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Scientific Investigations Map 3336

Delineation of Marsh Types From Corpus Christi Bay, Texas, to Perdido Bay, Alabama, in 2010

By

Nicholas M. Enwright,[1] Stephen B. Hartley,[1] Brady R. Couvillion,[1] Michael G. Brasher,[2,3] Jenneke M. Visser,[4] Michael K. Mitchell,[2] Bart M. Ballard,[5] Mark W. Parr,[3] and Barry C. Wilson[3]

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[1]U.S. Geological Survey.
[2]Ducks Unlimited, Inc.
[3]Gulf Coast Joint Venture.
[4]University of Louisiana at Lafayette.
[5]Texas A&M University-Kingsville.

Abstract

Coastal zone managers and researchers often require detailed information regarding emergent marsh vegetation types (that is, fresh, intermediate, brackish, and saline) for modeling habitat capacities and needs of marsh dependent taxa (such as waterfowl and alligator). Detailed information on the extent and distribution of emergent marsh vegetation types throughout the northern Gulf of Mexico coast has been historically unavailable. In response, the U.S. Geological Survey, in collaboration with the Gulf Coast Joint Venture, the University of Louisiana at Lafayette, Ducks Unlimited, Inc., and the Texas A&M University-Kingsville, produced a classification of emergent marsh vegetation types from Corpus Christi Bay, Texas, to Perdido Bay, Alabama.

This study incorporates about 9,800 ground reference locations collected via helicopter surveys in coastal wetland areas. Decision-tree analyses were used to classify emergent marsh vegetation types by using ground reference data from helicopter vegetation surveys and independent variables such as multitemporal satellite-based multispectral imagery from 2009 to 2011, bare-earth digital elevation models based on airborne light detection and ranging (lidar), alternative contemporary land cover classifications, and other spatially explicit variables. Image objects were created from 2010 National Agriculture Imagery Program color-infrared aerial photography. The final classification is a 10-meter raster dataset that was produced by using a majority filter to classify image objects according to the marsh vegetation type covering the majority of each image object. The classification is dated 2010 because the year is both the midpoint of the classified multitemporal satellite-based imagery (2009–11) and the date of the high-resolution airborne imagery that was used to develop image objects. The seamless classification produced through this work can be used to help develop and refine conservation efforts for priority natural resources.

Introduction

Detailed information on the extent and distribution of emergent marsh vegetation types throughout the northern Gulf of Mexico coast has been historically unavailable or, otherwise, available for only a portion of the geography (for example, coastal Louisiana; Sasser and others, 2008, 2014). Most existing large-scale land cover classifications across the northern Gulf of Mexico coast have identified emergent marsh as either palustrine (less than [<] 0.5 parts per thousand [ppt] salinity) or estuarine (≥0.5 ppt salinity) (the National Oceanic and Atmospheric Administration [NOAA] Coastal Change Analysis Program [C-CAP] and the U.S. Fish and Wildlife Service National Wetlands Inventory [NWI]) or used the combined categories of fresh-intermediate and brackish-saline to identify marsh types (Texas Ecological Classification Systems land cover maps developed by the Texas Parks and Wildlife Department [TPWD] and the Missouri Resource Assessment Partnership [MoRAP]). The limited extent and thematic coarseness of existing classifications have proven insufficient for large-scale, targeted conservation planning efforts conducted by natural resource managers and conservationists within the northern Gulf of Mexico coast area. To help meet these needs, the U.S. Geological Survey (USGS), in collaboration with the Gulf Coast Joint Venture, the University of Louisiana at Lafayette, Ducks Unlimited, Inc., and Texas A&M University-Kingsville, produced a seamless and standardized classification of marsh vegetation types indicative of salinity zones (fresh, intermediate, brackish, and saline; Nyman and Chabreck, 2012; Visser and others, 2012) for the northern Gulf of Mexico coast from Corpus Christi Bay, Texas, to Perdido Bay, Alabama, for 2010.

Methodology

Land cover was delineated within the study area into six classes: (1) fresh marsh, (2) intermediate marsh, (3) brackish marsh, (4) saline marsh, (5) water, and (6) “other” (nonmarsh). The study area covers approximately 91,352 square kilometers (km^2). The inland extent was defined by the 10-meter (m) elevation contour line, which was created from the USGS National Elevation Dataset (NED) 1/3 arc-second (10-m) elevation data, referenced to the North American Vertical Datum of 1988 (NAVD 88), that were accessed in July 2012. The classification was developed in two phases (fig. 1).

Growing season salinity and vegetation community relations throughout this area were assumed to be similar to those found in Louisiana. Fresh marsh salinity ranged from 0.1 to 3.4 ppt with an average of 1.0 ppt and was commonly dominated by *Panicum hemitomon* (maidencane), *Sagittaria lancifolia* (bulltongue), *Eleocharis* spp. (spikerushes), and *Alternanthera philoxeroides* (alligator weed) (O’Neil, 1949; Chabreck, 1972; Visser and others, 2012). Intermediate marsh salinity ranged from 0.5 to 8.3 ppt with an average of 3.3 ppt and was commonly dominated by *Spartina spartinae* (gulf cordgrass), *Spartina patens* (marshhay cordgrass), bulltongue, *Phragmites australis* (common reed), and *Bacopa monnieri* (coastal waterhyssop) (Chabreck, 1972; Nyman and Chabreck, 2012; Visser and others, 2012). Brackish marsh salinity ranged from 1.0 to 18.4 ppt with an average of 8.2 ppt and was commonly dominated by marshhay cordgrass and *Distichlis spicata* (seashore saltgrass) (Chabreck, 1972; Nyman and Chabreck, 2012). Saline marsh salinity ranged from 8.1 to 29.4 ppt with an average of 18.0 ppt and was commonly dominated by *Spartina alterniflora* (smooth cordgrass), seashore saltgrass, *Juncus roemerianus* (needlegrass rush), and *Batis maritima* (turtleweed) (Chabreck, 1972; Nyman and Chabreck, 2012; Battaglia and others, 2012).

Marsh vegetation types were classified by using decision-tree (DT) classification analyses and rulesets produced by using Rulequest See5 in combination with ERDAS IMAGINE 2010, National Land Cover Database (NLCD) Mapping Tool version 2.087, Esri ArcMap 10.1, and Trimble eCognition software packages. See5 has been used to produce broad land cover classifications, including NLCD (Homer and others, 2007) and C-CAP, as well as used for more targeted classifications, such as the mapping of shallow-water benthic habitats in south Texas (Finkbeiner and others, 2009). DT classification analyses use dependent variables (that is, ground reference data) and a suite of predictor variables (that is, independent spatial variables) to develop multivariate classification trees for classifying a target area. Thirteen Landsat Thematic Mapper (TM) scenes cover the study area (fig. 1). DT classification analyses were developed for each Landsat TM scene.

Building upon earlier efforts of Mitchell and others (2014), phase 1 of this study involved classification of marsh vegetation types in coastal Texas by using reference data from approximately 1,000 sample points collected via helicopter surveys during October 2011 and 2012, ground-based observations compiled by TPWD in 2009, and about 2,000 supplemental sample points derived from ancillary datasets (that is, C-CAP 2006 and NWI). Of the 2,000 supplemental sample points, about 250 points were for fresh marsh, 700 points were for water, and 1,000 points were for the “other” (nonmarsh) areas. All supplemental sample points were photoverified and classified on the basis of color-infrared aerial photography collected during 2010 (Enwright and others, 2014). About two-thirds of these data were used for training, and about one-third of the data were used to assess accuracy.

Phase 2 of the study involved classification of marsh types in coastal Louisiana, Mississippi, and Alabama. Reference data for phase 2 were acquired from helicopter-based surveys of Louisiana coastal marshes during summer and fall 2007 and June 2013, which included observations at about 8,800 sample points, as well as from maps produced from these data (Sasser and others, 2008, 2014). The 2007 generalized marsh-type vegetation map (Sasser and others, 2008) was overlaid with the 2013 generalized marsh-type vegetation map (Sasser and others, 2014). Areas that did not change marsh types from 2007 to 2013 were identified. Within these areas, approximately 281,000 sample points, stratified by marsh vegetation type coverage, were randomly selected and used as training data. About 2,500 sample points from the 2007 and 2013 surveys where marsh vegetation had not changed between survey periods, in addition to roughly 3,000 supplemental sample points from C-CAP 2010 (that is, for water and “other” classes), were used to assess accuracy of the classification.

Reference data were not collected directly from marshes of Mississippi and Alabama. We used available reference data from Louisiana to develop a DT that was used for all scenes from Landsat Path 21, which covered most of the area classified in Mississippi and Alabama (fig. 1; Landsat Path 21 Row 38, Path 21 Row 39, and Path 21 Row 40). We used the classification results from Landsat TM scene overlap between Landsat Path 21 and Path 20 Row 39 to develop a DT for the small portion of southeastern Alabama (fig. 1; Landsat Path 20 Row 39). Helicopter-based data collections for both phases followed the protocols of Visser and others (1998, 2000). Two-way indicator species analysis (TWINSPAN) was used to separate helicopter- and ground-based observations into four emergent marsh vegetation classes (fresh, intermediate, brackish, and saline). Sample points that did not intersect marsh were recorded as either the water class or the “other” class on the basis of field observations.

Independent variables included multitemporal satellite-based imagery from 2009 to 2011, a bare-earth digital elevation model (DEM; NED 1/9-arc-second [3-m] elevation data) based on airborne light detection and ranging (lidar), and other contemporary land cover classifications (table 1). All available cloud-free Landsat TM (table 2), Satellite Pour l’Observation de la Terre (SPOT) 4, and SPOT 5 (SPOT imagery was only used for phase 1) satellite imagery from 2009 to 2011 was included to capture phenological conditions, such as green-up and senescence phases, among coastal marsh plant species. SPOT 4 imagery and (or) SPOT 5 imagery were used only when cloud-free coverage acquired within a 30-day period was available for the entirety of a Landsat TM scene. In such cases, the study area coverage was compiled with individual SPOT 4 and (or) SPOT 5 scenes that were mosaicked to cover the Landsat TM scene area of interest. Imagery was downloaded from the USGS (http://glovis.usgs.gov/) with the Standard Terrain Correction (Level 1T); Level 1T correction provides systematic radiometric and geometric accuracy by incorporating ground control points while employing a DEM for topographic accuracy. No further geometric correction was applied, except for subpixel shifts to ensure pixel alignment among all Landsat TM scenes. All satellite multispectral imagery was processed in terms of top of atmosphere (TOA) reflectance units. Additionally, the Modified Normalized Difference Water Index (MNDWI; Xu, 2006) and the Normalized Difference Vegetation Index (NDVI; Rouse and others, 1974) were calculated and used as independent variables in the DT analyses. For all Landsat TM imagery, a tasseled cap transformation (Crist and Cicone, 1984) of Landsat TM bands 1–5 and 7 was applied to include additional information on brightness, greenness, and wetness as independent variables. In comparison to the Louisiana coastal zone, marshes in the Texas coastal zone occur within a much narrower transitional gradient between uplands and the open waters of the Gulf of Mexico. Phase 1 also included substantially less ground reference data, and thus additional independent variables were used to delineate marsh type for phase 1 (table 1).

Schmidt and others (2004) found elevation to be the greatest determining factor for mapping coastal vegetation. Inundation frequency, in part a function of elevation, was found to influence the occurrence of marsh communities in coastal Louisiana (Couvillion and Beck, 2013); therefore, to best leverage high-resolution (3-m) airborne lidar bare-earth DEMs when available in the study area, all datasets used in the DT analyses were resampled to 10 m from their native resolutions. Trimble eCognition version 9.0 was used to generate image objects from 2010 National Agriculture Imagery Program (NAIP) color-infrared aerial photography. The final 10-m classification was produced by using a script in ArcMap to determine the majority DT-based class for each image object. The classification is dated 2010 because the year is both the midpoint of the classified multitemporal satellite-based imagery (2009–11) and the date of the high-resolution airborne imagery that was used to develop image objects. We combined accuracy assessment points for each phase and determined the majority class mapped within a 30-m buffer to assess the accuracy of the refined seamless classification. This map includes minor revisions to the Texas classification (Enwright and others, 2014) in regards to water levels in marsh along the coast. Detailed information regarding the approach and methods for phase 1 can be found in Enwright and others (2014).

Table 1. Sources and uses of independent variables for classification of marsh types, northern Gulf of Mexico coast, 2010.

	Independent variable	Source of data	Use
Spectral variables	Multitemporal, multispectral-satellite at-satellite reflectance	Landsat Thematic Mapper (TM); SPOT 4; SPOT 5	Discriminate spectral differences found in training data by using decision-tree (DT) analyses.
	Modified Normalized Difference Water Index (MNDWI)	Landsat TM; SPOT 4; SPOT 5 (Xu, 2006)	Map land and (or) water by using thresholding; discriminate spectral differences found in training data by using DT analyses.
	Normalized Difference Vegetation Index (NDVI)	Landsat TM; SPOT 4; SPOT 5 (Rouse and others, 1974)	Discriminate spectral differences and phenology found in training data by using DT analyses.
	Tasseled cap transformation of Landsat TM imagery	Landsat TM (Crist and Cicone, 1984)	Brightness, greenness, and wetness bands were used to help discriminate spectral differences and phenology identified in training data by using DT analyses.
Topographic variables	Lidar-based National Elevation Dataset (NED) 1/9-arc-second data (3-m) digital elevation model (DEM)[1]	U.S. Geological Survey (USGS)	Identify spatial patterns in topography of marsh vegetation types identified in training data by using DT analyses.
	Lidar-based NED 1/9-arc-second data (3-m) DEM transformed from North American Vertical Datum of 1988 (NAVD 88) to local mean sea level (LMSL)[2]	USGS NED and National Oceanic and Atmospheric Administration (NOAA) VDatum v3.1	Identify spatial patterns in topography of marsh vegetation types identified in training data by using DT analyses.
	Euclidean distance from the intertidal zone (mean high higher water [MHHW] zone)[2]	Derived from the MHHW zone obtained from NOAA (Marcy and others, 2011)	Used as a proxy for the likelihood of an area being exposed to elevated salinity.
	Steady state compound topographic index (CTI)[2]	Derived for this project by using USGS NED and CTI algorithm (Moore and others, 1991)	Delineate between uplands and wetlands.
Contemporary land cover	National Wetlands Inventory (NWI) simplified into the nine classes	U.S. Fish and Wildlife Service	Leverage existing classifications.
	NOAA Coastal Change Analysis Program (C-CAP) land cover 2006 (2010 used in phase 2)	NOAA	Leverage existing classifications.
	Texas Ecological Classification Systems (TECS) crosswalked into the C-CAP classification system[2]	Texas Parks and Wildlife Department and Missouri Resource Assessment Partnership	Leverage existing classifications.
	Sum of areas mapped as wetland in NWI, C-CAP, and TECS[2]	Derived for this project	Delineate between uplands and wetlands.

[1]Independent variable was used only in phase 2.

[2]Independent variable was used only in phase 1.

Table 2. Satellite imagery acquisition dates by Landsat Thematic Mapper (TM) scene, northern Gulf of Mexico coast, 2009–11.

[—, no data]

	Phase 1				
Year	Path 26 Row 41	Path 26 Row 40	Path 25 Row 40	Path 25 Row 39	Path 24 Row 39
2009	11/01/2009	11/01/2009	05/18/2009 11/10/2009	02/11/2009 05/18/2009 11/26/2009	01/19/2009 02/04/2009 02/20/2009 10/18/2009 11/03/2009 12/05/2009
2010	03/25/2010 05/28/2010 10/2010[1] 10/03/2010 11/04/2010	03/28/2010 05/28/2010 10/03/2010 12/06/2010	03/18/2010 05/05/2010	03/18/2010 05/05/2010 08/25/2010	01/22/2010 04/28/2010 08/02/2010 10/05/2010 11/06/2010
2011	10/2011[1]	10/2011[1]	08/28/2011 10/31/2011	10/31/2011	06/02/2011 09/06/2011

[1]Mosaic of SPOT 4/5 imagery used for Landsat TM scene.

	Phase 2								
Year	Path 24 Row 39	Path 23 Row 39	Path 23 Row 40	Path 22 Row 39	Path 22 Row 40	Path 21 Row 38	Path 21 Row 39	Path 21 Row 40	Path 20 Row 39
2009	12/05/2009	11/12/2009	11/12/2009	—	—	—	—	—	—
2010	01/22/2010 04/28/2010 08/02/2010 10/05/2010 11/06/2010	02/16/2010 10/14/2010 10/30/2010 12/01/2010	02/16/2010 10/14/2010 10/30/2010 12/01/2010	02/25/2010 10/07/2010 11/08/2010	02/25/2010 10/07/2010 11/08/2010	09/30/2010 10/16/2010 11/17/2010 12/19/2010	09/30/2010 10/16/2010 11/17/2010 12/19/2010	09/30/2010 10/16/2010 11/17/2010 12/19/2010	01/26/2010 03/31/2010 12/03/2010 12/21/2010
2011	—	—	—	02/12/2011	02/12/2011	—	—	—	—

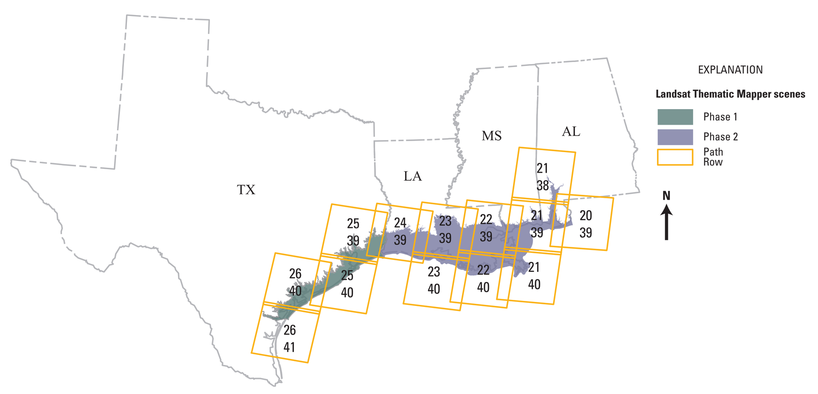

Figure 1. Phases and Landsat Thematic Mapper (TM) scenes for marsh-type classification along the northern Gulf of Mexico coast, 2010.

Results

Approximately 13,247 km^2 of marsh were classified in the four-marsh-type classification (table 3; fig. 2*A*). Overall accuracy corrected for bias (accuracy estimate incorporates true marginal proportions; Congalton and Green, 2009) was 90.0 percent (95 percent confidence interval [CI]: 88.0–92.0) with a kappa statistic of 0.81 (95 percent CI: 0.80–0.82). The classification performed best for saline marsh (user’s accuracy was 86.4 percent; producer’s accuracy corrected for bias was 67.2 percent) but showed a lesser ability to discriminate intermediate marsh (user’s accuracy was 69.9 percent; producer’s accuracy corrected for bias was 65.3 percent). Fresh marsh had the lowest producer’s accuracy (44.2 percent). For all marsh vegetation classes combined, mean user’s accuracy was 76.2 percent, and mean producer’s accuracy corrected for bias was 61.0 percent.

Because of confusion in intermediate and brackish marsh classes, particularly in Texas, an alternative classification containing only three marsh types was created for the Texas portion of the study (phase 1), in which intermediate and brackish marshes were combined into a single class (table 3; fig. 2*B*). Image objects were reattributed by using this alternative three-marsh-type classification. Overall accuracy corrected for bias was 90.1 percent (95 percent CI: 88.1–92.1) with a kappa statistic of 0.84 (95 percent CI: 0.81–0.87). The combined intermediate-brackish marsh class had a user’s accuracy of 80.0 percent and a producer’s accuracy corrected for bias of 74.8 percent. For all marsh vegetation classes in the three-marsh-type classification, mean user’s accuracy was 81.6 percent, and mean producer’s accuracy corrected for bias was 75.3 percent. Detailed information regarding phase 1 accuracy and results can be found in Enwright and others (2014).

Table 3. Error matrices for four-marsh-type and three-marsh-type classifications, northern Gulf of Mexico coast, 2010.

[FM, fresh marsh; IM, intermediate marsh; BM, brackish marsh; SM, saline marsh; W, water; O, other; ±, plus or minus; CI, confidence interval; I-BM, intermediate-brackish marsh]

Four-marsh-type classification

		Reference data								
		FM	IM	BM	SM	W	O	Row total	User's accuracy[1]	Square kilometers mapped
Map data	FM	**730**	59	4	2	84	76	955	76.4 ±3.0	3,990
	IM	29	**564**	71	13	49	81	807	69.9 ±3.3	3,719
	BM	5	68	**478**	31	51	29	662	72.2 ±3.2	2,983
	SM	1	4	24	**553**	41	17	640	86.4 ±2.5	2,555
	W	11	18	18	52	**2,286**	19	2,404	95.1 ±1.5	37,145
	O	64	11	5	3	4	**735**	822	89.4 ±2.2	40,960
	Column total	840	724	600	654	2,515	957	**6,290**		
Producer's accuracy[2]		44.2 ±6.6	65.3 ±6.2	67.1 ±2.3	67.2 ±1.4	97.5 ±1.0	97.0 ±0.9			

Overall accuracy[2]: 90 percent (95 percent CI: 88.0–92.0)

Kappa statistic: 0.81 (95 percent CI: 0.80–0.82)

Three-marsh-type classification

		Reference data							
		FM	I-BM	SM	W	O	Row total	User's accuracy[1]	Square kilometers mapped
Map data	FM	**46**	11	1	0	2	60	76.7 ±3.2	549
	I-BM	11	**116**	9	1	8	145	80.0 ±2.9	1,789
	SM	0	7	**66**	0	2	75	88.0 ±2.3	704
	W	1	5	4	**207**	2	219	94.5 ±1.6	7,161
	O	8	16	1	1	**230**	256	89.8 ±2.2	11,704
	Column total	66	155	81	209	244	**755**		
Producer's accuracy[2]		69.7 ±8.6	74.8 ±2.9	81.5 ±2.8	99.0 ±0.0	94.3 ±0.4			

Overall accuracy[2]: 90.1 percent (95 percent CI: 88.1–92.1)

Kappa statistic: 0.84 (95 percent CI: 0.81–0.87)

[1]±X.X represents confidence interval at 95 percent.

[2]Corrected for bias by using true map marginal proportions; ±X.X represents confidence interval at 95 percent.

Discussion

Throughout the study area, intermediate marsh was most readily confused with brackish marsh and fresh marsh. During the helicopter surveys conducted for this study, it was difficult to distinguish differences between the dominant plant species in these marsh types. Marshhay cordgrass in the brackish marsh and gulf cordgrass in the intermediate marsh looked very similar from a distance and could only be distinguished when hovering above the sample point. Moreover, classification of intermediate marsh is uncommon outside the northern Gulf of Mexico coast, likely because it is rare or because it is defined as “tidal freshwater marsh” in other regions (Nyman and Chabreck, 2012).

Obtaining cloud-free imagery along the northern Gulf of Mexico coast is often difficult, especially for multiple seasons of any given calendar year. Future efforts could explore the possibility of using a more targeted image date selection by analyzing phenological differences and spectral separability (Jeffries-Matusita) distance of marsh vegetation classes by using 30-m TOA multispectral reflectance and NDVI from Web-enabled Landsat data (WELD; Brown and others, 2006; Roy and others, 2010; Kovalskyy and others, 2012). Future work also could assess if the incorporation of additional landscape position-type parameters (such as distance to freshwater input, neighborhood slope, and neighborhood elevation) enhances classifications. Additionally, future efforts could aim to take a more targeted approach regarding independent variables to minimize redundancy. Lastly, future efforts could span the entire northern Gulf of Mexico coast and include ground reference data throughout the area mapped.

This study provides a more objective and repeatable method for classifying marsh types of the northern Gulf of Mexico coast at a greater extent (that is, outside Louisiana) and greater level of thematic detail than previously available. The most appropriate use of this classification is for understanding general distribution and overall changes in areal coverage of emergent marshes at the landscape level. Similar to C-CAP and NLCD, the marsh-type classification might warrant a 4- to 5-year update cycle. The seamless classification produced through this work can be used to help develop and refine conservation efforts for priority natural resources. Moreover, these data may improve projections of landscape change and serve as a baseline for monitoring future changes resulting from chronic and episodic stressors (Sasser and others, 2008, 2014).

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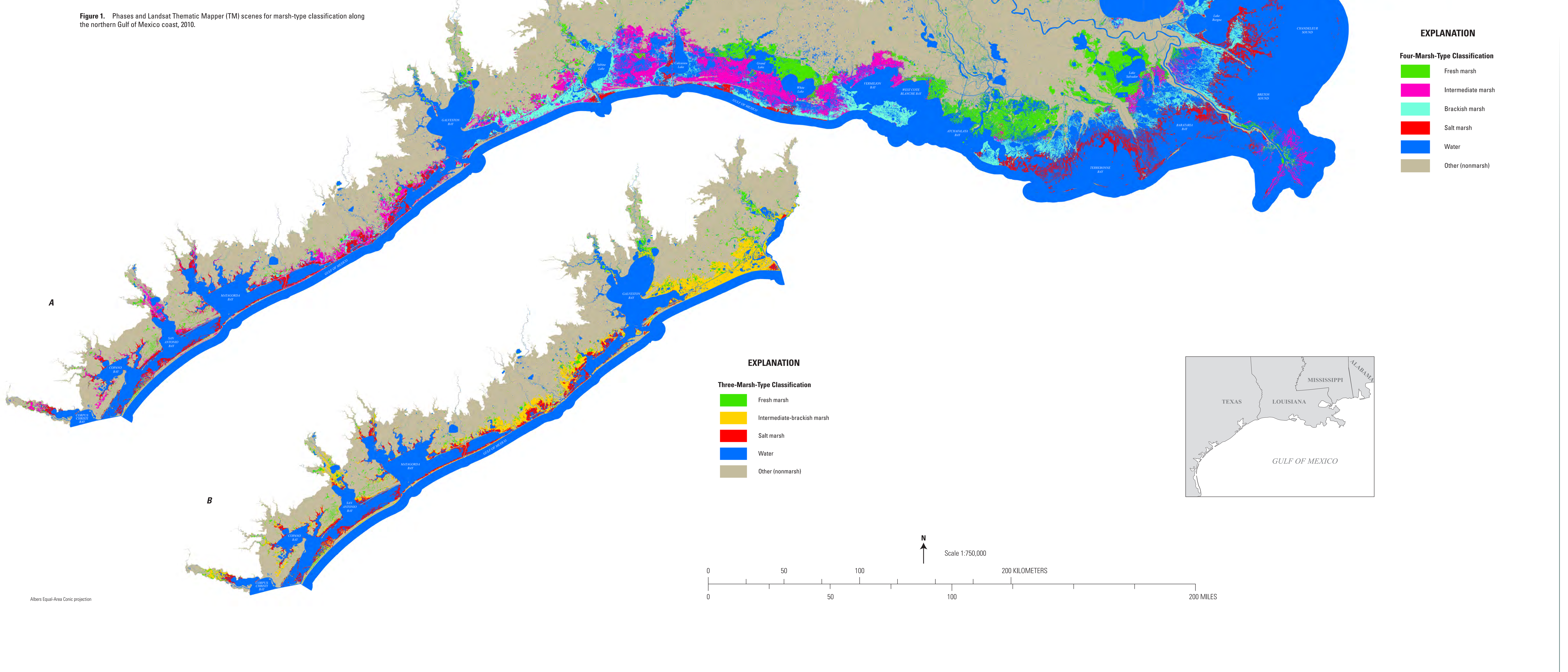

Figure 2. Marsh-type classifications along the northern Gulf of Mexico coast, 2010. *A*, Four-marsh-type classification. *B*, Three-marsh-type classification.

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