hypothesis is correct, planting strategies based on seedling transplants and/or one or more methods designed to prevent dispersal of detached mangrove progagules prior to rooting will be essential to establish viable mangrove stands along eastern shorelines and other areas subject to turbulent

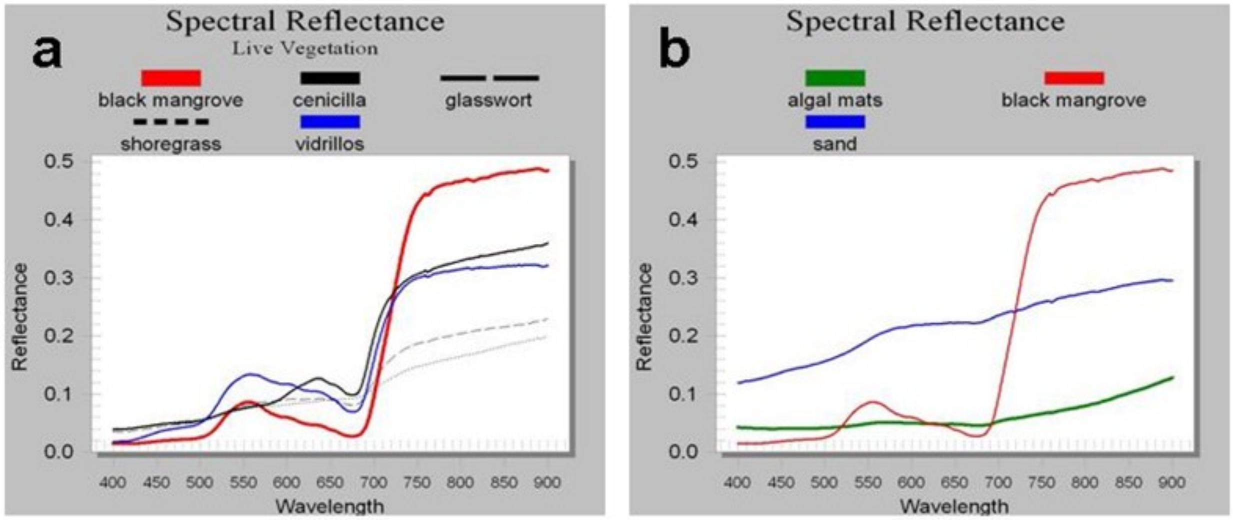

Fig. 6. Spectral reflectance curves of black mangrove plants in relation to other common halophytes occurring on spoil islands (a) and to sand and algal (cyanobacterial) mats (b).

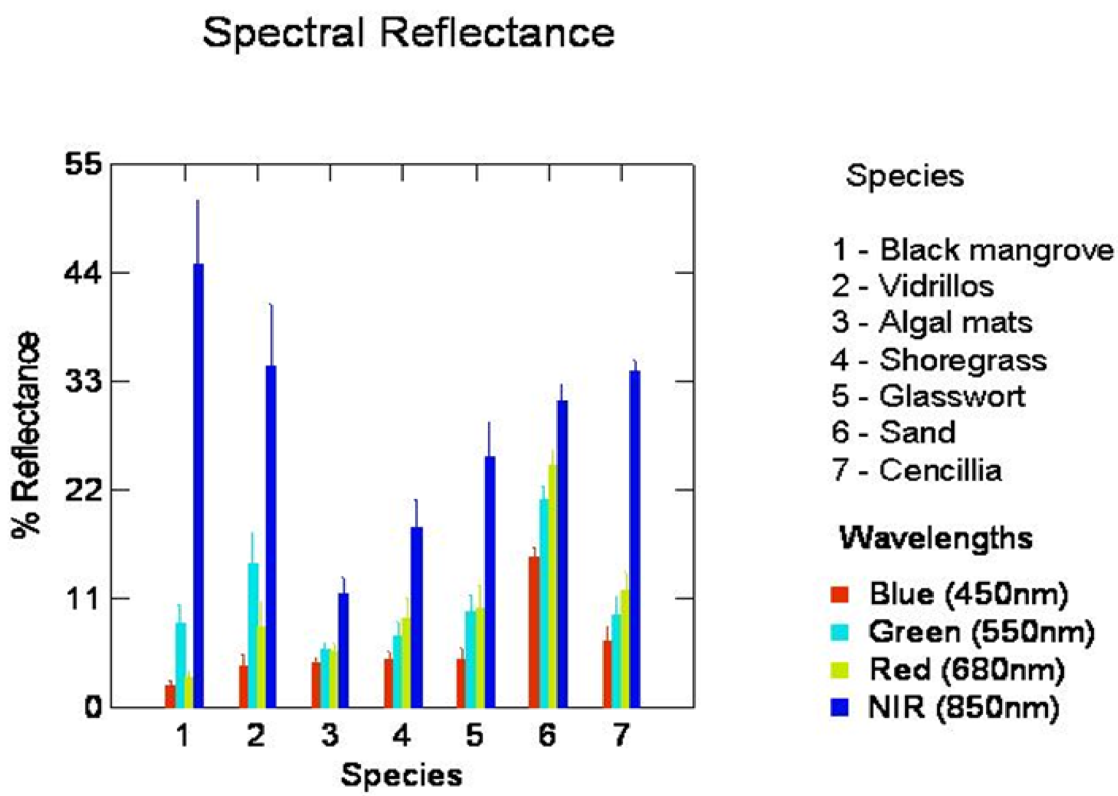

Fig. 7. Spectral reflectance of black mangrove in relation to common halophyte species and other features on spoil islands at the 450 nm (blue), 550 nm (green) , 680 nm (red) and 850 nm (near infrared) wavelengths.

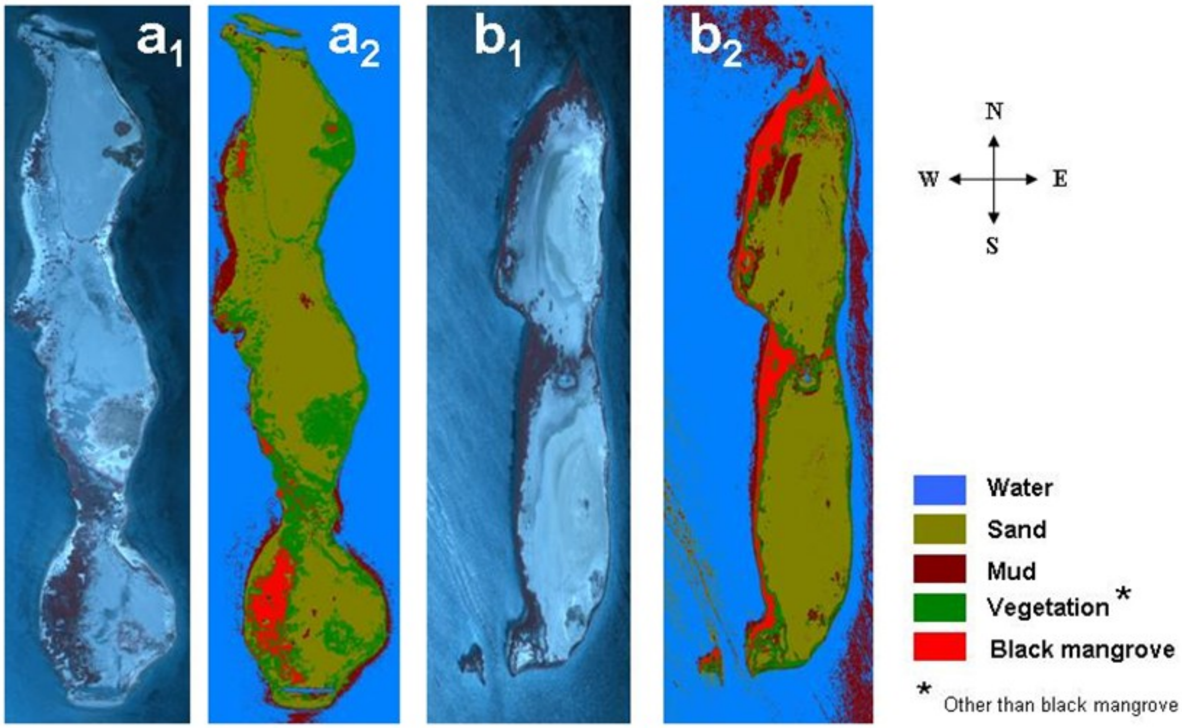

Fig. 8. Aerial CIR photographs (a_1 and b_1) and unsupervised image classifications (a_2 and b_2) for two typical islands, showing the distribution of black mangrove in relation to other vegetation and landscape features.

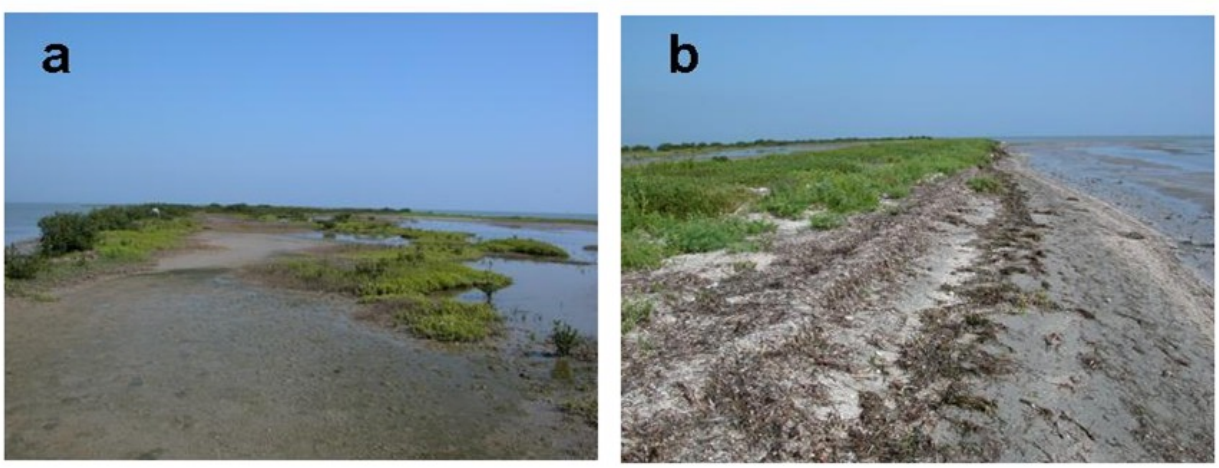

Fig. 9. On many islands with established mangrove stands, plant densities tend to be relatively abundant along western shorelines (a) and rare or absent along eastern shorelines (b).

Table 1. Error matrix for an image classification of two spoil islands in the Lower Laguna Madre, 2005.

Category[a]	Water	Sand	Mud	Other vegetation	Black mangrove	Row total
Water	49	0	2	0	0	51
Sand	0	27	2	1	0	30
Mud	1	0	19	0	0	20
Other vegetation	0	0	0	20	4	24
Black Mangrove	0	0	7	0	42	49
Column total	50	27	30	21	46	174

[a] Columns represent total numbers classified in each category.
Rows represent total numbers of each category which were classified correctly.

Overall accuracy = 157/174 = 90.2% *Kappa* = 0.87

Producer's Accuracy (omission error)

Water = 49/51 = 96%	4% commission error
Sand = 27/30 = 90%	10% commission error
Mud = 19/20 = 95%	5% commission error
Other Vegetation = 20/24 = 83%	17% commission error

User's Accuracy (commission error)

Water = 49/50 = 98%	2% omission error
Sand = 27/27 = 100%	0% omission error
Mud = 19/30 = 63%	37% omission error
Other Vegetation = 20/21 = 95%	5% omission error

Table 2. Census of black mangrove plants along shorelines of directional quadrats on two representative spoil islands.

Island	Quadrant	Plant size: Large (>1m)	Plant size: Small (<1m)	No. plants in transect	Length of transect (m)	Density (plants/m^2
1	NE	28	81	109	724	0.151
1	SE	28	90	118	1,170	0.024
1	NW	339	513	852	1,288	0.661
1	SW	390	707	1,097	926	1.185
2	NE	38	34	72	1,560	0.046
2	SE	12	5	17	2,324	0.007
2	NW	288	360	648	2,598	0.249
2	SW	150	291	441	1,662	0.265

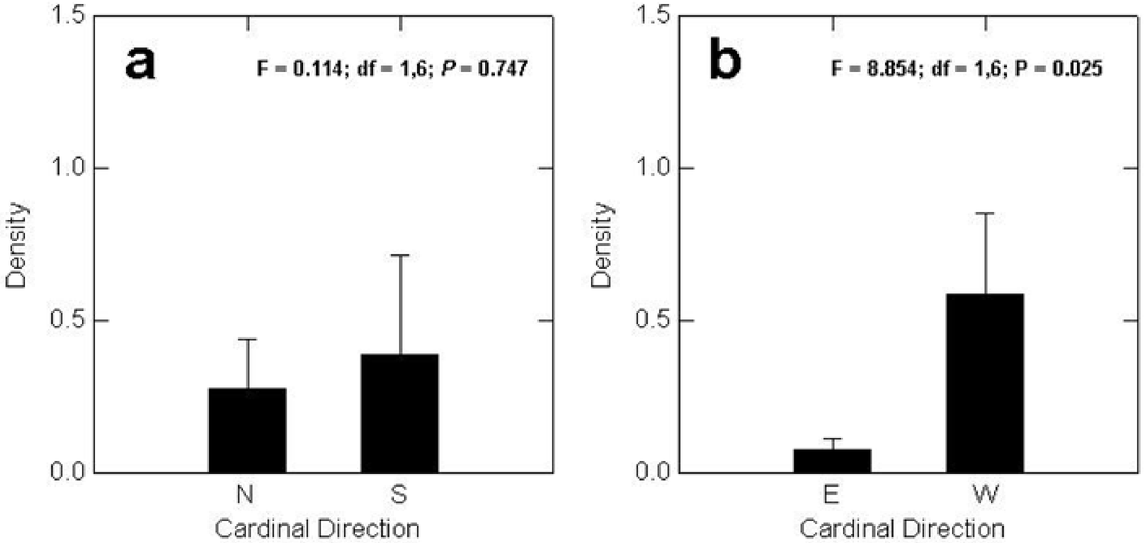

Fig. 10. Comparison of black mangrove densities along a N - S gradient (a) and E – W gradient (b) on selected spoil islands.

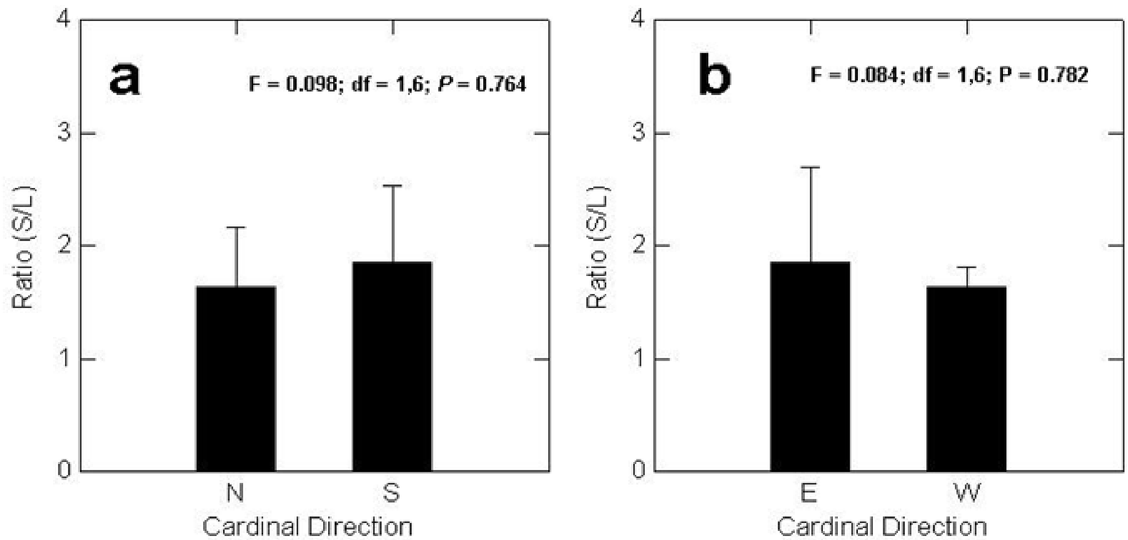

Fig. 11. Comparison of black mangrove reproduction (ratios of small to large plants) along a N - S gradient (a) and E – W gradient (b) on selected spoil islands.

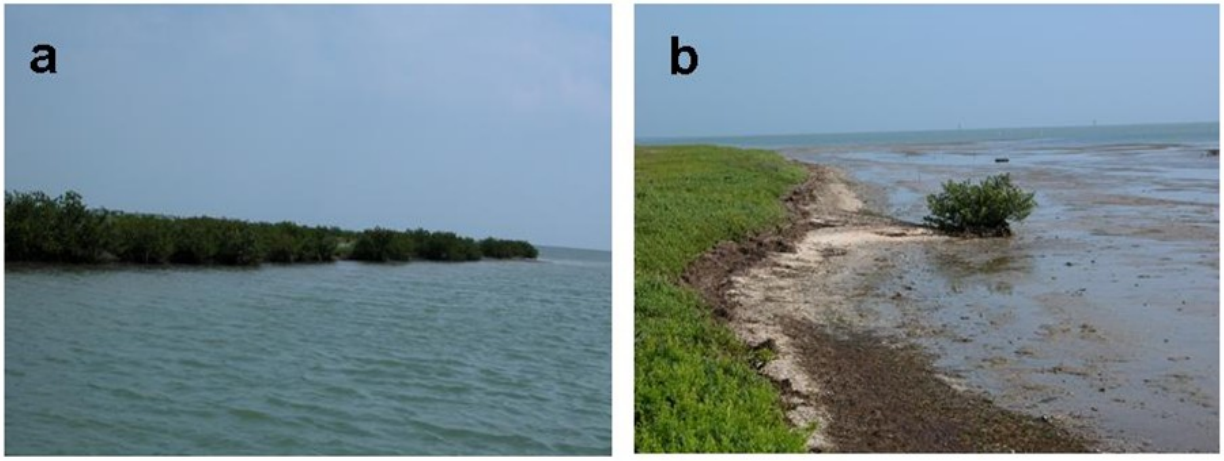

Fig. 12. The occurrence of significant stands of black mangrove along eastern shorelines of a minority of islands (a) demonstrates the ability of the plant to thrive and reproduce along eastern shorelines of islands. The relative rarity of black mangrove along eastern shorelines of most islands may relate to difficulty in establishment, possibly an effect of wave action caused by prevailing southeasterly winds during most of the year (b).

wave action. Data and imagery discussed in this paper clearly indicate that once black mangrove plants become established at a given shoreline location (regardless of aspect), they tend to grow and reproduce easily, and the pneumatophores they produce help ameliorate the effects of wave action and thus contribute to stability of the shoreline environment. Use of black mangrove and other native halophytes for the purpose of shoreline stabilization will be critical in the prevention and mitigation of the serious wave-caused erosion which currently threatens most of the spoil islands of the Lower Laguna Madre.

ACKNOWLEDGMENTS

The authors express sincere appreciation to members of the Lower Rio Grande Valley Power Squadrons for considerable assistance and support during the course of this study.

LITERATURE CITED

Amusan, A. A. and I. F. Adeniyi. 2005. Characterization and heavy metal retention capacity of soils in mangrove forests of the Niger Delta, Nigeria. *Communications in Soil Science and Plant Analysis*. 36:2033-2045.

Barko, J. W., R. M. Smart, C. P. Lee, M. C. Landin, T. C. Sturgis, and R. N. Gordon. 1977. Establishment and growth of selected freshwater and coastal marsh plants in relation to characteristics of dredged sediments. Technical Report D-77-2. U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. 41 pp.

Bhat, N. R. and M. K. Suleiman. 2004. Classification of soils supporting mangrove plantation in Kuwait. Archives of Agronomy and Soil Science. 50: 535-551.

Britton, J. C. and B. Morton. 1989. Shore Ecology of the Gulf of Mexico. University of Texas Press, Austin. 387 pp.

Campbell, J. B. 2007. Introduction to Remote Sensing (4th ed). Guilford, NY.

Chaney, A. H., B. R. Chapman, J. P. Cargas, D. A. Nelson, R. R. Schmidt, and L. C. Thebeau. 1978. The use of dredged material islands by colonial seabirds and wading birds in Texas. Waterways Experiment Station Report D-78-8. U. S. Army Corps of Engineers, Vicksburg, MS. 170 pp.

Chen, R. and R. R. Twilley. 1998. A Gap Dynamic Model of mangrove forest development along gradients of soil salinity and nutrient resources. Journal of Ecology. 86:37-51.

Congalton, R. G. and K. Green. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. Lewis Publishers, Boca Raton, FL.

Everitt, J. H., and F. W. Judd. 1989. Using Remote Sensing Techniques to Distinguish and Monitor Black Mangrove (*Avicennia germinans*). Journal of Coastal Research. 5(4):737-745.

Everitt, J. H., D. E. Escobar, and F. W. Judd. 1991. Evaluation of Airborne Video Imagery for Distinguishing Black Mangrove (*Avicennia germinans*) on the Lower Texas Gulf Coast. J. Coastal Research. 7: 1169-1173.

Everitt, J. H., F. W. Judd, D. E. Escobar, and M. R. Davis. 1996. Integration of remote sensing and spatial information technologies for mapping black mangrove on the Texas Gulf Coast. J. Coastal Research. 12(1): 64-69.

Everitt, J. H., C. Yang, K. R. Summy, F. W. Judd, and M. R. Davis. 2007. Evaluation of color-infrared photography and digital imagery to map black mangrove on the Texas Gulf Coast. J. Coastal Research 23(1):230-235.

Everitt, J. H., C. Yang, S. Sriharan, and F. W. Judd. 2008. Using high-resolution satellite to map black mangrove on the Texas Gulf Coast. J. Coastal Research 24(6):1582-1586.

Heep, M. R. 1982. The vegetation on the dredged material and natural islands in the Lower Laguna Madre, Texas. Unpublished report, Pan American University, Edinburg, TX. 140 pp.

Judd, F. W., R. I. Lonard, and S. L. Sides. 1977. The vegetation of South Padre Island, Texas in relation to topography. Southwestern Naturalist 22(1):31-48.

Judd, F. W., and S. L. Sides. 1983. The impact of Hurricane Allen on the near-shore vegetation of South Padre Island. Southwestern Naturalist 28:365-369.

Lonard, R. I., and F. W. Judd. 1980. Phytogeography of South Padre Island, Texas. The Southwestern Naturalist 25:313-322.

Lonard, R. I., and F. W. Judd. 1981. The terrestrial flora of South Padre Island, Texas. Austin (TX): University of Texas at Austin. Miscellaneous papers, Texas Memorial Museum. 74 pp.

Lonard, R. I. and F. W. Judd. 1985. Effects of a Severe Freeze on Native Woody Plants in the Lower Rio Grande Valley, Texas. The Southwestern Naturalist. 30(3): 397-403.

Lonard, R. I., and F. W. Judd. 1993. Recovery of vegetation of barrier island washover zones, pp. 2324-2331 In Proc. Eighth Symp. On Coastal and Ocean Management, "Coastal Zone '93". American Soc. Civil Engineers, New Orleans, LA, 3512 pp.

Lonard, R. I., and F. W. Judd. 1997. The biological flora of coastal dunes and wetlands. *Sesuvium portulacastrum*. J. Coastal Research 13:96-104.

Lonard, R. I., F. W. Judd, and S. L. Sides. 1978. Annotated Checklist of the Flowering Plants of South Padre Island, Texas. The Southwestern Naturalist. 23:497-510.

Lonard, R. I., F. W. Judd, J. H. Everitt, D. E. Escobar, M. A. Alaniz, I. Cavazos III, and M. R. Davis. 1999. Vegetative change on South Padre Island, Texas, over twenty years and evaluation of multispectral videography in determining vegetative cover and species identity. Southwestern Naturalist 44:261-271.

Mazariegos, R. A., K. R. Summy, F. W. Judd, R. I. Lonard, M. R. Heep, J. H. Everitt, and M. R. Davis. 2005. Evaluation of CIR photography in the development of vegetation maps for spoil islands of the Lower Laguna Madre, Texas. 20th Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imagery for Resource Assessment 05', American Society of Photogrammetry and Remote Sensing. Weslaco, Texas, October 4-6, 2005 (CDROM).

Richardson, A. 2002. Wildflowers and Other Plants of Texas Beaches and Islands. University of Texas Press, Austin, TX.

Scholander, P. F., L. Van Dam, and S. I. Scholander. 1955. Gas exchange in the roots of mangroves. Plant Physiol. 37:722-729.

Summy, K. R., F. W. Judd, R. I. Lonard, R. A. Mazariegos, J. H. Everitt, and M. R. Davis. 2005. Effectiveness of aerial color infrared photography for mapping vegetative cover within dune areas of South Padre Island, Texas. Proc. 21st Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imagery for Resource Assessment 05', American Society of Photogrammetry and Remote Sensing. Terra Haute, Indiana, May 15-17, 2007 (CDROM).

Tunnell, J. W. 2002. Geography, climate and hydrography. Ch. 2, pp. 7-27 *In* The Laguna Madre of Texas and Tamaulipas (J. W. Tunnell and F. W. Judd, eds). Texas A&M University Press, College Station. 346 pp.

Walsh, G. E. 1974. Mangroves, a review. Pp. 51-174 In Ecology of Halophytes (R. J. Reimhold and W. H. Queens, eds). Academic Press, New York.

Yeager, V. A., A. de la Fuente, F. W. Judd, R. A. Mazariegos, T. Whelan III, M. R. Heep, J.Everitt, and K. R. Summy. 2007. Use of color-infrared photography for mapping the distribution of black mangrove on spoil islands of the Lower Laguna Madre of Texas. Proc. 21st Biennial Workshop on Aerial Photography, Videography, and High Resolution Digital Imagery for Resource Assessment 05', American Society of Photogrammetry and Remote Sensing. Terra Haute, Indiana, May 15-17, 2007 (CDROM).