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The Impact of a Severe Drought on the Vegetation of a Subtropical Estuary

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ABSTRACT: In order to document the effect of the recent drought and the resulting marine intrusion event on plant-community shifts in a Louisiana estuary, we analyzed two vegetation data sets collected in Barataria estuary in 1997 and 2000 and compared community shifts to surface salinity changes at four points along the estuarine gradient within the study area. We used the major vegetation types identified in our previous research of larger data sets and tested the use of a simple vegetation classification technique. This vegetation classification technique is based primarily on the dominant and co-dominant species, and secondarily on the number of taxa observed. To distinguish vegetation types with similar dominant species but different associated species, the vegetation classification technique used a salinity score derived from the species composition. Surface water salinity increases were reflected by a change in species composition in the mesohaline to fresh marshes. The largest species composition shift observed was the shift from oligohaline wiregrass (species rich vegetation type dominated by *Spartina patens*) to mesohaline wiregrass (vegetation type dominated by *S. patens* with few other species). Shifts in vegetation composition may have been enhanced by the presence of the major dominant species at a low abundance in other vegetation types. The vegetation classification technique used could classify over 95% of the stations. This vegetation classification technique provides a simple method to classify Louisiana's coastal vegetation based on plant species composition.

Introduction

The Louisiana marshes were formed by overlapping delta lobes from the Mississippi River in the last 10,000 years (Kolb and van Lopik 1958). At present, the river is contained by large levees and most marshes in this delta plain are no longer nourished by the river. The reduction of freshwater and sediment input combined with high subsidence rates in the region and global sea-level rise (Baumann et al. 1984) are expected to lead to marine intrusion into the upper estuaries.

The onset of La Niña in mid-1998 resulted in a weather pattern with lower precipitation and higher temperatures for the northern Gulf of Mexico (Grymes 2001). At the same time, Mississippi River discharge was extremely low (Swenson 2001). As a result, 1999 and 2000 had the lowest freshwater input into Louisiana's estuaries during the period 1960 to 2000 (Swenson 2001). During the 2000 growing season, large areas of *Spartina alterniflora* prematurely senesced along the Louisiana coast. By August 2000, Linscombe et al. (2001) estimated that 42,723 ha of saline marsh in the Barataria-Terrebonne basins of coastal Louisiana were severely damaged (all *S. alterniflora* stems in this area had prematurely senesced), 59,058 ha were moderately damaged (some of the *S. alterniflora* stems in this area had senesced), and 55,707 ha were not damaged. The drought resulting from this 2-yr weather event and its effect on estuarine hydrology may provide a preview of changes in estuarine plant communities as global sea-level rise causes marine intrusion into estuaries to increase.

The objective of this study was to document the effect of the recent drought and the resulting marine intrusion event on plant-community shifts in a Louisiana estuary. We analyzed two vegetation data sets collected in Barataria estuary in 1997 and 2000 and compared community shifts to salinity changes in the study area. We developed a vegetation classification technique to conduct short-term (3-yr interval) vegetation change analysis with a relatively small (< 600 stations) data set.

Methods

STUDY AREA

The 625,000 ha study area in Barataria estuary contains approximately 257,000 ha of emergent marsh (Fig. 1). Wetland vegetation in this area is

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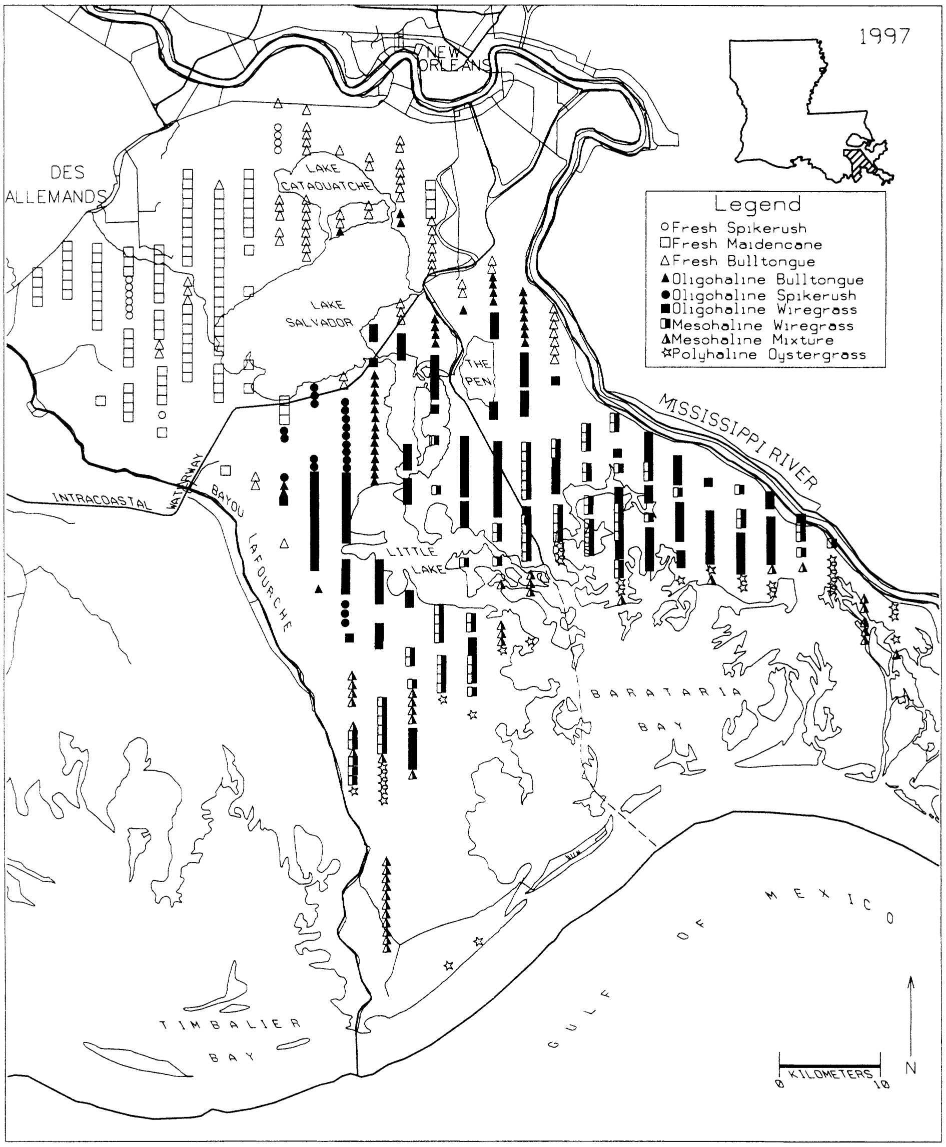

Fig. 1. Distribution of vegetation types in 1997.

diverse with different plant communities reflecting gradients in salinity and land elevation (Visser et al. 1998). In Barataria estuary, approximately 89,355 ha of marsh was converted to open water from 1956 to 1990. Most of this loss occurred in non-fresh marsh in the southern part of the basin (Fuller et al. 1995).

Data Collection

Data were collected along 29 north-south transect lines spaced at approximately 3 km intervals (Fig. 1) in 1997 and 2000. Along the transects, stations were located at 0.8 km intervals. The transects covered all fresh, intermediate, and brackish marshes, but due to budget limitations only a small portion of the saline marsh was surveyed along each transect. The same number of stations (976) was sampled in the late summer in each year. Stations were located using the helicopter's global positioning system (GPS) and are accurate to within 30 m.

Vegetation was surveyed by the same individual from a helicopter hovering above each station. Helicopter surveys were chosen over traditional ground survey methods to provide better spatial coverage over the extensive study area. The helicopter surveys are sufficient for the identification of large specimens and dominant species, but tend to omit inconspicuous species. Each species occurring in an approximately 30 m radius from the sta-

TABLE 1. Classification criteria for the ten vegetation types previously described for the Louisiana deltaic plain. Dominant species is the most important criteria followed by other species (see text).

Vegetation Type	Dominant Species	Other Species	Salinity Score
Fresh Maidencane	*Panicum hemitomon* > *Sagittaria lancifolia*		<2.0
Fresh Bulltongue	*Sagittaria lancifolia* ≥ *Panicum hemitomon*	no *Spartina patens*	<2.0
Fresh Spikerush	*Eleocharis* spp. and *Hydrocotyle* spp.	no *Spartina patens*	<2.0
Oligohaline Bulltongue	*Sagittaria lancifolia* ≥ *Spartina patens*	no *Panicum hemitomon*	≥2.0
Oligohaline Spikerush	*Eleocharis* spp. ≥ *Sagittaria lancifolia*	no *Panicum hemitomon*	≥2.0
Oligohaline Wiregrass	*Spartina patens* > *Sagittaria lancifolia*	>3	<7.5
Mesohaline Wiregrass	*Spartina patens*	≤2, no *Sagittaria lancifolia*	≥7.5
Mesohaline Mixture	*Spartina alterniflora* and *Spartina patens* and/or *Distichlis spicata*		<14.5
Polyhaline Oystergrass	*Spartina alterniflora*		≥14.5
Polyhaline Mangrove	*Avicennia germinans* and *Spartina alterniflora*		≥14.5

tion was recorded and assigned an abundance value (3 = abundant, 2 = common, and 1 = uncommon). Plant species nomenclature follows the International Taxonomic Information System (http://www.itis.usda.gov). The station was classified as natural marsh (with 4 habitat types: fresh, intermediate, brackish, and saline), forested (shrubs or trees), de-watered marsh, open water, beach, natural levee or ridge, spoil bank, or developed (towns, pastures, etc.). Habitat types were assigned based on species composition using the methods described in Chabreck (1970). We split the open water into two categories (large and small) based on additional field notes. Large open water included the large lakes and bays that are outlined in Fig. 1. Small open water consisted of marsh ponds, bayous (slow flowing rivers), and canals. We combined de-watered marsh and developed into an upland category, and beach, natural levee, and spoil bank into a non-marsh category. Natural marsh stations were analyzed as described below.

Vegetation Type Analysis

We have used two-way indicator species analysis (TWINSPAN) to identify the major vegetation types within the Louisiana coastal zone (Visser et al. 1998, 1999, 2000). Because interpretation of TWINSPAN output is subjective (Kent and Coker 1992), and problems with the program have been reported (Oksanen and Minchin 1997), we developed a vegetation classification technique suitable for monitoring of short-term vegetation change over small as well as large areas in the Louisiana coastal zone. The vegetation classification technique is based primarily on the dominant and co-dominant species, and secondarily on the number of taxa observed (Table 1). Stations were classified into the 10 vegetation types described for the Mississippi River Deltaic Plain region of Louisiana (Visser et al. 1998, 1999; Visser and Sasser 1999). The study area is part of this region.

TABLE 2. Values used to calculate a salinity score for each station based on species abundance and composition. Zone of peak occurrence for each species was based on Chabreck (1970). Value is the approximate mid-point of the salinity range for each zone based on the Cowardin classification (Cowardin et al. 1979).

Salinity Zone of Peak Occurrence	Salinity Range (‰)	Value
Fresh	0–0.5	0.25
Fresh and intermediate		1.50
Intermediate	0.5–5	2.75
Intermediate and brackish		7.15
Brackish	5–18	11.50
Brackish and saline		17.50
Saline	18–30	24.00

To distinguish vegetation types with similar dominant species but different associated species, a salinity score was derived from the species composition. For this calculation we used the distribution of each species over the four salinity zones described by Chabreck (1970) to assign a salinity value to each species (see Table 2). Zone of peak occurrence for each species was based on Chabreck (1970). The salinity value for each species is the approximate mid-point of the salinity range (in ‰) for each zone based on the Cowardin classification (Cowardin et al. 1979). If a species was equally distributed over two zones (e.g., fresh and intermediate), it was assigned to the approximate midpoint for both zones. The salinity score for the vegetation at a station is the weighted average of the salinity value of all species in the plot (using the abundance value of each species as a weight):

$$\text{score} = \frac{\sum_i \text{value}_i \times \text{abundance}_i}{\sum_i \text{abundance}_i}$$

The analysis used only those stations classified as natural marsh. In the 1997 survey, 566 stations were classified as natural marsh and 539 stations were classified as natural marsh in the 2000 survey. Due to the large size of the study plot (~ 2,800 m²) some stations classified as natural marsh contained parts of marsh ponds, spoil banks, or natural levees. We removed all submerged, free-floating, and tree species from the natural marsh data set, so that only emergent marsh species were included in the analysis. Some species that were difficult to identify correctly using helicopter surveys, such as some grasses and sedges, were grouped by genus.

Area of Vegetation Types

The areas represented by each vegetation type were calculated by multiplying the percentage of marsh sampling stations in each vegetation type with the total marsh area (257,182 ha). Since the transects stopped at the northern edge of the saline marsh and were not extended to the Gulf of Mexico, we added 182 saline marsh stations in each year to account for the under sampling of saline marsh. This number was derived by plotting the unsampled stations of each transect on recent (1998) aerial photographs of the study area and counting the number of stations that were on land instead of open water. The estimation of the number of unsampled stations was performed by the Louisiana Department of Natural Resources as part of the Coastwide Reference Monitoring System Design (Steyer et al. in press).

Salinity Data

Surface water salinity data for the period 1995 to 2000 were obtained from four existing stations that represent the salinity gradient in the study area. The Louisiana Department of Wildlife and Fisheries (LDWF) maintains three continuously recording gauges in the study area: Little Lake (gauge 326), Upper Barataria Bay (gauge 317), and Lower Barataria Bay (gauge 315). The data from each of the LDWF gauges were condensed into monthly means. At the northern boundary of the study area, the Louisiana Department of Environmental Quality takes monthly water samples from Bayou Des Allemands and determines surface water salinity.

Results

Salinity

Long-term surface water salinity measurements available in the study area are sparse compared with the number of stations sampled for vegetation composition. We used four existing surface water salinity stations that reflect the major salinity gradient up the estuary to compare actual surface water salinity changes with changes in vegetation composition. Only a cursory evaluation is possible due to spatial and temporal differences between the two data sets.

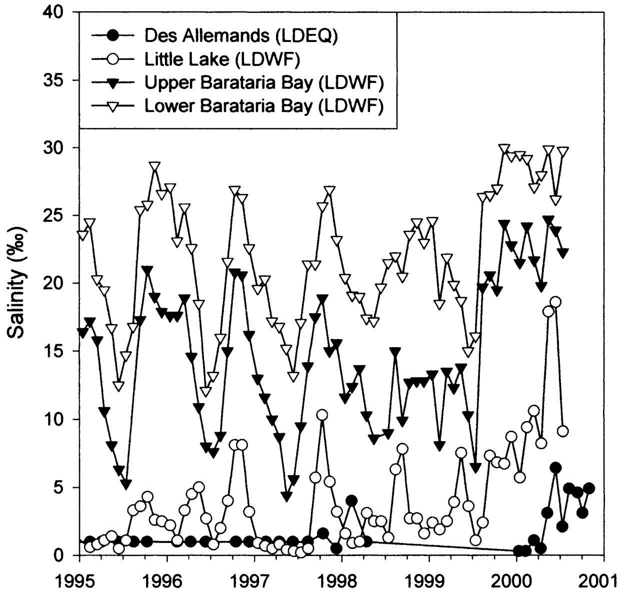

Fig. 2. Salinity changes from 1995 through 2000.

Surface water salinity in the study area shows large seasonal variation with salinity decreasing in the spring as flood waters from the Mississippi River decrease salinity offshore from the study area, and increasing in the fall (Fig. 2). This annual cycle did not occur in the spring of 2000, when surface water salinity at all stations increased. During the 2000 growing season (April to October) salinity was above the long-term average throughout the study area.

Vegetation Types

Analysis of the vegetation data collected in 1997 and 2000 using the vegetation classification technique (Table 1) resulted in the classification of 99.8% of the stations (565 of 566 stations) in 1997 and 98.1% of the stations (530 of 540 stations) in 2000 into nine vegetation types (Table 3). Polyhaline Mangrove was not observed, because this vegetation type is located in areas not covered by the surveys.

One station in 1997 and ten in 2000 could not be classified using the vegetation classification technique. One station in 2000 was co-dominated by *Schoenoplectus californicus* and *Schoenoplectus americanus* and represents the Oligohaline Bullwhip type previously described for the Chenier Plain (Visser et al. 2000). One station in 1997 and nine in 2000 were co-dominated by *Sacciolepis striata, Sagittaria latifolia,* and/or *Leersia oryzoides.* We are aware of several sites in Terrebonne Basin that are dominated by either *S. latifolia* or *S. striata* in the late summer that are dominated by *Eleocharis baldwinii* in the spring. These sites were classified as

TABLE 3. Classification of the natural marsh stations into vegetation types for 1997 and 2000.

	1997		2000	
Vegetation Type	Stations	Area (ha)+	Stations	Area (ha)
Fresh Spikerush	11	2,972	8	2,143
Fresh Maidencane	128	34,579	125	33,487
Fresh Bulltongue	74	19,991	37	9,912
Oligohaline Bulltongue	26	7,024	28	7,501
Oligohaline Spikerush	24	6,484	45	12,055
Oligohaline Bullwhip	0	0	1	268
Oligohaline Wiregrass	145	39,172	68	18,217
Mesohaline Wiregrass	87	23,503	134	35,898
Mesohaline Mixture	40	10,806	32	8,573
Polyhaline Oystergrass	31	57,542	62	65,367
Total Natural Marsh	566	202,072	540	193,423
Non-marsh*	52	14,048	65	17,413
Small Open Water*	152	41,063	173	46,346
Large Open Water*	185	284,832	177	284,832
Upland*	21	82,890	21	82,890
TOTAL Survey	976	624,904	976	624,904

+ Areas were calculated using the percentage of stations in each marsh type. To account for the stations not sampled in the saline marsh we added 182 Polyhaline Oystergrass stations in each year before calculating the percentage (see area of vegetation types in methods).

* See data collection in methods.

floating thin-mat marshes in the description of floating marshes in the Barataria and Terrebonne basins (Sasser et al. 1994). Because our surveys occurred in the late summer, we classified these ten stations as Fresh Spikerush type.

The distribution of vegetation types in the study area changed significantly (chi-square test $\alpha = 0.05$) from 1997 to 2000. The change of non-marsh from 52 stations (14,048 ha) in 1997 to 65 stations (17,413 ha) in 2000 (Table 3) shows the limits in the detection of change. No major change in the area of spoil banks, natural levees, and beach (the three categories that were combined into non-marsh) occurred in the study area between 1997 and 2000. We assumed that no change occurred in this category and that this difference illustrates the detection limits of our method. We consider meaningful only those changes involving more than 13 stations (3,500 ha).

The vegetation type representing the largest area in 1997 and 2000 was Polyhaline Oystergrass (Table 3). This vegetation type was located in the lower basin (Figs. 1 and 3) and most areas were not included in our surveys. Polyhaline Oystergrass stations were dominated by *S. alterniflora* and have either *Juncus roemerianus* or *Distichlis spicata* present (Table 4). Polyhaline Oystergrass increased from 22.4% (57,542 ha) in 1997 to 25.4% (65,367 ha) in 2000 (Fig. 4). New Polyhaline Oystergrass areas in 2000 were either Mesohaline Mixture or Mesohaline Wiregrass in 1997 (Figs. 1 and 3). Mesohaline Mixture stations were co-dominated by *S. alterniflora* and either *D. spicata* or *Spartina patens* (Table 4). The shift of an area from Mesohaline Mixture to Polyhaline Oystergrass reflects a decrease in the abundance of *D. spicata* and *S. patens* in these areas. The shift from Mesohaline Wiregrass to Polyhaline Oystergrass reflects a decrease in the abundance of *S. patens* combined with an increase in the abundance of *S. alterniflora.*

One of the major shifts was the conversion of Oligohaline Wiregrass to Mesohaline Wiregrass in the lower central basin (Figs. 1 and 3). In 1997, Oligohaline Wiregrass was the second most abundant vegetation type in the study area (39,172 ha). In 2000, large areas in the lower central basin converted from Oligohaline Wiregrass to Mesohaline Wiregrass (Table 3, Fig. 4), and Mesohaline Wiregrass became the second most common vegetation type. This shift occurred because several fresh to intermediate marsh species (see Table 4) were lost, while the dominant species, *S. patens,* remained the same.

Little change occurred in the Fresh Maidencane marshes dominated by *Panicum hemitomon.* In both years, approximately 13% (1997: 34,579 ha, 2000: 33,486 ha) of the study area was classified as Fresh Maidencane (Fig. 4), which dominated much of the northwestern part of the study area (Figs. 1 and 3). Fresh Bulltongue decreased from 19,991 ha in 1997 to 9,912 ha in 2000. In 1997, Fresh Bulltongue marshes were found mostly around Lake Cataouatche and southeast of Lake Salvador. In 2000, many of these areas had converted to Oligohaline Bulltongue and Oligohaline Spikerush. The shift from Fresh Bulltongue to Oligohaline Bulltongue reflects the appearance of *S. patens* in these areas. The shift of Fresh Bulltongue to Oligohaline Spikerush reflects the decrease in abundance of *Sagittaria lancifolia* in these areas.

Oligohaline Bulltongue represented approximately 3% (1997: 7,024 ha, 2000: 7,501 ha) of the study area in both years; however, a large shift occurred in the spatial distribution of this vegetation type. In 1997, only 11% (3 out of 26 stations) of the Oligohaline Bulltongue marshes were found north of the Gulf Intracoastal Water Way (GIWW); in 2000, 32% (9 out of 28 stations) of this type was found north of the GIWW. Oligohaline Spikerush increased from 6,484 ha in 1997 to 12,055 ha in 2000. In 1997, Oligohaline Spikerush was found mostly just south of the GIWW; but in 2000, areas surrounding Lake Salvador and north of The Pen also contained this type.

Small open water increased from 41,063 ha in 1997 to 46,346 ha in 2000 (Table 3). This indicates that some marsh may have converted to open water during this 3-yr period.

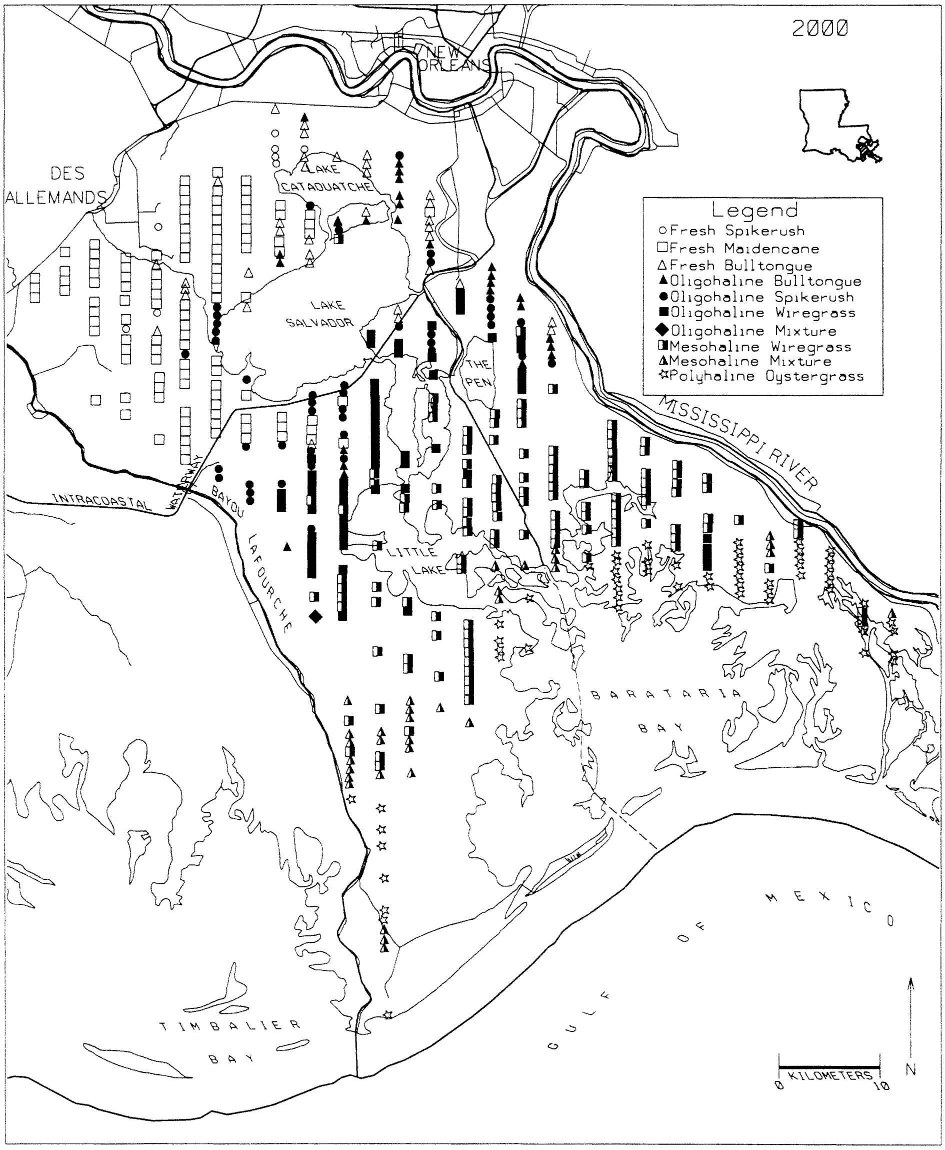

Fig. 3. Distribution of vegetation types in 2000.

Habitat Types

Within the basin a notable change of habitat types (fresh, intermediate, brackish, saline) as defined based on species composition by Chabreck (1970) occurred between 1997 and 2000 (Figs. 5 and 6). In general, the bands of habitat types shifted northward. The result was a reduction of Fresh and Intermediate Marsh area from 1997 to 2000 (Table 5). Brackish and Saline Marsh area increased from 1997 to 2000 (Table 5).

Discussion

Detecting Vegetation Changes at the Landscape Scale

Documenting marsh vegetation changes at the landscape scale has been done through mapping of aerial photography (Evers 1989; Jean and Bouchard 1991; Miller et al. 1996), establishment of permanent plots along transect lines (Roozen and Westhoff 1985; Allison 1992), use of randomly distributed plots (Warren and Niering 1993), or a combination of all of these (Ross et al. 2000). Van den Berg et al. (1985) found that detailed vegetation surveys of 80 permanent plots was less informative for vegetation change detection than annual mapping according to a rough typology. This study combines the vegetation classification based on dominants with a large number of semi-permanent plots and provides a spatial distribution figure for each year (Figs. 1 and 3). We used regularly-spaced, large plots (~ 2,800 m²) that are lo-

TABLE 4. Species composition of each vegetation type. The frequency and abundance of each species is presented in 7 frequency classes followed by the most frequent abundance value. Frequency classes represent the percentage of the stations in which a species was found: * = 1 station, t < 5%, 1 = 5% to 20%, II = 21% to 40%, III = 41% to 60%, IV = 61% to 80%, and V = 81% to 100%. Abundance values represent the density of each species at most stations: 1 = uncommon, 2 = common, and 3 = abundant.

		Vegetation Type[1]								
Class[2]	Species	FS	FM	FB	OS	OB	OW	MW	MM	PO
F	*Aeschynomene indica* L.	II.1		I.1		*	t.1			
F	*Bidens laevis* (L.) BSP	III.3	I.1	I.2						
F	*Cephalanthus occidentalis* L.	II.1	t.1	*		t.1				
F	*Cladium mariscus* (Crantz) Kukenth		t.1	*	t.1		t.1			
F	*Colocasia esculenta* (L.) Schott.		t.2				t.1			
F	*Decodon verticillatus* (L.) Ell.	III.3	III.2	t.1						
F	*Eupatorium capillifolium* (Lam.) Small		I.1							
F	*Hydrocotyle* spp. L.	V.3	I.1	I.2	II.2	II.1	t.1			
F	*Ludwigia* spp. L			II.1	t.1	I.2	t.2			
F	*Nelumbo lutea* Willd.		t.1	t.1						
F	*Nuphar lutea* (L.) Sm.	*	t.1							
F	*Nymphaea odorata* Ait.	II.1	t.1							
F	*Morella cerifera* (L.) Small	I.1	IV.1	II.1	I.1	II.1	I.1			
F	*Panicum hemitomon* Schultes	II.2	V.3	I.2	I.1					
F	*Phyla lanceolata* (Michx.) Greene			t.1		*				
F	*Polygonum punctatum* Ell.	*	t.1	I.2		I.2	t.1			
F	*Rhynchospera colorata* (L.) Pfeiffer				I.2		t.1			
F	*Sacciolepis striata* (L.) Nash.	III.3	t.1	I.2	t.1	I.2				
F	*Sagittaria latifolia* Willd.	III.3	II.2							
F	*Setaria magna* Griseb.	*	t.1							
F	*Thelypteris palustris* Schott		t.2	*	I.1	*	t.1			
F	*Triadenum virginicum* (L.) Raf.		t.1							
F	*Zizaniopsis miliacea* (Michx.) Doell. & Aschers	IV.1	II.1	I.1	*					
F-I	*Alternanthera philoxeroides* (Mart.) Griseb.	I.2	t.2	I.2	I.1	I.2	*			
N	*Ammannia coccinea* Rottb.		*							
N	*Andropogon virginicus* L.	*								
N	*Boehmeria cylindrica* (L.) Swartz		t.1	t.1	t.1					
F-I	*Cyperus* spp. L	II.1	t.2	I.1			I.1	t.1		
F-I	*Eleocharis* spp. R. Br.	V.2	II.1	II.2	V.3	II.2	I.1	t.1		
N	*Leersia oryzoides* (L.) Swartz	II.3	I.2	III.2	II.2	I.2	t.2			
F-I	*Hibiscus moscheutos* L.		I.1	t.1	I.1	I.1	t.1			
F-I	*Osmunda regalis* L.		t.1							
F-I	*Sagittaria lancifolia* L.	II.1	IV.2	V.3	V.2	V.3	II.2			
F-I	*Schoenoplectus californicus* (C. A. Meyer) Palla		I.1	I.1	*					
F-I	*Solidago sempervirens* L.		*				*			
F-I	*Typha* spp. L	II.1	III.1	IV.1	IV.1	II.1	I.1			
I	*Amaranthus australis* (Gray) Sauer					*	t.1	t.1		
I	*Baccharis halimifolia* L.			t.1	I.1	I.1	II.1	I.1	t.1	
I	*Bacopa monnieri* (L.) Pennel			t.1	I.2	*	I.1	t.1		
I	*Echinochloa walteri* (Pursh) Heller	I.1		t.2	t.1		t.1	t.1		
I	*Ipomoea sagittata* Poir.			I.2	*	I.1	II.1	t.1		
I	*Kosteletzkya virginica* (L.) Presl. ex Gray							t.1		
I	*Panicum* spp. L.									
I	*Paspalum vaginatum* Sw.						*			
I	*Phragmites australis* (Cav.) Trin. ex Steud.		*							
I	*Pluchea camphorata* (L.) DC.		t.1		*		I.1			
I	*Spartina cynosuroides* (L.) Roth.							t.1		
I	*Symphyotrichum subulatum* (Michx.) Nesom			t.2	I.2	I.1				
I	*Vigna luteola* (Jacq.) Benth.		t.1	II.2		II.2	II.2	I.2		
I-B	*Lythrum lineare* L.			*	I.1	I.2	I.1			
I-B	*Schoenoplectus americanus* (Pers.) Volk ex Schiz & Keller			I.2	I.2	II.1	IV.2	II.2	t.1	
I-B	*Sesbania drummondii* (Rydb.) Cory		*						I.1	
I-B	*Spartina patens* (Ait.) Muhl			*	II.1	V.2	V.3	V.3	IV.2	II.1
B	*Cuscuta indecora* Choisy					*				
B	*Iva frutescens* L.				*		t.1	I.1	t.1	

TABLE 4. Contoinued.

Class[2]	Species	Vegetation Type[1]								
		FS	FM	FB	OS	OB	OW	MW	MM	PO
B-S	*Distichlis spicata* (L.) Greene							I.1	V.2	II.1
B-S	*Juncus roemerianus* Scheele			t.1	t.1		II.1	II.1	II.1	III.1
S	*Avicennia germinans* (L.) L.									*
S	*Batis maritima* L.								*	
S	*Spartina alterniflora* Loisel.						I.1	II.1	V.3	V.3
Salinity score (standard error)		0.5 (0.0)	0.6 (0.0)	1.5 (0.1)	2.1 (0.1)	3.3 (0.1)	6.6 (0.2)	9.5 (0.2)	18.5 (0.3)	21.8 (0.2)
Number of taxa[3] (standard error)		5.1 (0.3)	5.1 (0.1)	5.1 (0.1)	5.1 (0.2)	5.1 (0.2)	4.8 (0.0)	2.4 (0.1)	3.0 (0.1)	2.1 (0.1)

[1] FS = Fresh Spikerush, FM = Fresh Maidencane, FB = Fresh Bulltongue, OS = Oligohaline Spikerush, OB = Oligohaline Bulltongue, OW = Oligohaline Wiregrass, MW = Mesohaline Wiregrass, MM = Mesohaline Mixture, PO = Polyhaline Oystergrass.

[2] F = Fresh Marsh, F-I = Fresh and Intermediate Marsh, I = Intermediate Marsh, I-B = Intermediate and Brackish marsh, B = Brackish Marsh, B-S = Brackish and Saline Marsh, S = Saline Marsh, N = not found in Chabreck (1970).

[3] The number of taxa observed in our surveys is much lower than the number of species observed during traditional ground surveys.

cated through the helicopter's GPS, which has an accuracy of 30 m, and not permanently marked. Although stations with the same identification number in different years were relatively close in space, they do not necessarily sample the exact same area. This method may be less accurate to describe vegetation change at a single station, but similar to randomly distributed plots can provide information on landscape level changes. We chose this method for the 625,000 ha study area as it was both less expensive and less time consuming than using more detailed photo-interpretation of aerial imagery.

Marine Intrusion and Vegetation Changes

Our results show that polyhaline and mesohaline vegetation types (i.e., Mesohaline Mixture and Mesohaline Wiregrass combined) and habitats increased in area between 1997 and 2000 and that oligohaline (i.e., Oligohaline Bulltongue, Oligohaline Spikerush, and Oligohaline Wiregrass combined) and fresh vegetation types and habitats decreased. It is also noteworthy, that the vegetation adjacent to the large open water bodies in the center of the study area showed more change than vegetation on the flanks of the study area (Figs. 1 and 3). Changes in vegetation types and habitat between 1997 and 2000 seem to reflect the increase in surface water salinity within the study area in 2000 relative to the five previous years (Fig. 2).

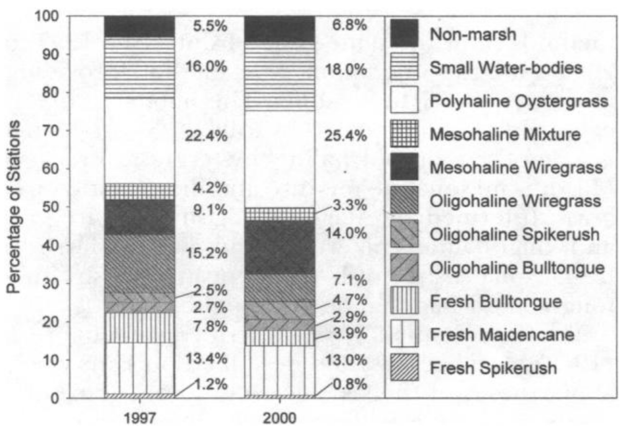

Fig. 4. Change in area of vegetation types from 1997 to 2000.

Our results show that under a scenario of rapid increase in surface water salinity a shift in species composition occurs in the fresh to mesohaline types, without large scale conversion to open water. Scattered throughout the fresh to mesohaline types conversion of marsh to open water occurred as illustrated by the increase of shallow open water (Table 3). During the same period large areas of polyhaline marsh were converted to open mudflats (Linscombe et al. 2001) with some invasion by *Avicennia germinans*. This phenomenon was not detected by our study, because our surveys did not cover all the polyhaline marsh (see methods). The rapid shifts in vegetation types in the mesohaline to fresh marshes in the study area were possible because there is overlap in the distribution among some of the most common dominant species (*P. hemitomon, S. lancifolia, S. patens,* and *S. alterniflora*; see Table 2). The change in relative abundance of dominant perennial species as a result of interannual differences in rainfall has also been documented in California salt marshes (Allison 1992). Dutch salt marshes show fluctuations in species composition as a result of annual variation in inundation frequency (Olff et al. 1988). Interannual changes in species composition of oligohaline marshes within the study area have been previously reported by Flynn et al. (1995) and Evers (1989).

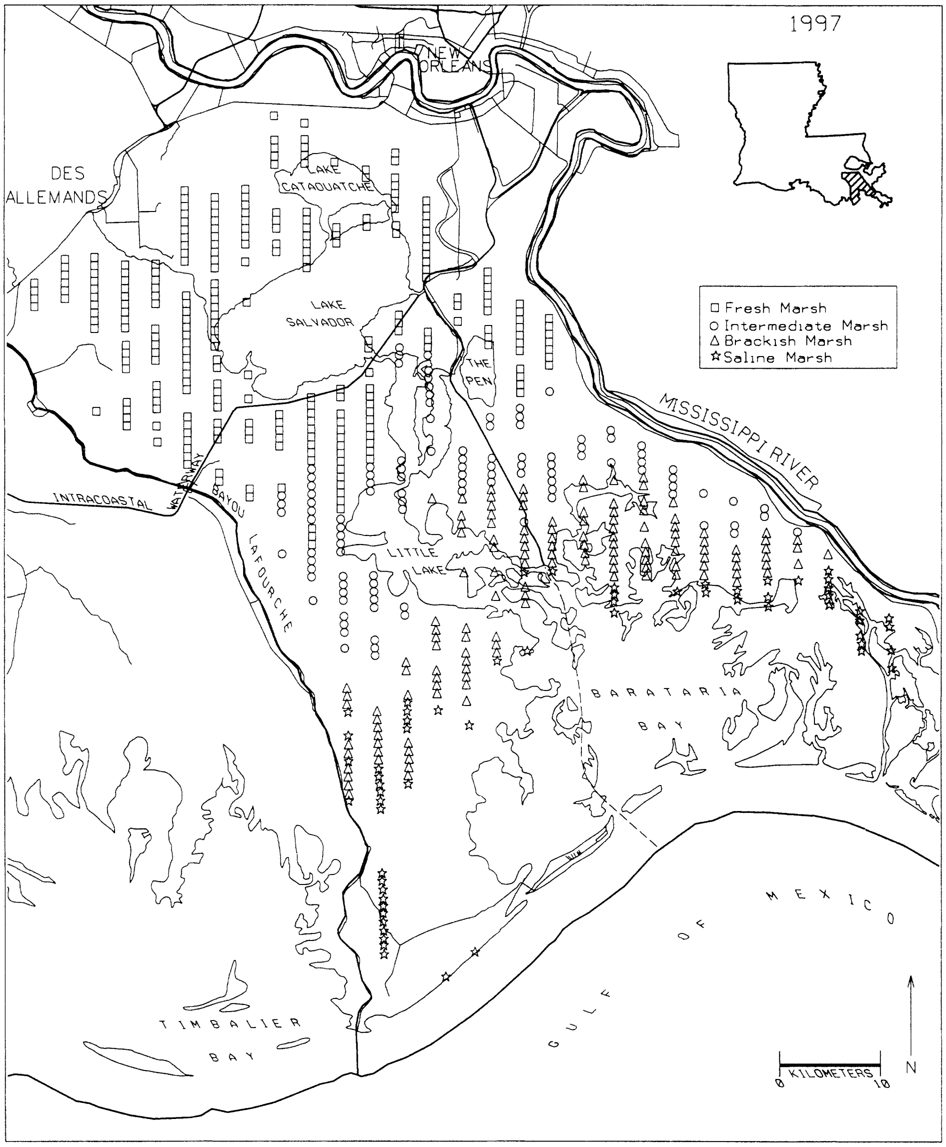

Fig. 5. Distribution of habitat types in 1997.

We are unaware of any reports documenting interannual changes in species composition of mesohaline and fresh marshes. Sasser et al. (1995) report on the stability in species composition and spatial extent of Fresh Maidencane marshes in the upper estuary as a result of their floating nature, which results in a constant hydroperiod even with fluctuating water levels.

Comparison of Habitat Types versus Vegetation Types

The habitat method is a broader classification scheme that shows the general bands of habitats along the coast, while the vegetation type method shows more intricate patterns. In general, both methods show the same general shift from 1997 to 2000 with the vegetation type method providing more details for these shifts. The habitat and vegetation types are equated as follows: Saline Marsh is composed of polyhaline oystergrass; Brackish Marsh is mesohaline mixture and mesohaline wiregrass; Intermediate Marsh is oligohaline wiregrass and oligohaline spikerush; and Fresh Marsh is fresh spikerush, fresh maidencane, fresh bulltongue, and oligohaline bulltongue.

The four habitat types described by Chabreck (1972) have been used to describe Louisiana coastal marshes over the last 30 years. Advances in computing power have allowed more quantitative techniques for analysis of the vegetation data and the

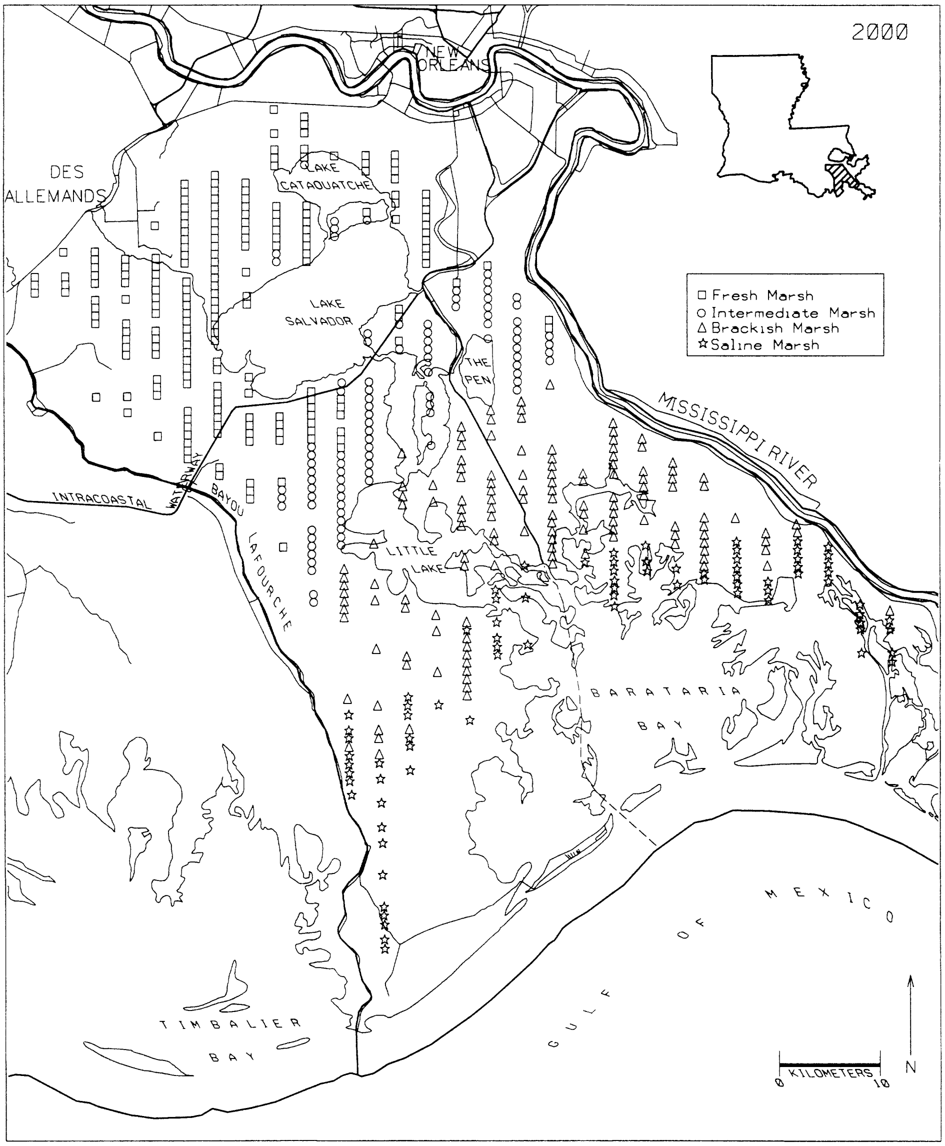

Fig. 6. Distribution of habitat types in 2000.

identification of several vegetation types that are recognized by marsh ecologists (Visser et al. 1998, 1999, 2000; Visser and Sasser 1999). These vegetation types allow us to recognize more detailed spatial and temporal vegetation shifts. The vegetation classification technique developed in this study allows a straightforward and simple classification of a Louisiana marsh in the Deltaic Plain into one of the ten vegetation types. The salinity score developed from the vegetation composition should only be used if distribution of dominants and selected other species fails to differentiate the vegetation into vegetation types. Since many factors affect the distribution of marsh plants, and many species occur over a wide range of salinity conditions, we expect a low correlation between the salinity score (based on species composition) and the average annual salinity at each site. Ross et al. (2000) showed that distance to the coast was

TABLE 5. Area of habitat types within the study area in 1997 and 2000.

Habitat Type	1997 Area (ha)	1997 Percentage	2000 Area (ha)	2000 Percentage
Fresh Marsh	88,058	34.2	72,477	28.2
Intermediate Marsh	48,526	18.9	39,298	15.3
Brackish Marsh	47,407	18.4	63,309	24.6
Saline Marsh	73,191	28.5	82,098	31.9
Total Marsh	257,182		257,182	

the best predictor of species composition in the estuarine part of the Florida Everglades, because coastal distance integrates a complex of physical factors that are strongly inter-correlated, but among which no single variable is dominant. A similar correlation among edaphic factors (organic matter, bulk density, pH, total phosphorus, etc.), salinity, and distance to the coast may occur along the Louisiana coast (Palmisano 1970).

Conclusions

The Louisiana coastal zone experienced an extreme drought in 2000 combined with extremely low flows of the Mississippi River. Surface water salinity was above the long-term average throughout the basin during the 2000 growing season. Surface water salinity increases between 1997 and 2000 were reflected by a change in species composition in the mesohaline to fresh marshes. The largest shift observed was the shift from oligohaline wiregrass to mesohaline wiregrass.

Shifts in vegetation composition were enhanced by the presence of the major dominant species at a low abundance in other vegetation types. The low abundance of *S. patens* in Oligohaline Bulltongue marshes increases the likelihood of a shift to Oligohaline Wiregrass as salinity increases since this shift only requires the increase in abundance not the establishment of *S. patens.*

The vegetation classification technique used could classify over 95% of the stations and provides a simple method to classify coastal marshes based on plant species composition. This vegetation classification technique can be used with any size data set.

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