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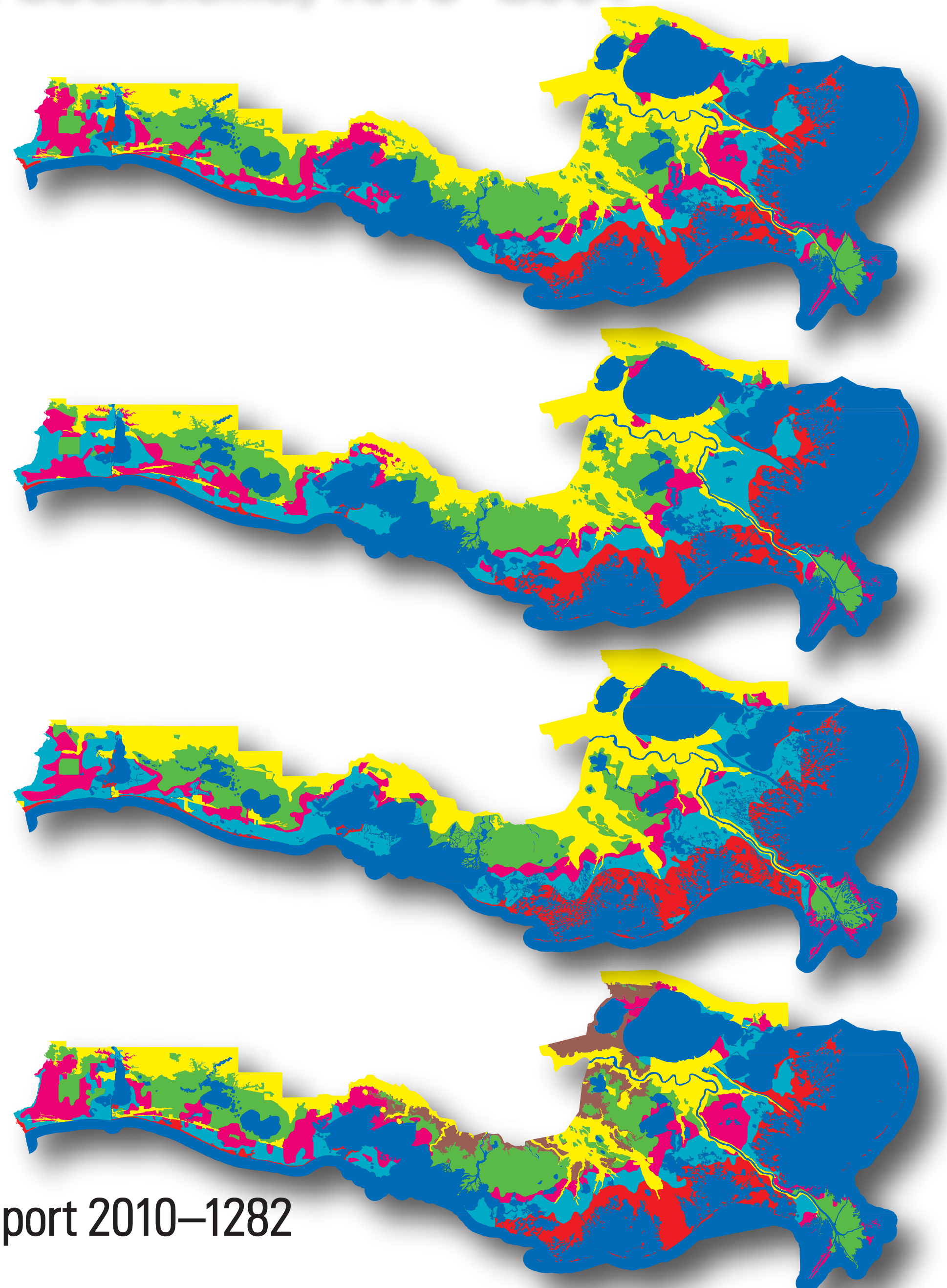
Analysis of Change in Marsh Types of Coastal Louisiana, 1978–2001



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U.S. Department of the Interior
U.S. Geological Survey

Analysis of Change in Marsh Types of Coastal Louisiana, 1978–2001

By Robert G. Linscombe and Stephen B. Hartley

Prepared in cooperation with Bureau of Ocean Energy Management, Regulation and Enforcement

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U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)

NOTE TO USGS USERS: Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas.

Analysis of Change in Marsh Types of Coastal Louisiana, 1978–2001

By Robert G. Linscombe[1] and Stephen B. Hartley[2]

Abstract

Scientists and geographers have provided multiple datasets and maps to document temporal changes in vegetation types and land-water relationships in coastal Louisiana. Although these maps provide useful historical information, technological limitations prevented these and other mapping efforts from providing sufficiently detailed calculations of areal changes and shifts in habitat coverage. The current analysis of habitat change draws upon these past mapping efforts but is based on an advanced, geographic information system dataset that was created by using Landsat 5 Thematic Mapper imagery and digital orthophoto quarter quadrangles. The objective of building this dataset was to more specifically define land-water relationships over time in coastal Louisiana, and it provides the most detailed analysis of vegetation shifts to date. In the current study, we have attempted to explain these vegetation shifts by interpreting them in the context of precipitation records, data from the Palmer Drought Severity Index, and salinity data.

During the 23 years we analyzed, total marsh acreage decreased, with conversion of marsh to open water. Furthermore, the general trend across coastal Louisiana was a shift to increasingly fresh marsh types. Although fresh marsh remained almost the same during the 1978–88 study period, there were greater increases during the 1988–2001 study periods. Intermediate marsh followed the same pattern, whereas brackish marsh showed a reverse (decreasing) pattern. Changes in saline (saltwater) marsh were minimal.

Interpreting shifts in marsh vegetation types by using climate and salinity data provides better understanding of factors influencing these changes and, therefore, can improve our ability to make predictions about future marsh loss related to vegetation changes. Results of our study indicate that precipitation fluctuations prior to vegetation surveys impacted salinities differently across the coast. For example, a wet 6 months prior to the survey may or may not have made up for a dry period during the earlier 12 months. More research is needed to better understand precipitation periods and how they affect salinity changes.

The ability to understand past dynamics and to anticipate future trends in vegetation change and related land loss in the coastal region of Louisiana is a vital part of ongoing and future efforts to conserve its critical wetland ecosystem. With the loss of marsh and resultant changes in hydrology, it is likely that changes in marsh type may show greater variation in the future, even if given only minor changes in precipitation levels.

Introduction

Scientists and geographers have provided multiple datasets and maps to document temporal changes in vegetation types and land-water relationships in coastal Louisiana. For example, under the auspices of the Louisiana Department of Wildlife & Fisheries, maps were produced in 1949, 1968, 1978, 1988, and 1997, and these have been collectively published in digital (CD-ROM) format by Chabreck and others (2001). In addition to these products, an important vegetation map was also published by Linscombe and others in 2001. Although these maps provide useful historical information, technological limitations prevented these and other mapping efforts from providing sufficiently detailed calculations of areal changes and shifts in habitat coverage.

The current analysis of habitat change draws upon these past mapping efforts but is based on an advanced, geographic information system (GIS) dataset that was created by using Landsat 5 Thematic Mapper (TM) imagery and digital orthophoto quarter quadrangles (DOQQs). Our primary data were derived by classifying the land-water interface on 30-meter (m) Landsat 5 TM imagery. To improve upon our classification of the Landsat TM data, we also used a digitized land-water interface from 1998 digital orthophoto quarter quadrangles (DOQQs). The objective of building this GIS dataset was to more specifically define land-water relationships over time in coastal Louisiana. To that end, we matched acquisition dates of the Landsat TM imagery as closely as possible with the dates of surveys used to produce the 1978, 1988, and 1997 maps of vegetation (collected in Chabreck and others, 2001) and the 2001 map of vegetation by Linscombe and others. This GIS dataset provides the most detailed analysis

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of vegetation shifts to date. In the current study, we have attempted to explain these vegetation shifts by interpreting them in the context of precipitation records, data from the Palmer Drought Severity Index (PDSI), and salinity data.

Interpreting shifts in marsh vegetation types by using climate and salinity data will provide a history of changes and a better understanding of factors influencing these changes and will, therefore, improve our ability to make predictions about future marsh loss related to vegetation changes. Rates of local precipitation (monthly and annual) influence the salinities of water and soil in coastal marshes, and drought data provide a good indication of normal, wet, or dry periods. The assumption was made that soil and water salinities occurring during the 18 months prior to our aerial surveys of vegetation would determine marsh types during the survey periods.

The ability to understand past dynamics and to anticipate future trends in vegetation change and related land loss in the coastal region of Louisiana is a vital part of ongoing and future efforts to conserve its critical wetland ecosystem. With our analysis, we hope to provide Federal and State agencies, as well as researchers and interested parties in the private sector, with current and detailed information upon which to base future decisions in the interest of preserving the coastal marshes of Louisiana.

In our analysis, we used the GIS database described above to study areal changes in marsh coverage within the nine hydrologic basins of coastal Louisiana defined by the Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1993. In the Louisiana chenier plain, these basins include the Calcasieu/Sabine, Mermentau, and Teche/Vermilion; in the deltaic plain, the basins include the Atchafalaya, Terrebonne, Barataria, Mississippi River Delta, Breton Sound, and Pontchartrain (fig. 1). For analysis of vegetation changes in these basins, we reviewed PDSI records and precipitation data available from the National Oceanic & Atmospheric Association's (NOAA) National Climatic Data Center (NCDC) for Louisiana climate divisions 7, 8, and 9 (southwestern, south central, and southeastern La., respectively) (fig. 2). Figure 2 shows an overlay of CWPPRA boundaries with the Louisiana climate divisions. Precipitation, including departures from normal, and the PDSI values were considered for each division as indicators of wet or dry conditions. For comparison between survey periods, we evaluated discrete water- salinity data collected by the Marine Fisheries Division of the Louisiana Department of Wildlife and Fisheries (LDWF) in seven coastal areas, including the Sabine National Wildlife Refuge, Cameron Prairie National Wildlife Refuge, and Rockefeller Wildlife Management Area and Game Preserve (fig. 3). These data provided a measure of existing salinities to compare with predictions of wetter or drier conditions based on precipitation and PDSI values and helped explain changes in marsh types.

In general, precipitation and PDSI values by climate division correctly predicted salinities as indicated by shifts in marsh vegetation type, and these fresh or saltier conditions were, in most instances, confirmed with available water salinity data; however, there were also instances when precipitation did not explain water salinity and water salinity data did not explain observed changes in marsh vegetation types. The available salinity data at some stations may not reflect hydrologic conditions that influenced marsh types observed during a survey. The location of salinity data sites was problematic in some basins. Salinity collection sites, used by Marine Fisheries Division, were associated with trawl samples for shrimp and tended to be in marshes with higher salinity values. Stations were not located in marshes with lower salinity values until the mid 1980s when finfish sampling was initiated. It is also probable that erosion and resultant land loss further changed hydrology between survey periods. Furthermore, during the process of compiling salinity data from the LDWF, it was pointed out that over time stations were abandoned or moved as a result of erosion.

Methods

Review of Past Efforts to Document Vegetation Types in Coastal Louisiana

Working in the southeastern portion of the State, Penfound and Hathaway (1938) conducted the earliest study of plant communities in coastal Louisiana. Their general approach to describing the marshes of southeastern Louisiana may have been influenced by earlier studies of salt marshes on the east coast. Based on the work of Penfound and Hathaway, the first map of vegetation types in coastal Louisiana was produced in 1949 (collected in Chabreck and others, 2001).

Nine marsh types, along with dominant and other important species listed for each type, were classified on the 1949 map. These nine marsh types included fresh marsh, floating fresh marsh, excessively drained salt marshes, brackish three-cornered grass (*Schoenoplectus americanus*) marsh, floating three-cornered grass (*Schoenoplectus americanus*) marsh, intermediate marsh (between brackish and fresh), leafy three-cornered grass (coco marsh) (*Schoenoplectus robustus*), sawgrass (*Cladium mariscus* ssp. Jamaicense) marsh, and sea rim (sand and shell deposits). The 1949 map and the six similar maps to follow in 1968, 1978, 1988, 1997 (collected in Chabreck and others, 2001), 2001 (Linscombe and others); and 2008 (Sasser and others) were all developed by wildlife biologists with the objective of evaluating marsh habitat to better understand and predict fish and wildlife productivity and to manage marshes for these resources.

For the 1968 map (collected in Chabreck and others, 2001), data were collected through visual field observations, and the identification of dominant plants was made by conducting an aerial survey (Bell G4-A helicopter) along north/south transects spaced 7.5 minutes (min) (1 min is equal to approximately 1.0 mile [mi] or 1.6 kilometer [km]) apart from the Texas State line to the Mississippi State line. Data

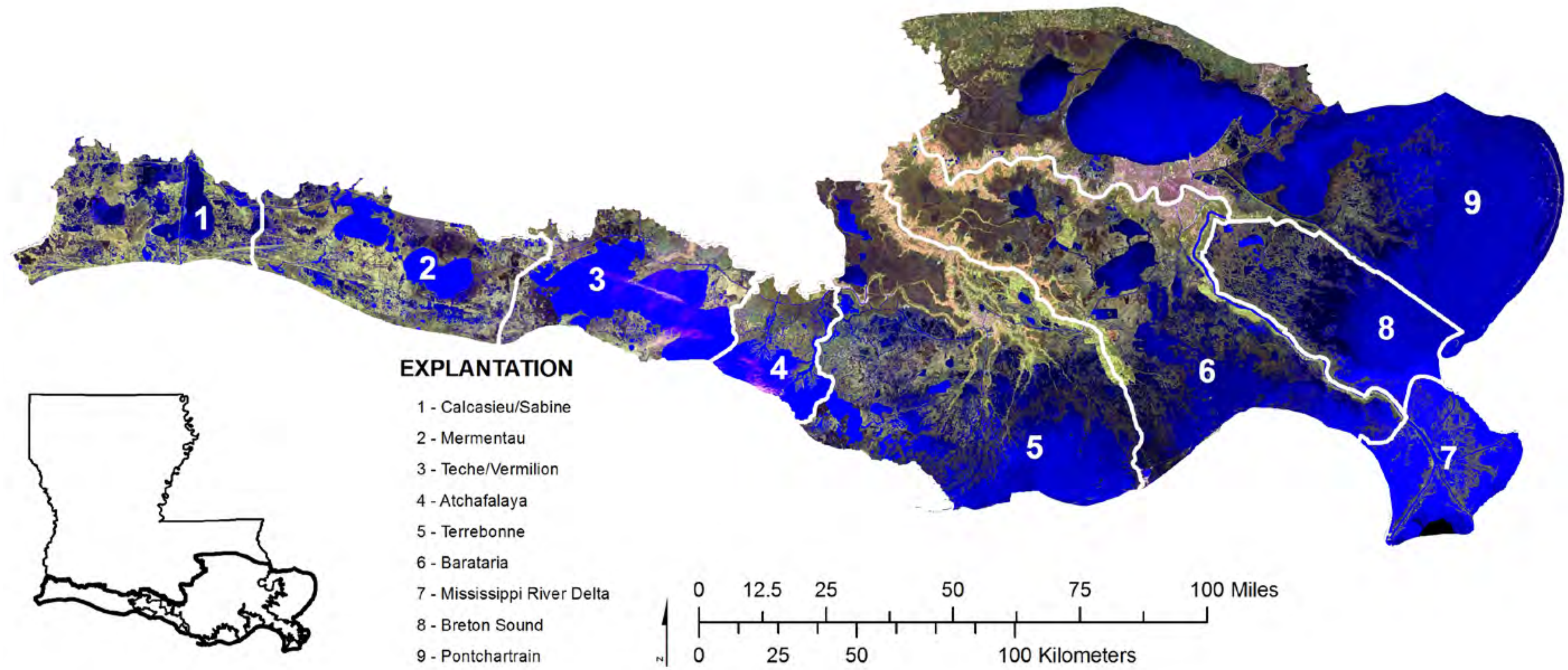


Figure 1. Coastal Louisiana, including hydrologic basins (as defined by the Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1993).

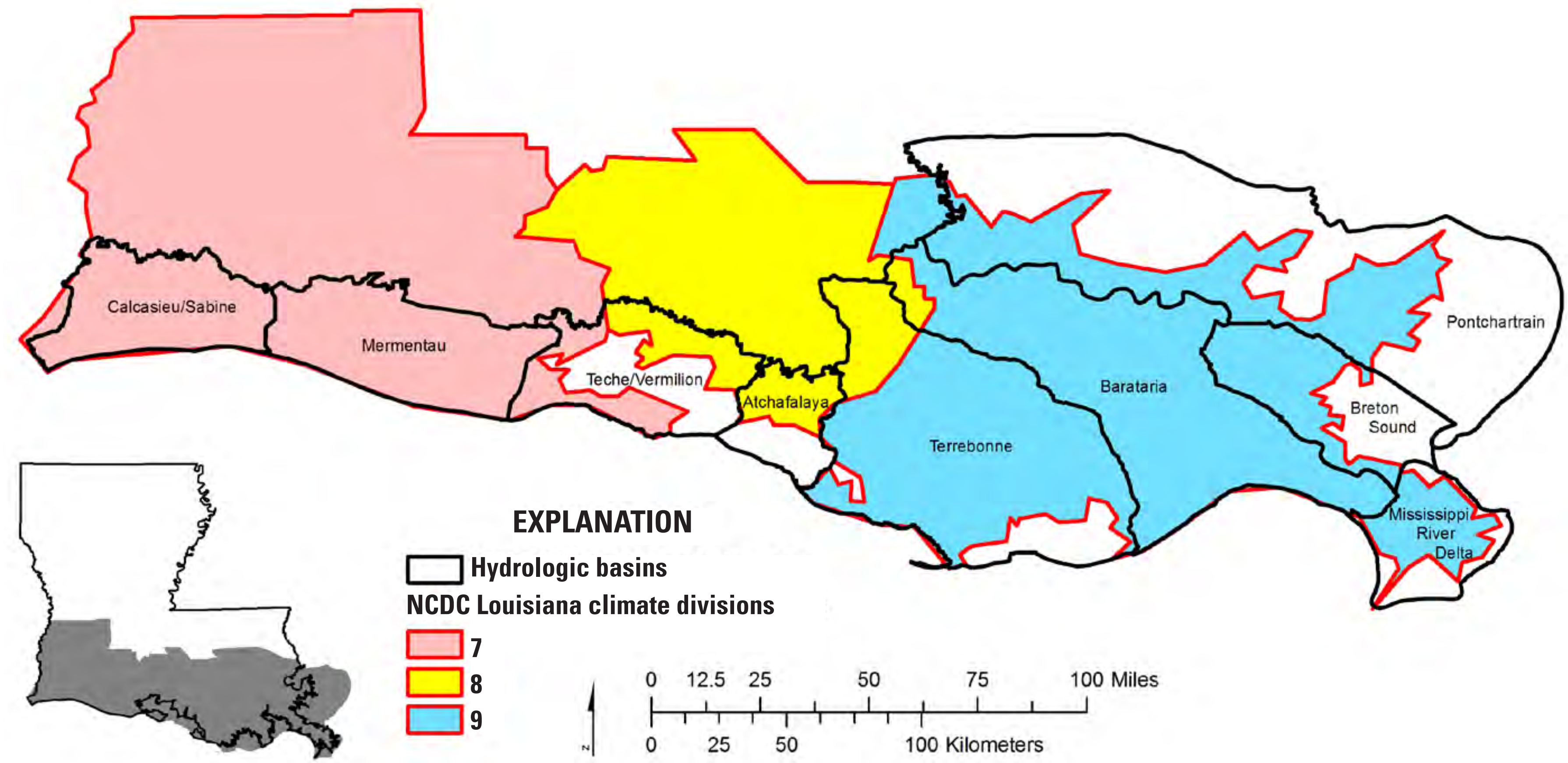


Figure 2. Louisiana hydrologic basins (as defined by the Louisiana Coastal Wetlands Conservation and Restoration Task Force [1993]) along with Louisiana climate divisions (as defined by the National Climatic Data Center [NCDC]). For this study, we analyzed data for climate divisions 7, 8, and 9.

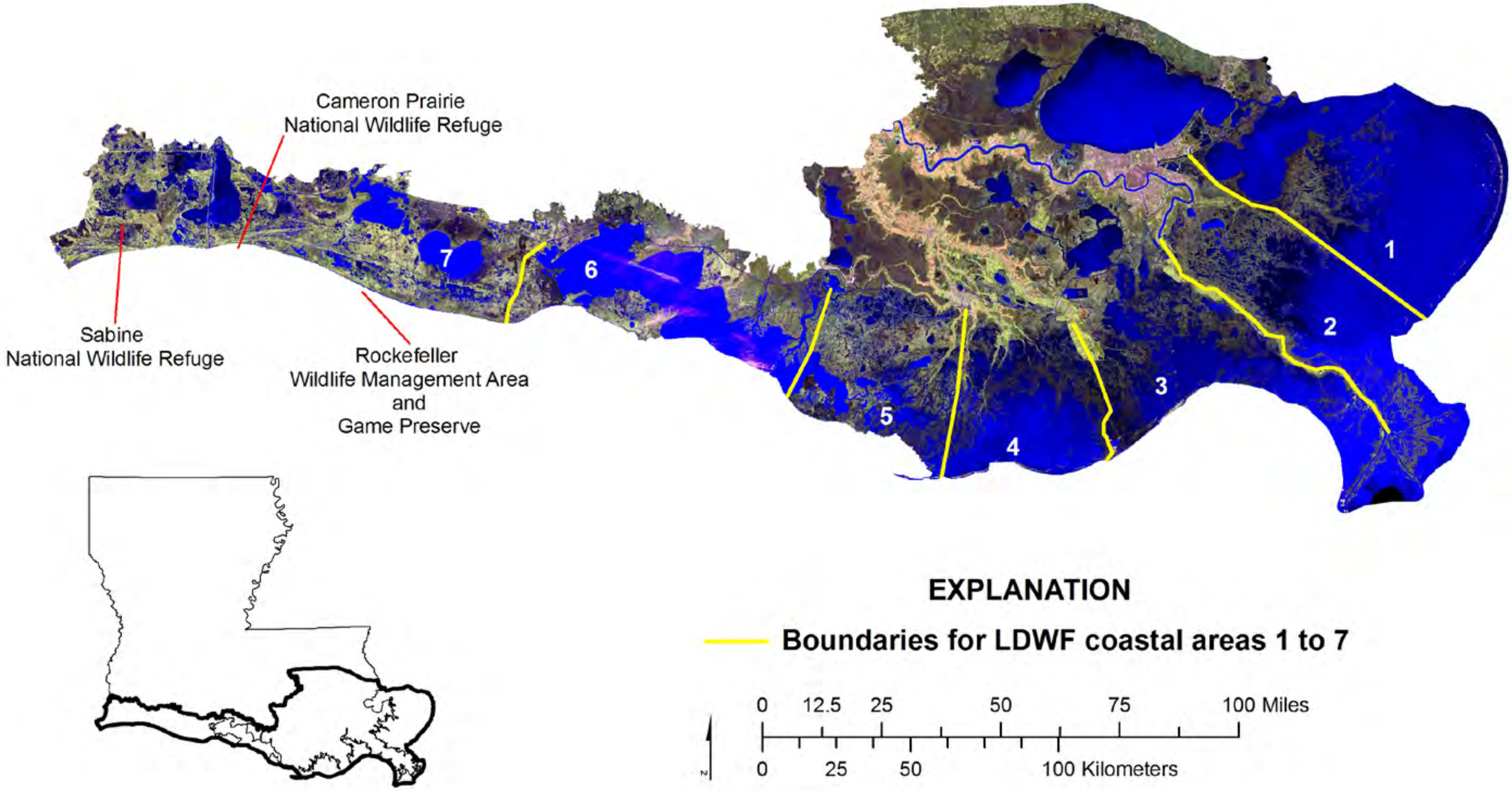


Figure 3. Coastal areas one through seven of the Louisiana Department of Wildlife and Fisheries (LDWF). Salinity data were collected by the LDWF in all areas, including the Sabine National Wildlife Refuge, Cameron Prairie National Wildlife Refuge, and Rockefeller Wildlife Refuge in coastal area seven.

on vegetation coverage, including species composition, were obtained at predetermined stations at intervals of a quarter of a mile (402.34 m) along each transect. The 1968 map was the first to delineate four marsh types in coastal Louisiana, which are described as follows: (1) saline (saltwater) marsh (combination of *Spartina alterniflora*, *Juncus roemerianus*, *Batis maritima*, *Avicennia germinans*, and *Distichlis spicata*), (2) brackish marsh (combination of *Spartina patens*, *Schoenoplectus americanus*, *Schoenoplectus robustus*, and *Eleocharis parvula*), (3) intermediate marsh (combination of *Spartina patens*, *Vigna luteola*, *Schoenoplectus californicus*, *Echinochloa walteri*, *Sagittaria* sp., *Cladium mariscus* spp., *jamaicense*, and *Phragmites australis*), and (4) fresh marsh (combination of *Panicum hemitomon*, *Hydrocotyle* sp., *Pontederia cordata*, *Sagittaria* sp., and *Alternanthera philoxeroides*).

Using the same four marsh classifications, the maps created in 1978, 1988, and 1997 (collected in Chabreck and others, 2001) and in 2001 by Linscombe and others were produced by using data collected during four aerial surveys (Bell 206 Jet Ranger). These aerial observations included notations of the dominant plant species present at predetermined stations along each transect. Each map was an update to the previous one, but some changes were made over the course of their production with regards to the spacing of transects and navigation methods.

During the 1978 aerial survey, north/south transects were added to the original transects used in the 1968 survey to create a spacing of 3.75 min (3.75 mi or 6.03 km). The spacing of the predetermined stations was increased from a quarter mile (402.34 m) to a half mile (804.67 m) along each transect. During the next aerial survey, additional transects were again added, which created a spacing of 1.87 min (1.87 mi or 3.01 km).

The aerial survey for the 1988 vegetation data was conducted in late summer of 1987 and was captured with ten 1:100,000-scale maps covering the entire coast. These maps were printed and dated August 1988 and are widely known among the local natural resources community as the 1988 vegetation maps; therefore, both the aerial survey and the vegetation data are noted as 1988. The vegetation data derived from the aerial survey were used to augment the 1988 National Wetlands Inventory (NWI) dataset. The modified 1988 NWI dataset and Landsat TM imagery were used to produce a "new" 1988 vegetation dataset.

The 1997 aerial survey by Chabreck and Linscombe was the first to incorporate Global Positioning System (GPS) navigation technology along transects during data collection.

The 2001 map and data by Linscombe and others were produced only in digital format and are posted on-line at http://brownmarsh.com/data/III_8.htm. In the current paper we do not analyze the 1968 survey because Landsat TM data were not available until the mid 1980s. We did not include results from the Sasser and others, 2008, report because it was not available when the study was started. An analysis of 2007 would be very interesting because of potential long-term impacts of Hurricanes Katrina and Rita, with significant marsh loss, changes in hydrology, and the extended drought following Rita.

Collection and Analysis of PDSI, Precipitation, and Salinity Data

The NCDC collects and combines data on precipitation, potential evaporation, and water surplus that are all calculated monthly to produce a PDSI value, http://www.ncdc.noaa.gov/temp-and-precip/time-series/. Within this index, normal values are from 0.5 to -0.5; negative values indicate drought (incipient drought values are –0.5 to –1.0, and extreme drought values are < -4.0), and positive values indicate wetness (incipient wetness values are 0.5 to 1.0, and extreme wetness values are >4.0).

Unpublished salinity data were collected from the Cameron Prairie and Sabine National Wildlife Refuges, Rockefeller Wildlife Management Area and Game Preserve, and the Marine Fisheries Division of the LDWF. We collected data from coastal areas 1 through 7 of the LDWF (fig. 3), which coincide with Louisiana climate divisions 7, 8, and 9 of the NCDC (fig. 2). Available data on average monthly and yearly salinities were reviewed from the listed sources for the four survey periods (1978, 1988, 1997, and 2001).

Along with salinity data, precipitation and PDSI data were compiled for a period of approximately 18 months prior to each aerial survey of vegetation. The 1978 and 1997 vegetation surveys were conducted in July of those years. The 1988 vegetation survey was conducted in September 1987, and the 2001 survey was conducted in June of that year. Dates for collection of precipitation and PDSI data were generalized to range from January to December of the year preceding each survey and from January to June of the year in which each survey occurred. For this study, we assumed that soil and water salinities occurring during an approximate period of 18 months prior to our vegetation surveys could influence marsh vegetation types during the survey periods. We recognize, however, that long periods of drought or wetness prior to those preceding (approximate) 18-month intervals could have had an extended impact on soil and water salinities. Likewise, extended effects from any extreme conditions occurring just prior to our aerial surveys may not have yet been realized. We therefore point to a potential weakness in the accuracy of our methodology. In terms of precipitation data, we were interested in departures from normal precipitation rates during the approximate 18-month intervals leading up to the vegetation surveys. For selected locations within a basin, PDSI and precipitation data were synthesized with reviews of available salinity measurements taken during the approximate 18-month periods of interest in order to help explain shifts in marsh types.

Analysis of Changes in Marsh Types within the Chenier Plain (Calcasieu/Sabine, Mermentau, and Teche/Vermilion Basins)

Overview of the Chenier Plain

The Louisiana coastal wetlands are divided into the chenier plain west of Vermilion Bay and the deltaic plain to its east. The chenier plain extends 322 km (200 mi) from Vermilion Bay in Louisiana to East Bay in Texas, and several rivers running north to south divide this area into six fairly distinct drainage systems (Gosselink and others, 1979). The chenier plain includes the Calcasieu/Sabine, Mermentau, and Teche/Vermilion hydrologic basins (fig. 1, but see individual basin maps within this report for specific localities), as defined by the Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1993. In discussing hydrodynamics in the chenier plain, Gosselink and others (1979) identify processes that control circulation in shallow estuaries as being river discharge, tides, winds, evaporation, and precipitation. They use a modular approach, developed by Lee and Rooth (1972) that provides an understanding of shallow estuaries. This approach divides all three of the hydrologic basins in the chenier plain into four subunits: the tidal region, the riverine region, the wind-driven region, and the wetland region. The geology of the chenier plain historically limited the influence of gulf waters into the area, but the shallow gulf passes located at the Calcasieu and Sabine Rivers were deepened for navigational purposes, and this deepening has dramatically increased saltwater intrusion. Vermilion Bay is essentially open to the gulf but is greatly influenced by freshwater from the Atchafalaya River. The subunits of these basins are influenced by freshwater input from local precipitation and river discharge. The extent of this influence varies annually with local and basin precipitation and related river discharge.

Gosselink and others (1979) discussed the Calcasieu/Sabine basin separately from the other basins of the chenier plain because the freshwater budget of the Calcasieu/Sabine basin is dominated by river discharge, while the other basins are dependent on local precipitation. The hydrologic subunits dominated by wind-driven currents are large shallow lakes such as the Sabine and Calcasieu Lakes. These systems are tidally impacted, but their north-south orientation and prevailing north-south winds dramatically change water levels and salinity quickly. The Gulf Intracoastal Waterway and adjacent levees, the system of navigational locks in the Mermentau basin, and numerous canals and levees interact to form irregular patterns of marsh types when compared to the deltaic plain (Gosselink and others, 1979).

A study completed in 2002 by the Louisiana Department of Natural Resources (LDNR) presented information for both the Mermentau and the Calcasieu/Sabine basins, including all available hydrologic records, elevation data, and results of landscape-change analysis and hydrologic modeling. For the 2002 report, LDNR also interviewed managers and reviewed records to produce a general description of land management in the Mermentau and Calcasieu/Sabine basins.

Calcasieu/Sabine Basin

Literature Review

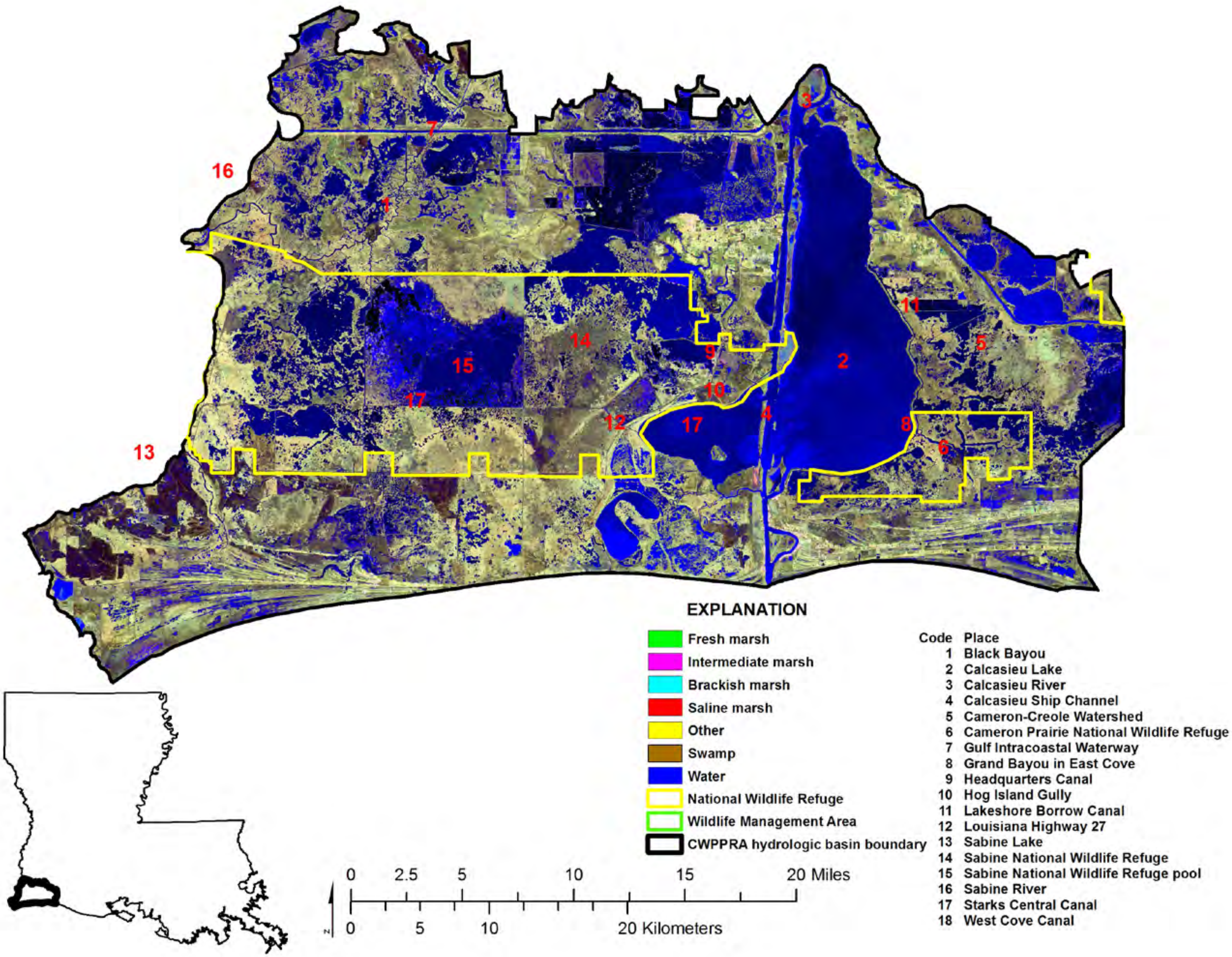
Chabreck and Linscombe (1982) compared changes in marsh types between the 1968 and 1978 aerial surveys and reported that vegetation in this basin (fig. 4) shifted to a more saline (saltwater marsh) profile over an area of 17,920 acres (7,252 hectares [ha]). Total area of the Calcasieu/Sabine basin is 574,265 acres (232,405ha) (table 1).

The Calcasieu/Sabine Cooperative River Basin Study Report was completed by the Natural Resources Conservation Service (NRCS) in 1999. This study involved several agencies working cooperatively to evaluate problems of water quality and habitat loss and to develop strategies for each hydrologic unit in the basin. This detailed report provides a history of the basin and human activities that have introduced water with higher salinity into the Sabine and Calcasieu Lakes and the canals connecting the interior of the Sabine National Wildlife Refuge to these lakes. Visser and others (1998) also described vegetation of the chenier plain in 1997 and compared those with the Mississippi River deltaic plain.

The LDNR (2002) compiled all available hydrologic data for the basin. Study results found a negative relationship between salinity and Sabine River discharge (higher river discharge with reduced salinity) at four of nine NOAA stations in Sabine Lake. This study also found significant relationships among levels of salinity at Sabine National Wildlife Refuge and Sabine River discharge, Calcasieu River water level, precipitation, and time of year. This report concluded that with the exception of the east end of the Sabine National Wildlife Refuge, interior salinities are more influenced by the Sabine River. For most of the salinity stations at Sabine National Wildlife Refuge (32 out of 38), no long-term salinity trend was detected. Data at five stations indicated increased salinities and at one station decreased salinity. The LDNR (2002) also looked at habitat shifts in this basin from 1949 through 1997. The analysis of habitat by LDNR showed a long-term trend towards freshening of the central and eastern basin and salinity increases adjacent to the Calcasieu Ship Channel and in some marshes near Sabine Lake.

Salinities collected by refuge personnel at eight locations across the Sabine National Wildlife Refuge over 27 years (1966–93) show a long-term average salinity of

A


EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Black Bayou
2 Calcasieu Lake
3 Calcasieu River
4 Calcasieu Ship Channel
5 Cameron-Creole Watershed
6 Cameron Prairie National Wildlife Refuge
7 Gulf Intracoastal Waterway
8 Grand Bayou in East Cove
9 Headquarters Canal
10 Hog Island Gully
11 Lakeshore Borrow Canal
12 Louisiana Highway 27
13 Sabine Lake
14 Sabine National Wildlife Refuge
15 Sabine National Wildlife Refuge pool
16 Sabine River
17 Starks Central Canal
18 West Cove Canal
0 2.5 5 10 15 20 Miles
0 5 10 20 Kilometers
N
1
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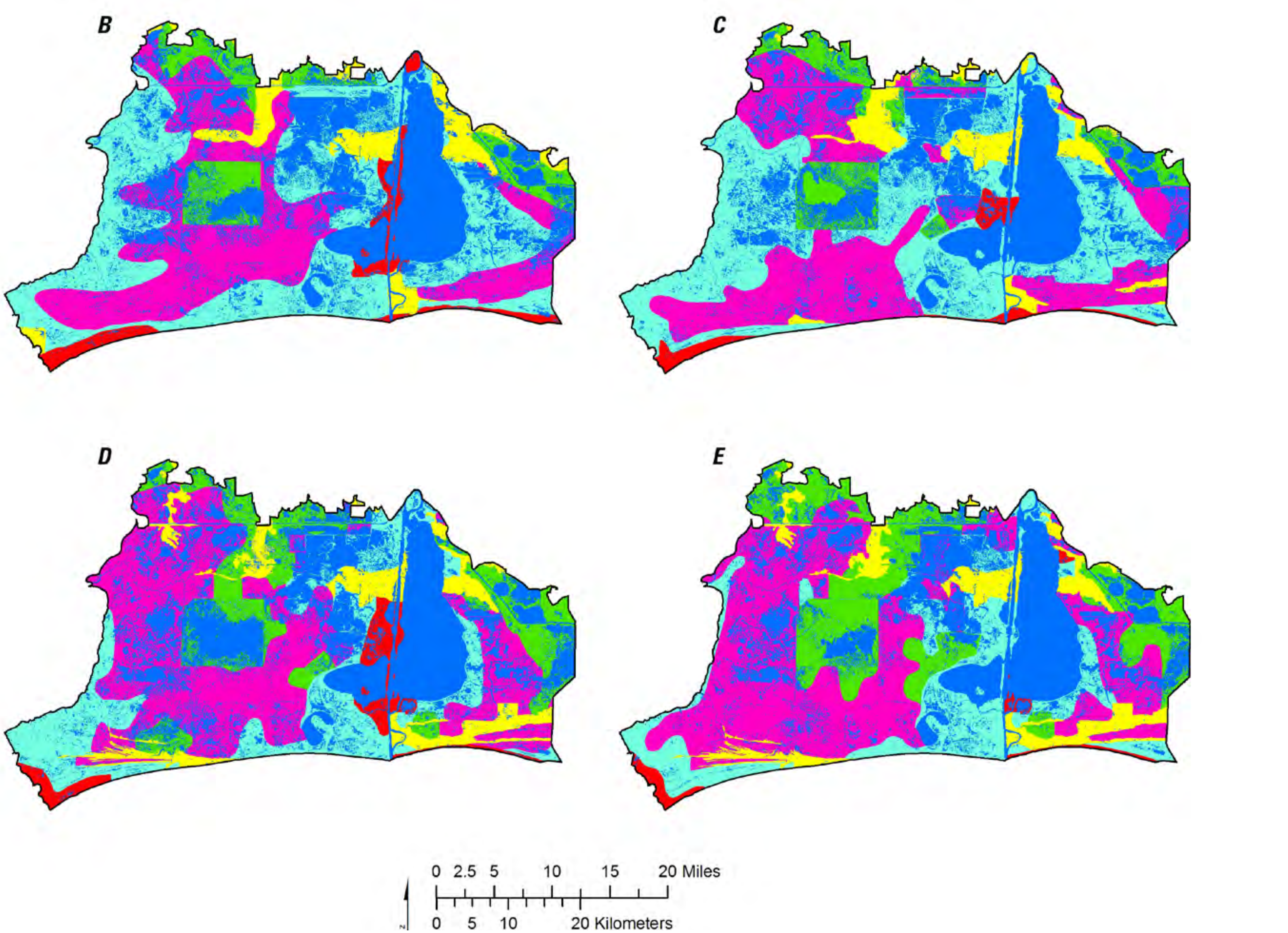

Figure 4. Localities and marsh types in the Calcasieu/Sabine basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Calcasieu/Sabine basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

Table 1. Habitat coverages by area and percentages per hydrologic basin.

[Basin areas and habitat coverages provided in acres (hectares). The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988]

Habitat	Year 1978	Year 1988	Year 1997	Year 2001	Percentage 1978	Percentage 1988	Percentage 1997	Percentage 2001
Calcasieu/Sabine, 574,265 (232,405)								
Fresh marsh	37,655 (15,239)	38,687 (15,656)	61,526 (24,899)	90,242 (36,521)	10.88	10.97	19.70	26.04
Intermediate marsh	129,137 (52,261)	136,244 (55,138)	147,300 (59,612)	167,022 (67,593)	37.31	38.63	47.16	48.20
Brackish marsh	159,517 (64,556)	164,436 (66,547)	84,372 (34,145)	81,051 (32,801)	46.09	46.62	27.01	23.39
Saline marsh	19,776 (8,003)	13,366 (5,409)	19,172 (7,758)	8,176 (3,308)	5.71	3.79	6.14	2.36
Total marsh	346,087 (140,061)	352,735 (142,752)	312,370 (126,416)	346,492 (140,225)				
Mermentau, 733,042 (296,662)								
Fresh marsh	270,703 (109,553)	222,100 (89,883)	268,691 (108,739)	277,092 (112,139)	57.82	47.38	60.18	57.28
Intermediate marsh	82,184 (33,260)	131,888 (53,375)	108,075 (43,738)	121,091 (49,005)	17.55	28.13	24.20	25.03
Brackish marsh	102,113 (41,325)	92,555 (37,457)	47,557 (19,246)	60,212 (24,367)	21.81	19.74	10.65	12.45
Saline marsh	13,165 (5,327)	22,229 (8,996)	22,187 (8,979)	25,373 (10,268)	2.81	4.74	4.97	5.24
Total marsh	468,167 (189,467)	468,773 (189,712)	446,511 (180,703)	483,769 (195,781)				
Teche/Vermilion, 659,799 (267,021)								
Fresh marsh	30,682 (12,417)	51,005 (20,641)	56,824 (22,996)	33,526 (13,568)	12.42	20.41	22.93	13.66
Intermediate marsh	47,260 (19,126)	46,876 (18,971)	133,796 (54,147)	123,883 (50,135)	19.14	18.76	53.98	50.49
Brackish marsh	163,368 (66,115)	146,836 (59,424)	54,832 (22,190)	83,025 (33,600)	66.15	58.75	22.12	33.84
Saline marsh	5,645 (2,284)	5,205 (2,106)	2,411 (975)	4,927 (1,994)	2.29	2.08	0.97	2.01
Total marsh	246,957 (99,943)	249,924 (101,144)	247,864 (10,0310)	245,363 (99,298)				
Atchafalaya, 277,246 (112,201)								
Fresh marsh	69,807 (28,251)	68,843 (27,860)	57,056 (23,090)	75,609 (30,599)	99.59	99.72	99.92	99.03
Intermediate marsh	25 (10)	0 (0)	25 (10)	667 (270)	0.04	0.00	0.04	0.87
Brackish marsh	263 (106)	195 (79)	17 (7)	69 (28)	0.38	0.28	0.03	0.09
Saline marsh	0 (0)	0 (0)	0 (0)	0 (0)	0.00	0.00	0.00	0.00
Total marsh	70,096 (28,367)	69,039 (27,940)	57,100 (23,108)	76,346 (30,897)				
Terrebonne, 1,712,685 (693,124)								
Fresh marsh	219,149 (88,689)	246,676 (99,829)	241,529 (97,746)	245,195 (99,230)	34.95	38.65	43.36	44.05
Intermediate marsh	80,585 (32,612)	57,153 (23,130)	60,698 (24,564)	51,768 (20,950)	12.85	8.95	10.90	9.30
Brackish marsh	147,500 (59,693)	138,653 (56,112)	103,688 (41,962)	116,214 (47,031)	23.52	21.72	18.61	20.88
Saline marsh	179,774 (72,754)	195,794 (79,238)	151,171 (61,179)	143,418 (58,041)	28.67	30.68	27.14	25.77
Total marsh	627,009 (253,750)	638,277 (25,8310)	557,087 (225,453)	556,597 (225,254)				
Barataria, 1,607,065 (650,379)								
Fresh marsh	152,633 (61,770)	175,526 (71,035)	210,240 (85,084)	172,124 (69,658)	29.46	33.30	44.54	38.50
Intermediate marsh	89,835 (36,356)	72,850 (29,482)	65,763 (26,614)	72,284 (29,253)	17.34	13.82	13.93	16.17
Brackish marsh	112,471 (45,517)	121,826 (49,303)	76,975 (31,151)	68,630 (27,774)	21.71	23.11	16.31	15.35
Saline marsh	163,212 (66,052)	156,889 (63,493)	119,091 (48,196)	134,046 (54,248)	31.50	29.76	25.23	29.98
Total marsh	518,153 (209,696)	527,093 (213,314)	472,071 (191,047)	447,086 (180,935)				

Table 1. Habitat coverages by area and percentages per hydrologic basin.—Continued

[Basin areas and habitat coverages provided in acres (hectares). The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988]

Habitat	Year				Percentage			
	1978	1988	1997	2001	1978	1988	1997	2001
Mississippi River Delta, 403,888 (163,453)								
Fresh marsh	47,539 (19,239)	48,863 (19,775)	52,983 (21,442)	74,115 (29,994)	54.74	55.04	65.58	76.57
Intermediate marsh	3,4297 (13,880)	37,763 (15,282)	27,717 (11,217)	22,339 (9,040)	39.49	42.54	34.31	23.08
Brackish marsh	3,974 (1,608)	1,242 (502)	59 (24)	312 (126)	4.58	1.40	0.07	0.32
Saline marsh	1,034 (418)	907 (367)	30 (12)	23 (9)	1.19	1.02	0.04	0.02
Total marsh	86,845 (35,146)	88,777 (35,928)	80,791 (32,696)	96,790 (39,171)				
Breton Sound, 605,327 (244,976)								
Fresh marsh	0 (0)	1,231 (498)	3,606 (1,459)	7,050 (2,853)	0.00	0.60	1.90	3.90
Intermediate marsh	6,323 (2,559)	2,935 (1,188)	90,836 (36,761)	92,931 (37,609)	3.27	1.42	47.86	51.43
Brackish marsh	132,400 (53,582)	132,689 (53,699)	62,673 (25,364)	49,087 (19,865)	68.43	64.32	33.02	27.17
Saline marsh	54,769 (22,165)	69,441 (28,103)	32,670 (13,221)	31,615 (12,794)	28.31	33.66	17.21	17.50
Total marsh	193,493 (78,306)	206,298 (83,489)	189,786 (76,806)	180,684 (73,122)				
Pontchartrain, 2,704,537 (1,094,526)								
Fresh marsh	8,467 (3,426)	34,522 (13,971)	25,595 (10,358)	9,886 (4,001)	2.92	10.78	9.04	3.67
Intermediate marsh	28,856 (11,678)	38,336 (15,514)	49,735 (20,128)	52195 (21,123)	9.96	11.97	17.57	19.36
Brackish marsh	179,918 (72,813)	146,255 (59,189)	115,694 (46,821)	110,068 (44,544)	62.12	45.67	40.88	40.82
Saline marsh	72,410 (29,304)	101,095 (40,913)	91,990 (37,228)	97,517 (39,465)	25.00	31.57	32.50	36.16
Total marsh	289,654 (117,222)	320,209 (129,588)	283,016 (114,536)	269,668 (109,134)				
Coastal Louisiana, 9,277,854 (3,754,748)								
Fresh marsh	836,639 (338,587)	887,457 (359,154)	978,054 (395,818)	984,844 (398,566)	29.39	30.38	36.96	36.44
Intermediate marsh	4985,06 (201,745)	524,050 (212,083)	683,948 (276,793)	704,184 (284,983)	17.51	17.94	25.84	26.05
Brackish marsh	1,001,529 (405,318)	944,690 (382,316)	545,871 (220,914)	568,672 (230,141)	35.19	32.34	20.63	21.04
Saline marsh	509,788 (206,311)	564,930 (228,627)	438,727 (177,552)	445,097 (180,131)	17.91	19.34	16.58	16.47
Total marsh	2,846,463 (1,115,963)	2,921,129 (1,182,181)	2,646,601 (1,071,079)	2,702,799 (1,093,823)				

6.2 parts per thousands (ppt) (Paille, unpub. data, 1993). The higher salinities were generally east of the Sabine National Wildlife Refuge pool (hereafter referred to as “the pool”) and associated with Calcasieu Lake and the Calcasieu Ship Channel. The pool is an area of impounded fresh marsh located in the center of the Sabine National Wildlife Refuge. In the current study, changes in percentages of marsh types (fig. 5) were calculated for the Calcasieu/Sabine basin for the four survey periods.

Comparison of Data for the 1978–88 Study Period

Overview of Marsh Changes

Percentages of vegetation coverage during the 1978 and 1988 vegetation surveys are shown in figure 5. Comparing these surveys, we estimate that during the interval fresh marsh remained the same at 11 percent, intermediate marsh increased from 37 to 39 percent, brackish marsh increased from 46 to 47 percent, and saline (saltwater) marsh declined from 6 to 4 percent; thus, the changes in marsh types during this interval in the Calcasieu/Sabine basin were minor.

Figure 4 shows spatial changes within the marsh types observed between the 1978 and 1988 surveys. During the 1978 vegetation survey, we observed two fingers of intermediate marsh extending westward and southwestward from the pool, but by the 1988 survey, those areas of intermediate marsh had changed to brackish. Another change that occurred between the 1978 and 1988 surveys is that brackish marsh increased immediately to the east and south of the pool and also to the west of West Cove Canal (fig. 4). Brackish marsh also moved further eastward into the Cameron-Creole Watershed Management Project (WMP) managed by the National Resources Conservation Service (NRCS).

Precipitation

Precipitation rates for the Calcasieu/Sabine basin, which falls within Louisiana climate division 7 (fig. 2) of the NCDC, are presented in table 2. Division 7 records for 1977 indicate that it was a wet year, with a total of 64.47 inches (163.75 cm), a 7.08-inch (17.98-cm) departure from normal. The precipitation from January to June 1978 was slightly below normal (-1.48 inches [-3.76 cm]). The wet and dry cycles during this period resulted (at least theoretically)

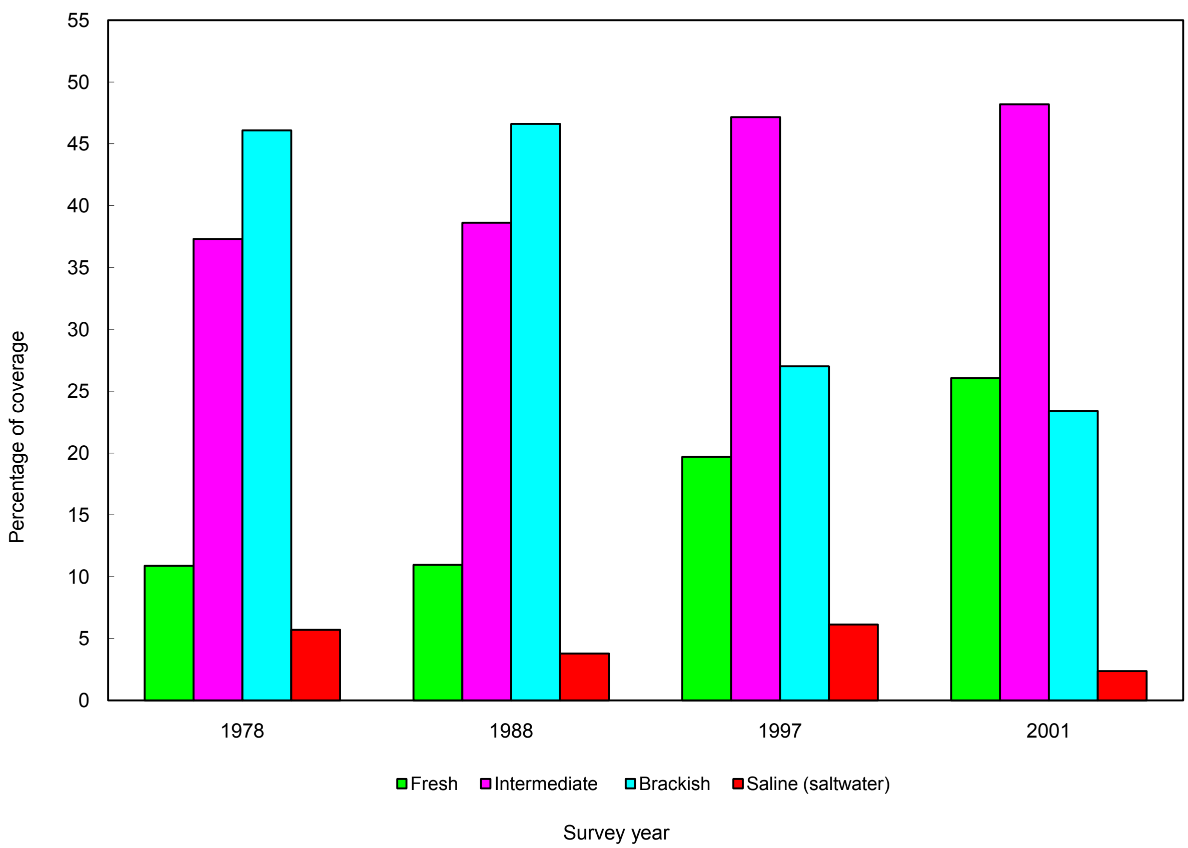

Figure 5. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Calcasieu/Sabine basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

in average salinities impacting vegetation prior to the 1978 survey. The PDSI values shown in figure 6 indicate both wet and dry periods in division 7 from January 1977 to June 1978.

Precipitation records indicate that 1986 was a dry year in division 7, with a total of 53.99 inches (137.13 cm), -3.35-inch (-8.5-cm) departure from normal (table 2). The precipitation from January to June 1987 was slightly above normal (2.56 inches [6.50 cm]). The PDSI values shown in figure 6 indicate dry conditions in early 1986 and slightly wet in late 1986 and early 1987. Precipitation for this year can be interpreted as nearly average.

Salinity

The availability of detailed salinity data from Sabine National Wildlife Refuge allowed a detailed analysis of spatial changes (unpub. data, 1993). The average salinity on Sabine National Wildlife Refuge during 1986 was 9.1 ppt, and during the first six months of 1987 the salinity averaged 4.9 ppt. These salinities, if averaged, appear to be only slightly higher than salinities in 1977 (5.4 ppt) and early 1978 (7.3 ppt). The similarity in salinity between the 1978 and 1988 vegetation surveys appears to reflect similarity in precipitation during these periods.

Table 2. Precipatation (in inches) by month, total annual, and departure from normal (annual) in Louisiana divisions 7, 8, and 9 of the National Climatic Data Center, 1977–2001.

	Month													
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total, annual precipitation	Departure from normal
Division 7														
1977	5.77	2.11	3.87	7.82	1.61	4.53	5.29	11.22	4.33	5.28	8.85	3.79	64.47	7.08
1978	7.85	2.55	1.58	1.58	1.61	6.74								
1986	2.44	1.96	2.65	2.48	5.02	6.69	4.01	3.36	4.90	5.51	7.97	7.00	53.99	-3.35
1987	7.03	6.46	3.55	0.34	6.23	9.42								
1996	3.47	1.51	1.58	3.22	1.38	6.05	5.09	8.61	7.72	8.75	4.48	3.93	55.79	-3.27
1997	5.63	9.08	4.36	8.15	6.32	4.87								
2000	1.28	0.74	2.35	3.88	6.53	5.52	3.36	2.33	3.30	1.92	12.72	2.73	46.66	-12.40
2001	5.90	1.35	9.17	2.05	1.21	12.35								
Division 8														
1977	5.74	2.24	2.92	7.28	1.82	2.74	7.06	11.67	8.96	5.02	9.57	4.27	69.29	9.59
1978	10.09	2.18	3.40	3.73	6.22	9.57								
1986	3.52	3.34	1.98	2.27	3.88	7.78	7.79	5.39	4.60	4.81	5.91	6.49	57.76	-1.52
1987	7.37	7.13	3.07	1.60	6.43	12.65								
1996	2.94	2.14	2.56	2.98	1.78	8.25	5.25	8.87	6.79	9.45	2.76	5.41	59.18	-2.07
1997	4.70	6.20	3.65	8.04	7.36	10.00								
2000	2.68	0.88	3.11	0.92	0.72	6.05	5.36	3.37	5.23	1.25	13.43	3.09	46.09	-15.16
2001	4.49	2.37	10.23	1.45	2.02	20.47								
Division 9														
1977	5.58	2.35	4.13	4.32	3.14	1.68	5.37	13.62	9.78	4.48	10.08	4.43	68.96	7.83
1978	11.40	2.93	4.15	3.59	6.40	6.99								
1986	3.37	3.97	2.44	1.47	4.19	5.89	4.67	5.80	3.76	4.06	6.16	5.52	51.30	-9.88
1987	7.81	6.52	5.37	1.77	5.17	11.95								
1996	4.13	2.42	3.94	3.69	1.58	7.08	7.91	7.17	5.54	2.12	2.46	6.48	54.52	-7.11
1997	5.30	6.05	3.95	6.01	7.81	5.64								
2000	2.58	0.85	3.93	0.98	0.44	6.93	2.66	4.04	7.71	2.16	10.63	2.98	45.89	-15.74
2001	4.97	6.04	5.90	7.07	1.26	20.62								

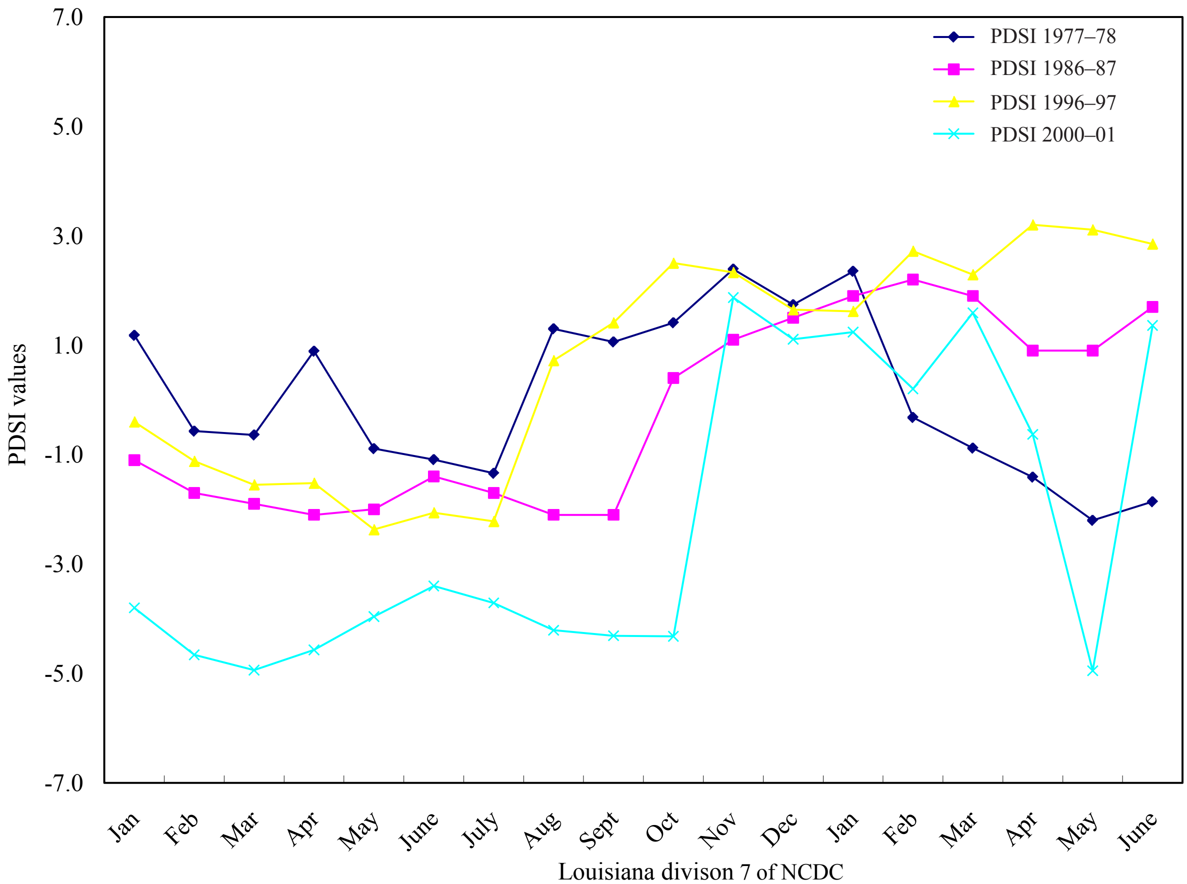

Figure 6. Palmer Drought Severity Index (PDSI) values for Louisiana climate division 7 (fig. 2) of the National Climatic Data Center (NCDC) during survey periods from January 1977 to June 2001. Normal values = 0.5 to -0.5; incipient drought values = –0.5 to –1.0; extreme drought values = < -4.0), incipient wetness values = 0.5 to 1.0; extreme wetness values = >4.0.

The increase in brackish marsh immediately to the east and south of the pool and also to the west of West Cove during the interval is likely the result of increasing salinity levels to the west of and in the Calcasieu Ship Channel (11.9 ppt in 1978 and 17.6 ppt in 1987). These changes occurred in spite of the fact that in 1981, water control structures had been installed in the Headquarters Canal, Hog Island Gully, and the West Cove Canal (fig. 4) in order to reduce salinities to the east and southeast of the pool; however, records indicate that the tainter gates on these structures were left in the open position until 1988, when improvements funded through CWPPRA allowed operation of the gates in order to reduce saltwater intrusion (Louisiana Department of Natural Resources, 2002). Because of saltwater intrusion, salinity averages near Headquarters Canal (just west of the Calcasieu Ship Channel) increased from 10.0 ppt in 1977 to 18.4 ppt in 1986. Again, these increases in salinity likely explain the shift from intermediate to brackish marsh that we observed during the 1978 and 1988 surveys of vegetation. Precipitation during these periods does not explain the higher salinity values in the Calcasieu Ship Channel.

Movement of brackish marsh further eastward into the Cameron-Creole Watershed WMP is explained by an increase in average salinities taken at the mouth of Grand Bayou in the East Cove of Calcasieu Lake, which were 10 ppt during 1977–78 and 14.1 ppt during 1986–87.

Comparison of Data for the 1988–97 Study Period

Overview of Marsh Changes

Figure 5 shows dramatic changes in percentages of marsh types between the 1988 and 1997 vegetation surveys, while table 1 shows the acreage changes. The portion of fresh marsh in the Calcasieu/Sabine basin nearly doubled from 11 to 20 percent during this interval; the intermediate marsh type increased by 8 points from 39 to 47 percent; the brackish marsh type decreased by 20 points from 47 to 27 percent; and saline (saltwater) marsh did not change significantly (with a minimal increase of 4 to 6 percent).

Figure 4 demonstrates spatial changes within the marsh types between the two surveys. To the west of Calcasieu Lake, fresh marsh increased on the north side and northeastern corner of the pool, and intermediate marsh increased on all sides of the pool. Along Black Bayou (fig. 4), brackish marsh disappeared completely in 1997, and intermediate marsh pushed two-thirds of the way to the Sabine Lake shoreline directly west of the pool. Brackish marsh was also eliminated along the Starks Central Canal on the southern side of the pool, and on the eastern side of the pool, intermediate marsh moved eastward half way to Calcasieu Lake. Fresher conditions were also obvious east of Calcasieu Lake in the Cameron-Creole WMP. Figure 4 shows that intermediate marsh moved westward by 8.0 mi (12.9 km) from Louisiana Highway 27 toward Calcasieu Lake. This shift of intermediate marsh left a strip of brackish marsh along the shoreline that measured about 1.3-mi (2.1-km) wide. Fresh marsh moved 4.5 mi (7.2 km) westward away from Louisiana Highway 27.

Precipitation

Figure 6 shows PDSI values for this period in division 7. As discussed earlier, precipitation during 1986–87 indicated a -0.79-inch (-2-cm) departure from normal. During 1996–97, precipitation was 94.2 inches (239.27 cm) (table 2), a 4.67-inch (11.86-cm) departure from normal, resulting in the classification of a wet 18 months. During this period, PDSI values indicated drier than normal conditions from January to July 1996, then wetter than normal for the rest of the period.

Salinity

Salinity data leading up to the 1997 vegetation survey clearly shows the shift to fresher conditions as a result of the wetter period in 1996–97. The average salinity across five stations on Sabine National Wildlife Refuge from January 1996 through June 1997 was 7 ppt, but the average from January 1997 through June 1997 was only 3.5 ppt. During this later period, the salinities averaged 2.5 ppt near Sabine Lake, 1.6 ppt on the southeastern corner of the pool, and 5.5 ppt near Calcasieu Lake.

Salinities in Calcasieu Lake near the Grand Bayou water-control structure (part of the Cameron-Creole WMP) averaged 14.1 ppt in 1986 and during the first six months of 1987. During the same months in 1996 and 1997, salinities averaged 11 ppt at the Grand Bayou water-control structure, but this average perhaps overstates the salinity levels when compared to lows occurring at other times during 1996–97. In 1996, the average of salinity inside the water-control structure was only 6 ppt, and in 1997 the average salinities dipped to 1.7 ppt from January through June. These salinities from 1996 and 1997 were the lowest salinities recorded in the unit between 1989 and 2000.

Salinity levels between the 1988 and 1997 vegetation surveys were probably influenced by engineering projects in the Calcasieu/Sabine basin. In 1989, a levee and five water-control structures were completed along the eastern shoreline of Calcasieu Lake as part of the NRCS Cameron-Creole WMP. In 1997 two plugs were installed in the Lakeshore Borrow Canal (fig. 4) (part of the Cameron-Creole WMP) to moderate water circulation and flow. Operation of the water control structures along the west side of Calcasieu Lake may have influenced the shift to fresher marsh types to the east of the pool.

Comparison of Data for the 1996–2001 Study Period

Overview of Marsh Changes

Based on a comparison of the percentages of marsh types in 1997 and 2001, we show that fresh marsh increased from 20 percent in 1997 to 26 percent in 2001. We also conclude that intermediate marsh remained almost constant (from 47 percent in 1997 to 48 percent in 2001); brackish marsh decreased only slightly (from 27 percent in 1997 to 23 percent in 2001); and saline (saltwater) marsh decreased from 6 percent in 1997 to only 2 percent in 2001 (fig. 5).

Figure 4 shows spatial changes within the marsh types between the vegetation surveys. On the western end of Sabine National Wildlife Refuge, intermediate marsh moved westward almost to Sabine Lake. Only a narrow strip of brackish marsh remained on the Sabine Lake shoreline to the west of the pool. Fresh marsh appeared outside of the pool to the south and southwest and outside of the Cameron-Creole WMP management units on the eastern end of the refuge. Some movement of marsh types occurred within the Cameron-Creole WMP, but overall, changes were minor. Furthermore, saline (saltwater) marsh that had been present to the west of the Calcasieu Ship Channel in 1997 disappeared by 2001.

Precipitation

Figure 6 shows PDSI values for this period in division 7. As previously discussed the 1996–97 period was wet. Although outside the scope of our study, which does not generally examine 1999 data, it is necessary to mention that in 1999 the precipitation in division 7 was 44.7 inches (113.5 cm), a departure from normal of -14.4-inch (-36.6-cm), indicating the onset of a drought. The drought continued in 2000 when precipitation in division 7 was 46.66 inches (118.52 cm), a -12.4-inch (-31.5-cm) departure from normal (table 2). Figure 6 documents that the drought continued through October 2000 and then reversed to wetter conditions from November 2000 to April 2001. Figure 5 shows an increase of fresher marsh types between 1997 and 2001. These changes occurred in spite of the preceding two years of severe drought, indicating that the wetter conditions from the fall of 2000 through the spring of 2001 must have made up for the drought in 1999 and 2000. This is difficult to understand when examining the -10.84-inch (-27.53-cm) departure from normal during 2000–01; however, this phenomenon may be an indication of the role of precipitation during fall and spring in determining marsh types during the following summer.

Salinity

As for the previous comparison periods, we reviewed salinity data leading up to the June 1997 and 2001 surveys (the data leading up to the 1997 survey has already been discussed). In 2000, salinities on the eastern side of Calcasieu Lake near Grand Bayou averaged 18.4 ppt, and in the Cameron-Creole WMP they averaged 10.9 ppt just west of Louisiana Highway 27. During the same year, salinities on the western end of the Sabine National Wildlife Refuge peaked in November at 19 ppt, and in the middle of the refuge, they reached 16.3 ppt. At the same time, salinity levels reached 30 ppt on the eastern end of the refuge near the Calcasieu Ship Channel. Less than a month later, however, conditions had changed dramatically because of increased precipitation. By December 19, salinities near Sabine Lake were 7.6 ppt, and in the interior of the refuge they were 1.7 ppt. Salinities continued to decline from January through June 2001, averaging only 6.2 ppt near Calcasieu Lake and only 3.2 ppt inside the Cameron-Creole WMP.

Marsh type changes between 1997 and 2001 in the Cameron-Creole WMP were slight and might be explained by the balancing out of very high salinities in 2000 and very low salinities in January through June 2001.

Mermentau Basin

Literature Review

There have been at least six major studies of wetland habitats in the Mermentau basin. The work of Gosselink and others (1979) was discussed earlier. Chabreck and Linscombe (1982) compared marsh type changes in the Mermentau basin between the 1968 and 1978 aerial surveys and reported that there was an increase of saline (saltwater) marsh across 34,304 acres (13,883ha). Total area of the Mermentau basin is 733,042 acres (296,662 ha). Under the auspices of the Louisiana Coastal Wetlands Restoration Plan, problems and potential solutions for the Mermentau basin were reviewed (Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1993). A study by the U.S. Army Corps of Engineers (USACE) was conducted in 1996 to evaluate methods to reduce wetland flooding in the Lakes Subbasin. The Lakes Subbasin, as defined by the Louisiana Coastal Wetlands Conservation and Restoration Task Force (1993) is the portion of wetlands north of Highway 82 within the Mermentau basin (see basin localities map within this report). The NRCS completed a cooperative study of the Mermentau basin in 1997 to examine ways to address water levels in the Lakes Subbasin. The NRCS study also examined alternative management by small hydrologic units. The LDNR (2002) study traced the history of hydrologic alterations in this system, including cultivation of rice in the freshwater reservoir, highway construction, management of wildlife habitat, construction of access canals for mineral production, and engineering of restoration projects funded by State and Federal government. The LDNR study also analyzed water levels, salinity fluctuations, marsh flooding, and shifts in habitat and concluded that there was a general freshening of marsh in the Lakes Subbasin and an increase in saline (saltwater) marsh in the Chenier Subbasin (fig. 8) between 1949 and 1997. The Chenier Subbasin, as defined by the Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1993, is the portion of wetlands south of Highway 82 within the Mermentau basin.

Comparison of Data for the 1978–88 Study Period

Overview of Marsh Changes

Figure 7 shows percentages of change in marsh types calculated for the 1978–1988 study period, while table 1 shows the acreage changes. Fresh and intermediate marsh showed the greatest changes between the 1978 and 1988 surveys, with fresh marsh decreasing from 58 to 47 percent and intermediate marsh increasing from 18 to 28 percent. Brackish marsh showed a slight decrease from 22 to 20 percent. While, saline (saltwater) marshes did not reflect this change, but showed a slight increase in coverage from 3 to 5 percent.

Figure 8 shows spatial changes within the marsh types between the surveys. Saline (saltwater) marsh replaced brackish marsh northeast of lower Mud Lake, to the east of the Mermentau River. On Rockefeller Wildlife Refuge, saline (saltwater) marsh moved up Little Constance Bayou, thus replacing brackish marsh north of Flat Lake and Big Constance Lake (fig. 8). Brackish marsh was replaced by intermediate marsh in the southeastern corner of the Mermentau basin. Intermediate marsh increased on the eastern end of Pecan Island, replacing brackish marsh to the south and to the east across the Freshwater Bayou Channel. To the west of the Mermentau River and north of the Grand Chenier Ridge (fig. 8), intermediate marsh moved into what had been fresh marsh. Changes in marsh types east of the Mermentau River and north of the Grand Chenier Ridge indicated higher salinities moving east into Little Pecan Bayou and east of Little Pecan Lake. In this area, brackish and intermediate marsh increased to the east and north, replacing fresh marsh (fig. 8). Spatial changes could not be explained by precipitation.

Precipitation

Along with the Calcasieu/Sabine basin, the Mermentau basin falls within Louisiana climate division 7 of the NCDC.

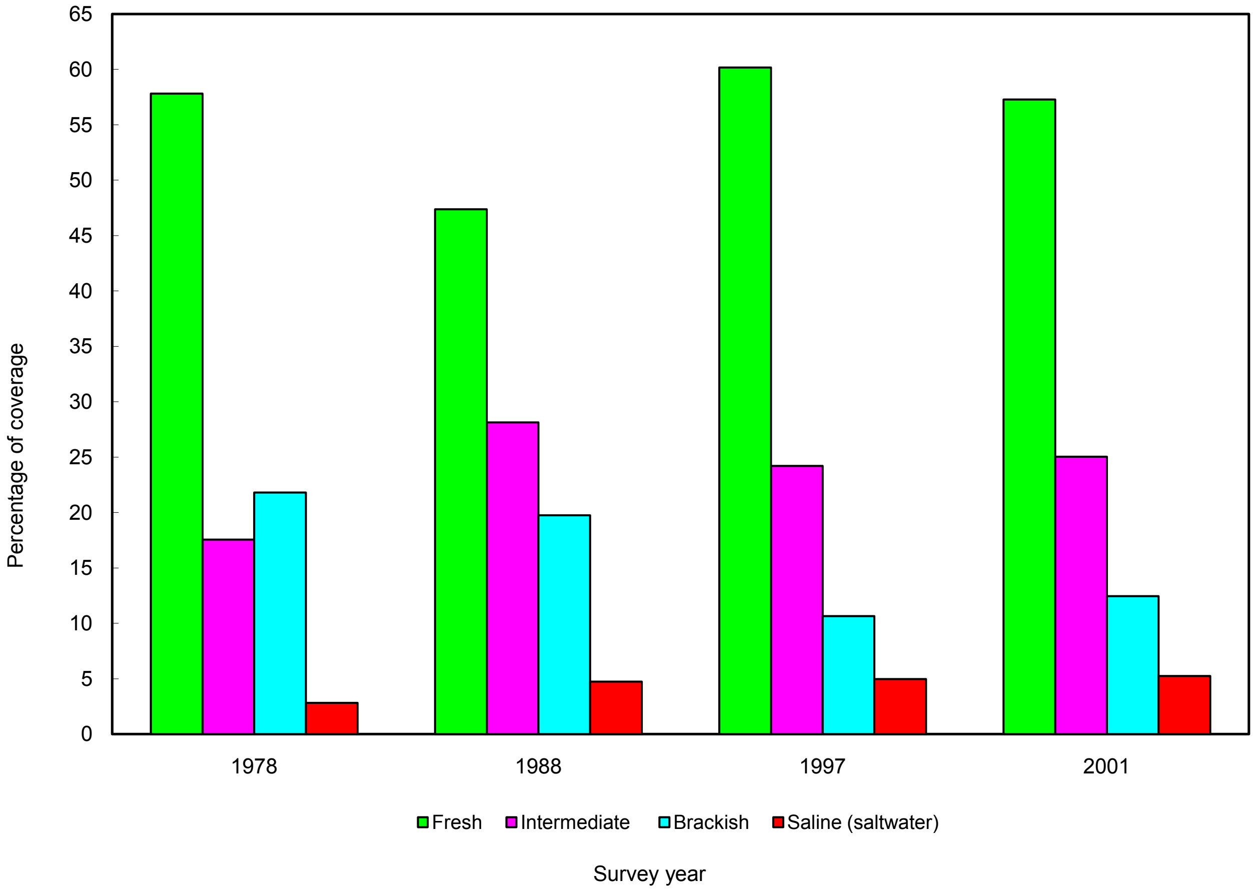

Figure 7. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Mermentau basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

The PDSI values for division 7 during this period are shown in figure 6 and are discussed in the section covering climate data for this period in the Calcasieu/Sabine basin. As previously noted, average precipitation levels in Louisiana climate division 7 during this period resulted (at least theoretically) in average salinities impacting vegetation prior to the 1978 survey.

As previously discussed, precipitation records indicate that 1986–87 was a wet 18 months. The PDSI values shown in figure 6 indicate dry conditions in early 1986 and then slightly wet in late 1986 and early 1987.

Salinity

The availability of salinity data for the Mermentau basin during the 1978–88 study period was limited and could not be used to explain most spatial changes. Salinity taken from February 1977 through June 1978 on the Mermentau River at the bridge on Louisiana Highway 82 averaged 11.6 ppt. This location provides salinity data for the largest source of gulf water entering the basin, and the data reflects conditions in connected, adjacent marshes to the south of Catfish Locks (at the junction of the Mermentau River and Grand Lake). Salinities in Joseph Harbor Bayou (fig. 8), located along the south side of a section of Louisiana Highway 82 on Rockefeller Wildlife Refuge, averaged 9.8 ppt during April 1977 through June 1978. This average salinity would reflect conditions in the central part of Rockefeller Wildlife Refuge. In 1986 the average salinity increased to 11.2 ppt in the same area.

Information from a former member of the Little Pecan Island hunting club indicated that a water control structure south of Little Pecan Bayou and an open location connected to the eastern end of Little Pecan Bayou allowed water with higher salinity into adjacent marshes (Thomas Hess, oral commun., 2004). Water with higher salinity could have also moved north into Superior Canal.

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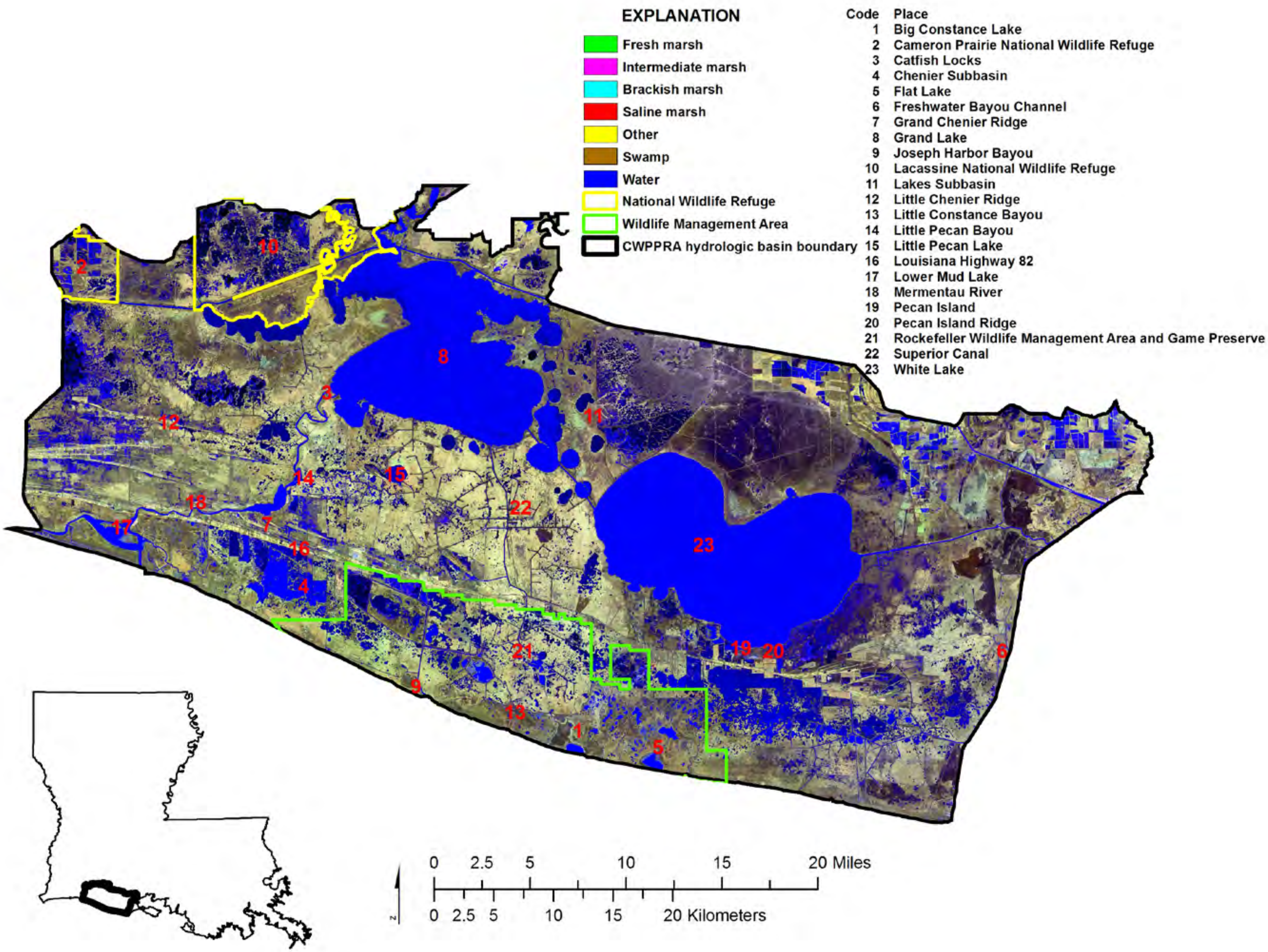
EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Big Constance Lake
2 Cameron Prairie National Wildlife Refuge
3 Catfish Locks
4 Chenier Subbasin
5 Flat Lake
6 Freshwater Bayou Channel
7 Grand Chenier Ridge
8 Grand Lake
9 Joseph Harbor Bayou
10 Lacassine National Wildlife Refuge
11 Lakes Subbasin
12 Little Chenier Ridge
13 Little Constance Bayou
14 Little Pecan Bayou
15 Little Pecan Lake
16 Louisiana Highway 82
17 Lower Mud Lake
18 Mermentau River
19 Pecan Island
20 Pecan Island Ridge
21 Rockefeller Wildlife Management Area and Game Preserve
22 Superior Canal
23 White Lake
0 2.5 5 10 15 20 Miles
0 2.5 5 10 15 20 Kilometers
N

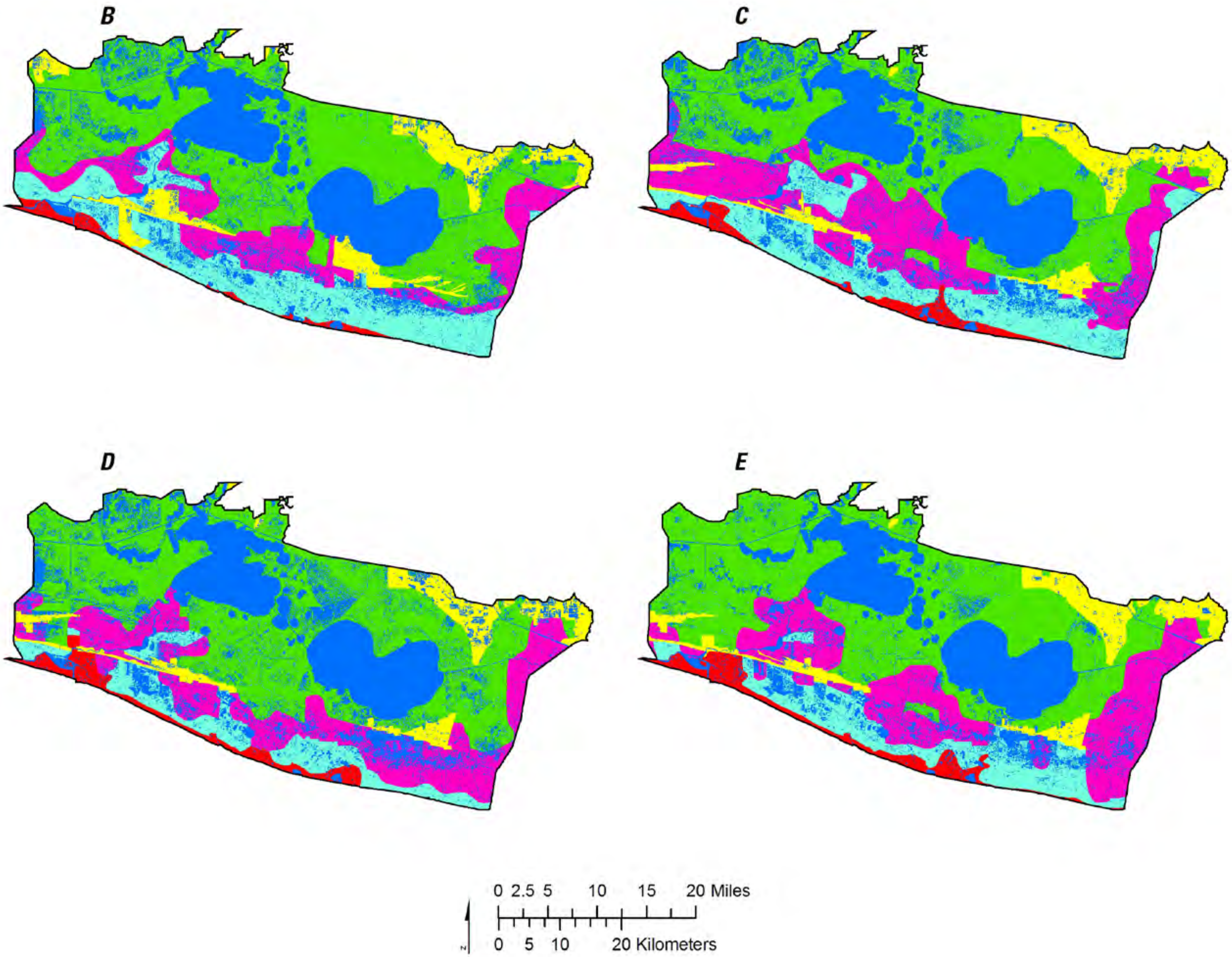

Figure 8. Localities and marsh types in the Mermentau basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Mermentau basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

Comparison of Data for the 1988–97 Study Period

Overview of Marsh Changes

Figure 7 shows that between the vegetation surveys of 1988 and 1997, marsh in the Mermentau basin progressively shifted to fresher types. Fresh marsh increased from 47 to 60 percent, and intermediate marsh decreased slightly from 28 to 24 percent. Brackish marsh decreased from 20 to 11 percent, and saline (saltwater) marsh remained the same.

Figure 8 shows an increase in fresh marsh to the west of the Mermentau River and to the south of the Little Chenier Ridge. With the exception of the area just southeast of Catfish Locks (south of Little Pecan Bayou) and a small area south of White Lake, fresh marsh replaced all intermediate marsh north of the Grand Chenier Ridge. Fresh marsh moved southward of the Grand Chenier Ridge near to and to the east of the Superior Canal. Intermediate marsh replaced some brackish marsh on Rockefeller Wildlife Refuge and to the south of the Pecan Island ridge.

Precipitation

The PDSI values for this period in division 7 (shown in figure 6) were drier than normal from January to July 1996, then wetter than normal for the rest of the period. The precipitation for the approximate 18-month period preceding the 1997 vegetation survey was wetter than average (table 2).

Salinity

Available salinity data indicate fresher conditions across the basin during the 1988 to 97 study period. Data from the northeast corner of Rockefeller Wildlife Refuge, which was more influenced by water from the gulf, was 11.1 ppt during 1986–87 and 9.7 ppt during 1996–97; however, the average salinity inside Catfish locks was only 1 ppt in 1996–97. This increase in fresh water explains the expansion of fresh marsh southward along the Superior canal and across the Grand Chenier Ridge (fig. 8) and the replacement of brackish marsh by intermediate marsh on and east of Rockefeller Wildlife Refuge.

Comparison of Data for the 1997–2001 Study Period

Overview of Marsh Changes

The 2001 survey was conducted in June. Figure 7 shows that between the vegetation surveys of 1997 and 2001 there was a slight increase to more saline (saltwater) marsh types in the Mermentau basin. Fresh marsh decreased from 60 to 57 percent, while intermediate marsh and brackish marsh remained steady (from 24 to 25 percent and from 11 to 12 percent, respectively). Saline (saltwater) marsh remained steady at 5 percent.

Although percentages of change were slight, figure 8 shows that in 2001, based on coverage of marsh types, more saline (saltier) conditions existed in marsh adjacent to the Mermentau River (to the south of the Catfish Locks) as compared to conditions detected in the 1997 survey. To the east of the Mermentau River and south of Little Pecan Bayou, intermediate marsh moved southward to the Grand Chenier Ridge, but some brackish marsh also became intermediate. Much of Rockefeller Wildlife Refuge shifted from intermediate marsh to brackish marsh during the 1997–2001 study period. Intermediate marsh moved northward along the Superior Canal north of the Grand Chenier Ridge. Brackish marsh increased south of Pecan Island, and saline (saltwater) marsh moved northward between Flat Lake and Big Constance Lake on Rockefeller Wildlife Refuge. Intermediate marsh replaced most fresh marsh located between Freshwater Bayou and Louisiana Highway 82.

Precipitation

As discussed earlier, 1999 was a drought year, and dry conditions continued through October 2000. Precipitation was 12.4 inches (31.49 cm) below normal (table 2). The PDSI values for this period in division 7 are shown in figure 6, with -3.0 or drier values in 11 of the 18 months. Precipitation increased after October 2000 and was above normal; however, these conditions did not result in lower salinities as was the case in the Calcasieu/Sabine basin. The extended 1999–2000 drought was not reversed by higher precipitation in late 2000 through June 2001.

Salinity

The review of data leading up to the 1997 and 2001 vegetation surveys show that salinity levels at Catfish Locks showed a dramatic increase (average of 11.1 ppt) during 2000 and from January through June of 2001 as compared to the average (1 ppt) from January 1996 to June 1997. These much higher salinities from January 2000 to June 2001 demonstrate the impact of the 1999–2000 drought. During the same period (2000–2001), salinities in the eastern part of Rockefeller Wildlife Refuge were also very high, averaging from 15.3 to 18 ppt, whereas during the 1996–97 period in that area, salinity averages ranged much lower, from 5.2 to 11 ppt.

Teche/Vermilion Basin

Literature Review

Chabreck and Linscombe (1982) compared changes in marsh types between the 1968 and 1978 surveys and reported that there was an increase of saline (saltwater) marsh on 40,576 acres (16,421 ha) of the Teche/Vermilion basin. Total area of the Teche/Vermilion basin is 659,799 acres (267,021 ha) (table 1). The NRCS completed the Teche/Vermilion Cooperative River

Basin Study Report in 1999. This report provided an overall management plan for the entire basin.

Comparison of Data for the 1978–88 Study Period

Overview of Marsh Changes

Figure 9 shows changes in vegetation coverage between the 1978 and 1988[1] vegetation surveys, while table 1 shows the acreage changes. The changes in vegetation include a shift to fresher marsh types. Fresh marsh increased from 12 to 20 percent; intermediate marsh stayed the same at 19 percent; brackish marsh decreased from 66 to 59 percent; and saline (saltwater) marsh remained the same at 2 percent.

[1] The 1988 aerial vegetation survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.

Figure 10 shows a replacement of brackish marsh with intermediate marsh on Cypremort Point and intermediate marsh converting to fresh marsh at The Jaws. Fresh marsh also moved westward from Cote Blanc Island toward Cypremort Point. Brackish marsh converted to fresh marsh on Point Marone, and brackish marsh converted to intermediate marsh in the southwest corner of this basin.

Precipitation

The Teche/Vermilion basin falls partly within the Louisiana climate division 7 of the NCDC and partly within division 8. Climate data for this period in division 7 are shown in figure 6 and table 2. Division 8 precipitation data for this period are also shown in table 2, and PDSI values are presented in figure 11. Precipitation records leading up to the 1978 vegetation survey indicate that the precipitation in 1977 in division 8 was 69.29 inches (175.99 cm), a 9.59-inch (24.36-cm) departure from normal, resulting in a wet year. Table 2 shows that January–June 1978 was also a wet period,

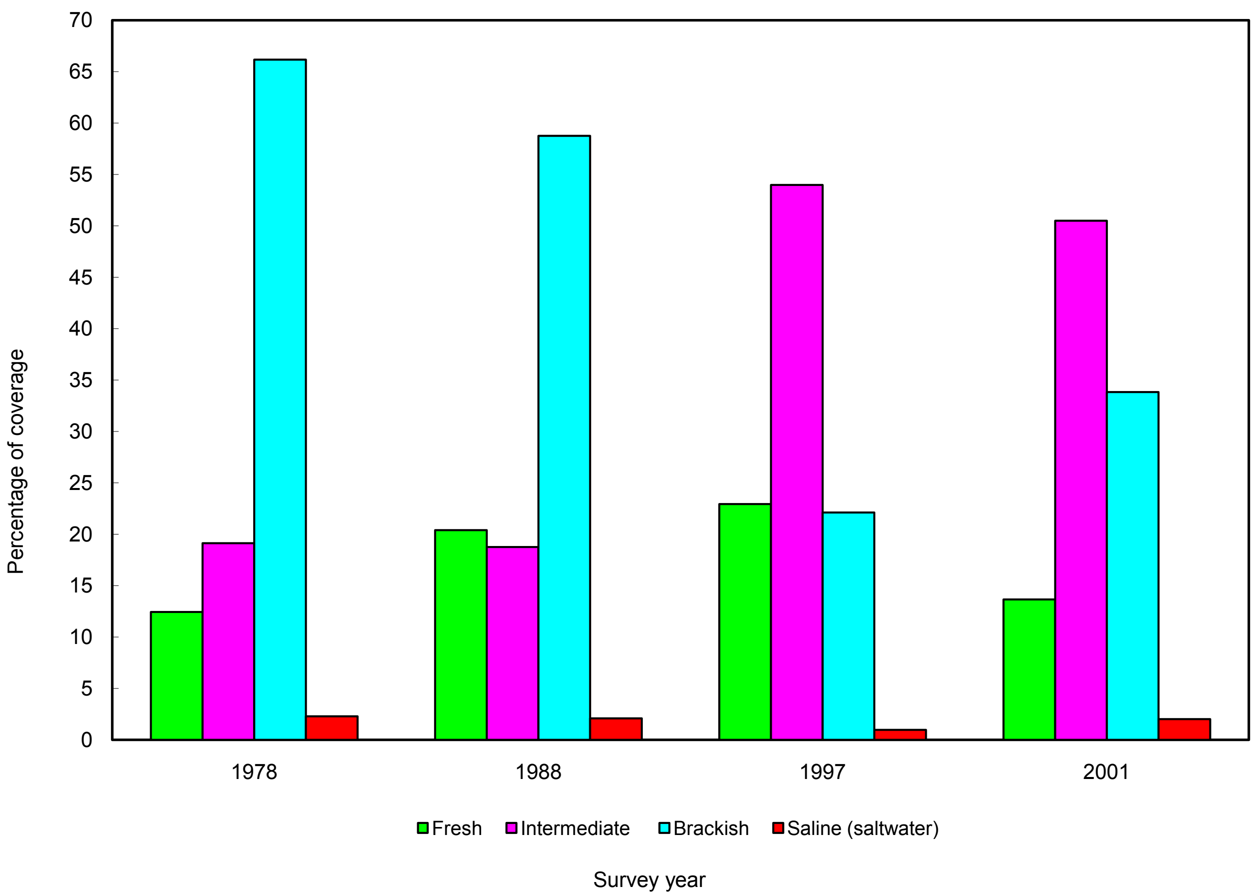

Figure 9. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Teche/Vermilion basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

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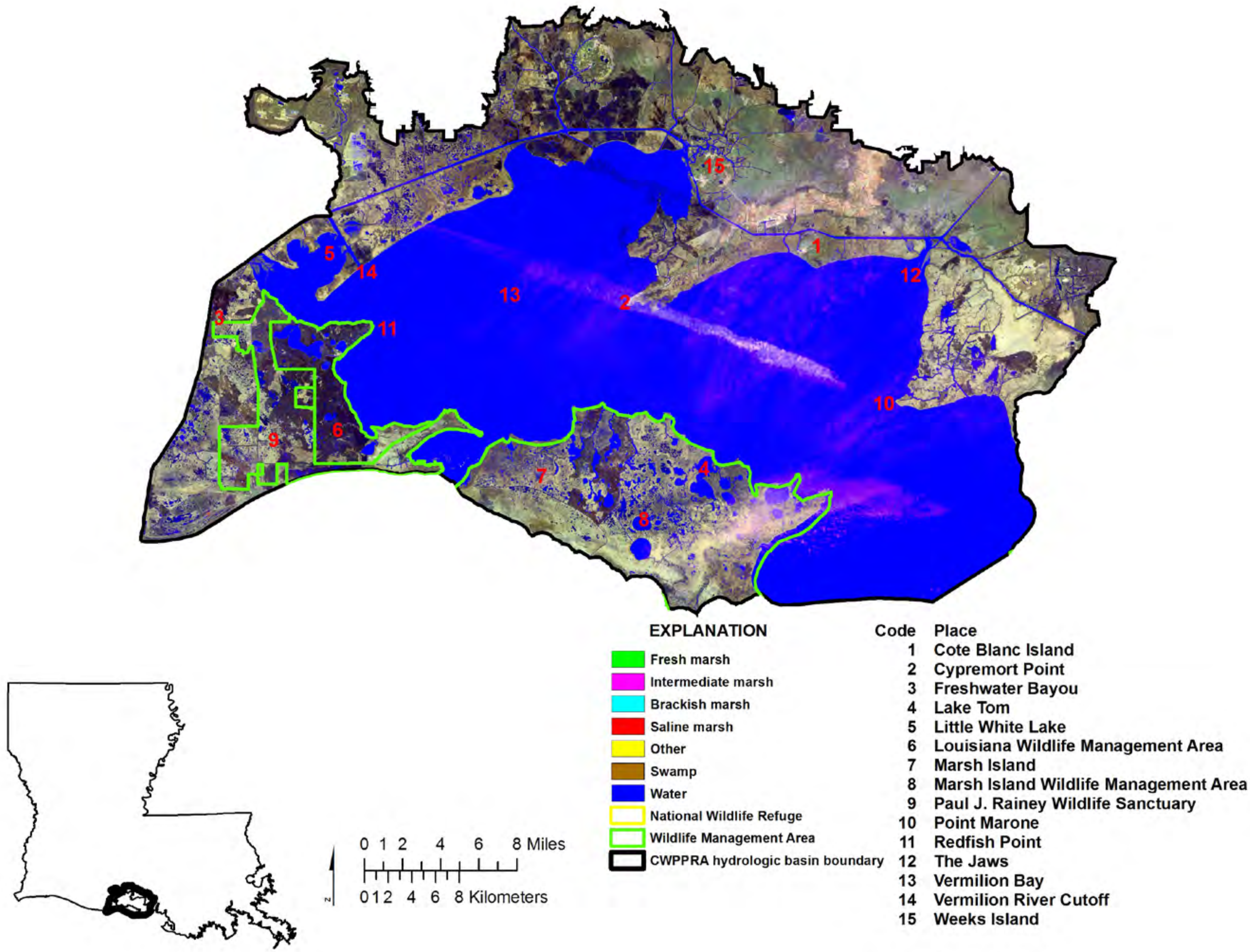

EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
0 1 2 4 6 8 Miles
0 1 2 4 6 8 Kilometers
N
Code Place
1 Cote Blanc Island
2 Cypremort Point
3 Freshwater Bayou
4 Lake Tom
5 Little White Lake
6 Louisiana Wildlife Management Area
7 Marsh Island
8 Marsh Island Wildlife Management Area
9 Paul J. Rainey Wildlife Sanctuary
10 Point Marone
11 Redfish Point
12 The Jaws
13 Vermilion Bay
14 Vermilion River Cutoff
15 Weeks Island

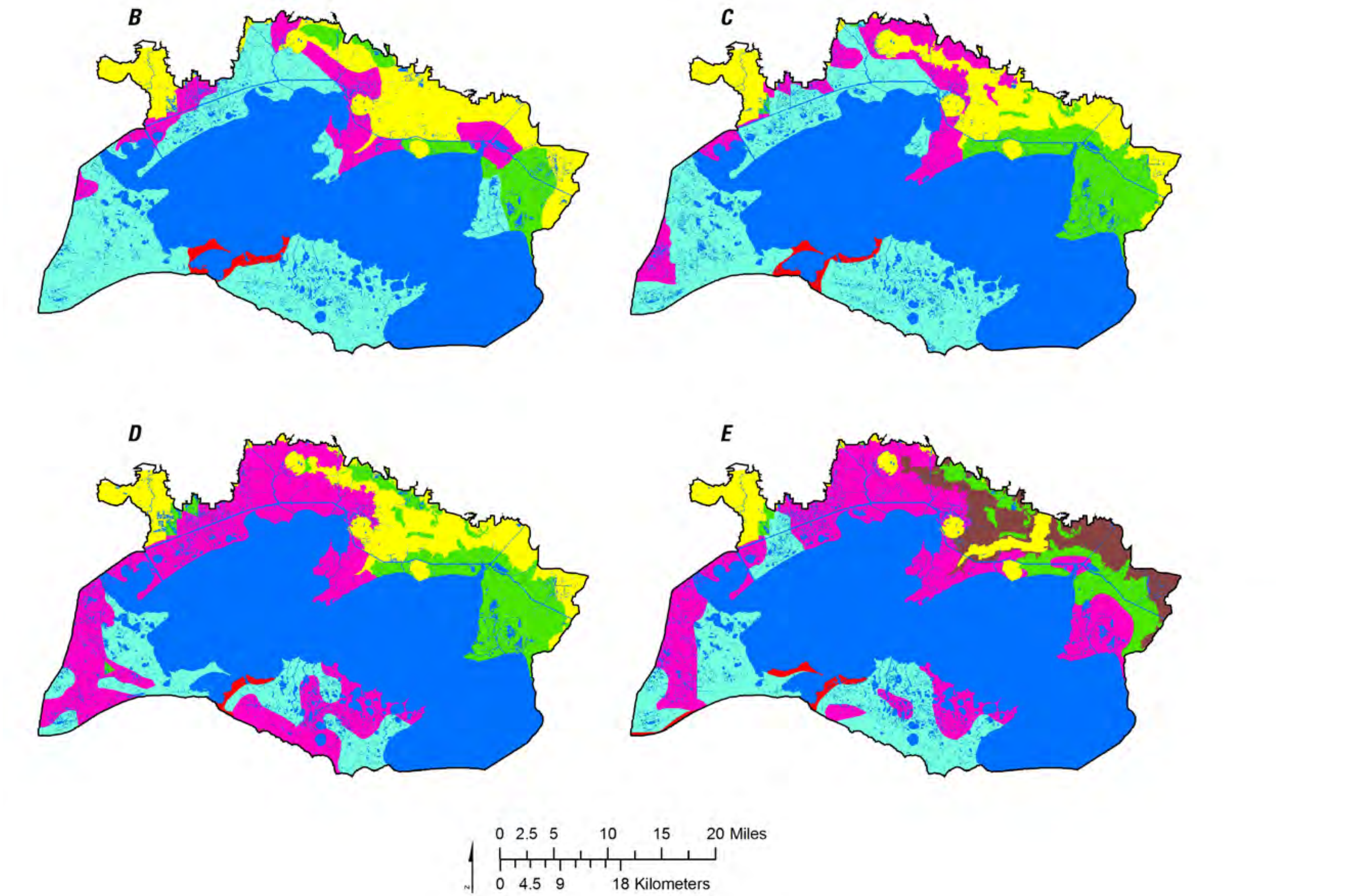

Figure 10. Localities and marsh types in the Teche/Vermilion basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Teche/Vermilion basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

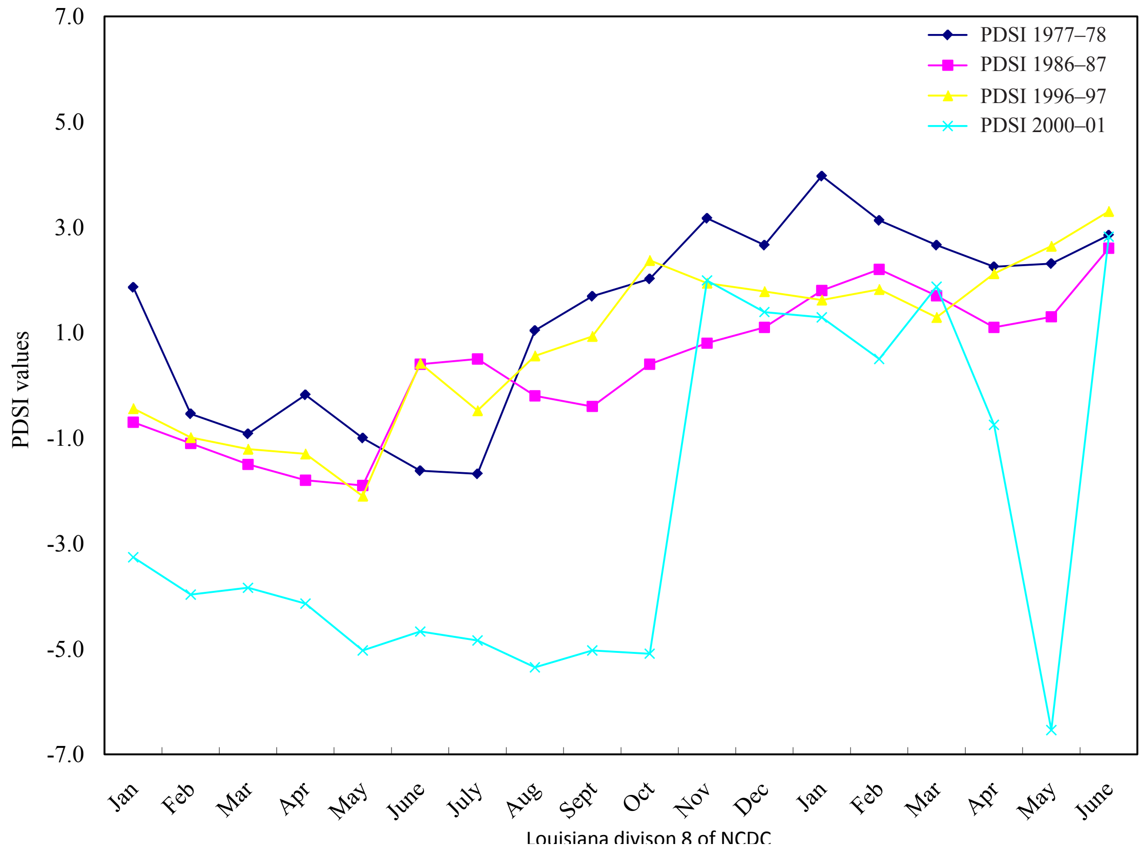

Figure 11. Palmer Drought Severity Index (PDSI) values for Louisiana climate division 8 (fig. 2) of the National Climatic Data Center (NCDC) during survey periods from January 1977 to June 2001. Normal values = 0.5 to -0.5; incipient drought values = –0.5 to –1.0; extreme drought values = < -4.0), incipient wetness values = 0.5 to 1.0; extreme wetness values = >4.0.

with a 4.16-inch (10.57-cm) departure from normal and PDSI values averaging 2.0 (fig. 11). These wet conditions prior to the 1978 survey lowered salinities. Precipitation in 1986 was 57.76 inches (144.17 cm), a -1.52-inch (3.86-cm) departure from normal. Precipitation from January–June 1987 was high, with a 7.22-inch (18.34-cm) departure from normal. Figure 11 shows that PDSI values were in the normal range during 1986 and were in the slightly wet range during the first 6 months of 1987. These precipitation levels indicate that conditions prior to the 1988 vegetation survey were wetter than normal.

Salinity

Salinity in the center of Vermilion Bay averaged 8 ppt prior to the 1978 vegetation survey and 6.8 ppt prior to the 1988 survey. A long-term freshening pattern has been observed since the 1968 map of marsh types was produced (collected in Chabreck and others, 2001). This freshening appears to be directly related to the influence of the Atchafalaya River and the Wax Lake Outlet, along with the forcing of water to the east and west by the two emerging deltas (Atchafalaya and Wax Lake).

During high flows, the Atchafalaya River has always had an impact on the salinities in the Teche/Vermilion basin. After the emergence of the main delta of the Atchafalaya River in 1973 and the Wax Lake delta later, the influence of the river increased because these deltas diverted more water to the east and west. During the flood year of 1973, the sum of daily discharges from the river was 137,740,000 ft^3/s (3,900,797 m^3/s) (U.S. Army Corps of Engineers, 2010) at Simmesport, La. This measurement can serve as an index of the total annual discharge and provides a comparison for other years. The peak flow during this flood event was 781,000 ft^3/s (22,118 m^3/s) per day. In 1977, the sum of daily discharges in the river was 58,830,000 ft^3/s, (1,665,880 m^3/s). The sum of daily discharge in 1978 was higher at 73,237,000 ft^3/s (2,073,005 m^3/s). Generally speaking, the highest flows occur during late winter and spring; therefore, most of the high flows would have been prior to our aerial surveys of vegetation in a given year. The sum of daily discharge in 1986 was significantly higher at 81,245,000 ft³/s (2,300,602 m³/s) and 63,706,000 ft³/s (1,803,953 m³/s) in 1987. This higher flow in 1986 explains the freshening pattern of marshes to the west of the Wax Lake Outlet.

Comparison of Data for the 1988–97 Study Period

Overview of Marsh Changes

Figure 9 shows changes in vegetation type coverage between the 1988 and 1997 vegetation surveys, indicating an increase of fresher marsh types. Between the surveys, fresh marsh increased from 20 to 23 percent; intermediate marsh increased from 19 to 54 percent; brackish marsh decreased from 59 to 22 percent; and saline (saltwater) marsh decreased from 2 to 1 percent.

Figure 10 shows spatial changes within the marsh types between the two surveys. There was a dramatic shift of intermediate marsh westward across the north shore of Vermilion Bay from Weeks Island to Little White Lake. Intermediate marsh, replacing brackish marsh, also moved eastward from Freshwater Bayou a third of the way to Vermilion Bay. On Marsh Island, intermediate marsh, replacing brackish marsh, stretched from the northeastern corner southwestward across the island.

Precipitation

Figure 6 and table 2 show climate data for this period in Louisiana in division 7, which have already been discussed in previous sections covering this period in the Calcasieu/Sabine and Mermentau basins. Data for climate division 8 during this period are shown in figure 11 and table 2. Precipitation records for the period leading up to the 1988 vegetation survey have already been discussed. Division 8 records indicate mixed conditions leading up to the 1997 vegetation survey. Conditions in 1996 were somewhat dry, with a total of 59.18 inches (150.32 cm) of precipitation, a -2.07-inch (-5.23-cm) departure from normal, but conditions were wet during January–June 1997, with an 8.92-inch (22.66-cm) departure from normal. The PDSI values were normal from August 1996 through June 1997.

Salinity

Precipitation levels, PDSI values, and river discharges indicate lower salinities prior to the 1997 vegetation survey than those recorded prior to the 1988 vegetation survey. Salinities across Vermilion Bay, from east Marsh Island to Redfish Point (fig. 10), measured ahead of the 1997 survey averaged 3.7 ppt, whereas the average salinities ahead of the 1988 survey were 6.8 ppt. Leading up to the 1997 survey, the sum of daily discharge from the Atchafalaya River was 88,171,000 ft³/s (2,497,003 m³/s) in 1996 and 93,649,000 ft³/s (2,652,140 m³/s) in 1997 (U.S. Army Corps of Engineers, 2010). Both of these years had higher flow rates than those recorded for the 1986–87 period.

Comparison of Data for the 1997–2001 Study Period

Overview of Marsh Changes

Figure 9 shows changes in vegetation types between the 1997 and 2001 surveys, indicating a shift to higher salinity conditions. Between the surveys, fresh marsh decreased from 23 to14 percent; intermediate marsh also decreased from 54 to 50 percent; brackish marsh increased from 22 to 34 percent; and saline (saltwater) marsh increased from 1 to 2 percent.

Figure 10 shows that in 2001, the pattern of freshening marsh conditions present in 1997 was reversed. Fresh marsh on Point Marone was converted to intermediate marsh, as did portions of fresh marsh west of Cote Blanc Island and in an area west of Vermilion River Cutoff and across Marsh Island. Brackish marsh also replaced intermediate marsh between Freshwater Bayou and the western shore of Vermilion Bay.

Precipitation

Climate data for this period in Louisiana climate division 7 are shown in figure 6 and table 2 and have already been discussed in previous sections covering this period in the Calcasieu/Sabine and Mermentau basins. Data for climate division 8 during this period are shown in figure 11 and table 2. Division 8 records leading up to the June 2001 aerial survey indicate that precipitation in 2000 was low, totaling 46.09 inches (117.07 cm), a -15.16-inch (-38.51-cm) departure from normal. These dry conditions in 2000 were an extension of a drought that started in 1999 and that was also evident in Louisiana climate division 7 (see sections on the Calcasieu/Sabine and Mermentau basins). Precipitation during January–June 2001 was above normal, but the approximate 18-month period prior to the 2001 survey was still dry overall, with a -5.16-inch (13.11-cm) departure from normal. Leading up to the 2001 survey, the sum of daily discharge from the Atchafalaya River was 52,825,000 ft³/s (1,495,837 m³/s) in 2000 (U.S. Army Corps of Engineers, 2010). This was the lowest flow during all the years we examined in relation to our vegetation surveys. River flow during 2001 was higher at 78,138,000 ft³/s (2,212,621 m³/s); however, based on salinity data, this higher river flow did not buffer the already higher salinities resulting from the drought.

Salinity

The average salinity across Vermilion Bay increased from 3.7 ppt ahead of the 1997 vegetation survey to 6.7 ppt ahead of the 2001 vegetation survey. Salinities at Lake Tom (fig. 10) on the northeastern shoreline of Marsh Island increased from 3.4 ppt in to 6.7 ppt. This increase in salinity during the 1997–2001study period explains the shift of intermediate marsh back to brackish marsh in the interior of Marsh Island (fig. 10). At the Vermilion River Cutoff, average salinity values increased from 4.3 ppt during 1996–97 to 7 ppt during 2000–01. This higher salinity explains the shift from intermediate marsh to brackish marsh east of the Vermilion River Cutoff.

Analysis of Changes in Marsh Types within the Deltaic Plain (Atchafalaya, Terrebonne, Barataria, Mississippi River Delta, Breton Sound, and Pontchartrain Basins)

Overview of the Deltaic Plain

The deltaic plain consists of the largest continuous wetland system in the United States and extends from the western shore of Vermilion Bay to the Pearl River delta (Gosselink, 1984). The interdistributary basins (Atchafalaya and Mississippi River Delta), as defined by the Louisiana Coastal Wetlands Conservation and Restoration Task Force, 1993, demonstrated historical shifts in the Mississippi River (Gosselink, 1984). The Atchafalaya basin is the youngest and receives one-third of the combined flow of the Red and Mississippi Rivers. The Mississippi River Delta basin is the next youngest and receives two-thirds of the flow of the Mississippi River. The other basins in order of increasing age are Barataria, Terrebonne, Vermilion, and Pontchartrain (Gosselink, 1984).

In 1986 the NRCS completed the Lafourche-Terrebonne Cooperative River Basin Study Report. This report contained inventory data for coastal marshes, data from watershed investigation (west fork of Bayou L'Ourse watershed and Bayou Penchant-Lake Penchant watershed), and data for existing and potential marsh management projects and implementation.

In 1989 the NRCS completed the East Central Barataria Cooperative River Basin Study Report. This report discusses the causes and consequences of coastal erosion, and it identifies associated problem areas, as well as existing and potential projects to mitigate and prevent further impacts.

Visser and others (1998) quantitatively analyzed the 1968 data on vegetation coverage in the Barataria and Terrebonne basins to determine more detailed vegetation associations. This analysis indicated nine vegetation types present in the deltaic plain. The Barataria basin had larger percentages of intermediate and brackish marshes, while the Terrebonne basin had larger percentages of fresh and saline marshes. Visser and others (2002) analyzed two vegetation datasets collected in the Barataria basin (1997 and 2000), which documents the effect of the 1999–2000 drought.

Atchafalaya Basin

Literature Review

Chabreck and Linscombe (1982) compared changes in marsh types between the 1968 and 1978 aerial surveys and reported no changes in this totally fresh marsh system.

Review of Data for the 1978, 1988, 1997, and 2001 Study Periods

Overview of Marsh Changes

In the Atchafalaya basin, the Atchafalaya River dominates the conditions that determine salinity and marsh types. With the exception of 2001, when there was a slight increase (more than half a percent) in intermediate marsh, the system remained fresh over the years covered by our study. Figure 12 shows changes (or lack thereof) in marsh type percentages calculated during this study for the Atchafalaya basin. The 1999–2000 drought, along with low river flow, explained the slight increase in intermediate marsh in 2001. Figure 13 shows no significant changes in marshes types in this basin during the 1978, 1988[2], 1997, and 2001 vegetation surveys.

Because conditions in this basin were rather static, we have elected to discuss all the survey periods collectively rather than individually (as we have done for other basins).

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[2] The 1988 aerial vegetation survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.

Precipitation

The Atchafalaya basin falls completely within Louisiana climate division 8 of the NCDC. Figure 11 and table 2 illustrate climate data for division 8, all of which have already been discussed in previous sections (see discussions of precipitation in the Teche/Vermilion basin). The impacts of the 1999–2000 drought on the Teche/Vermilion basin have already been discussed.

Salinity

Availability of salinity data in this basin was very limited. The Marine Fisheries Division of the LDWF did not sample for salinity in this basin because of very low salinities. Salinity data taken from the Atchafalaya Delta Wildlife Management Area (fig. 13) reflect salinity averages of less than 1 ppt (Louisiana Department of Wildlife and Fisheries, unpublished data).

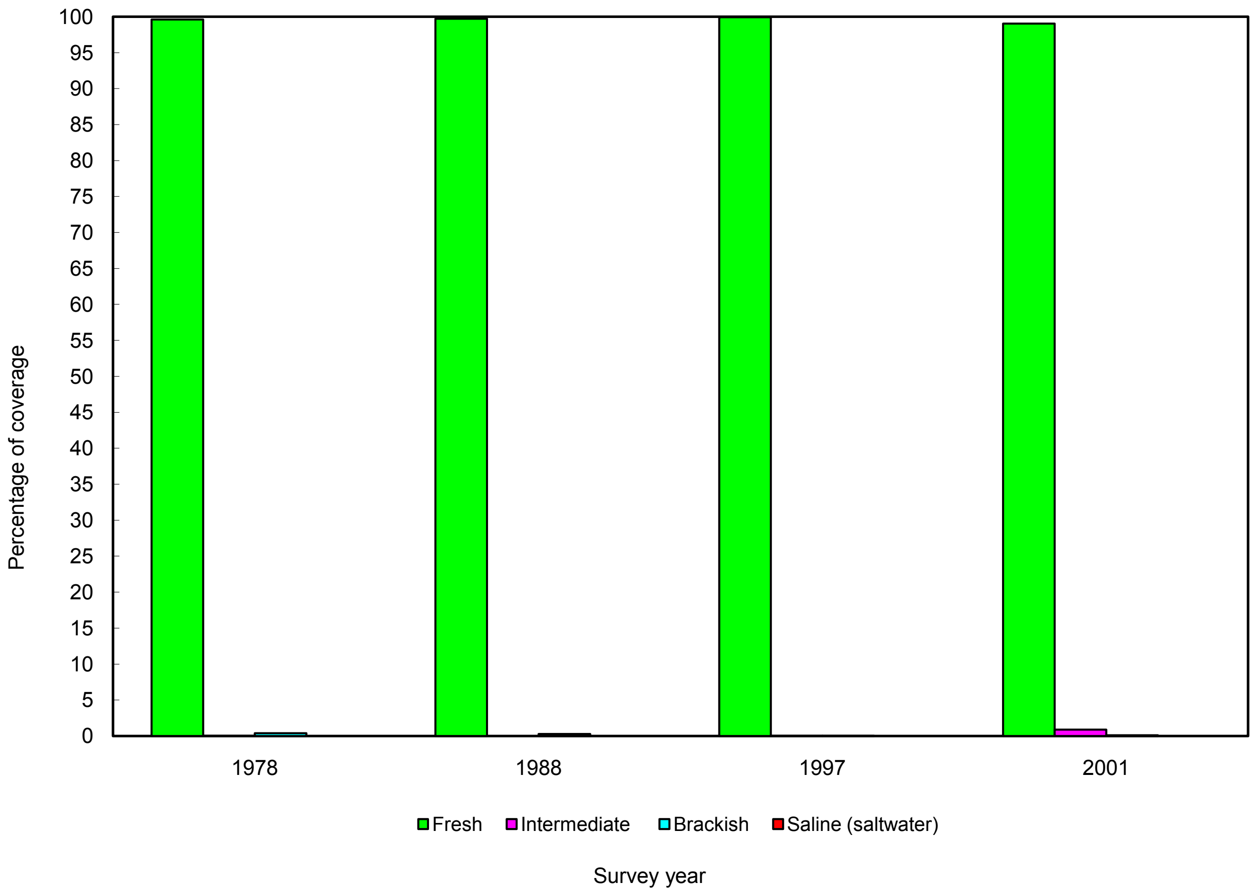

Figure 12. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Atchafalaya basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

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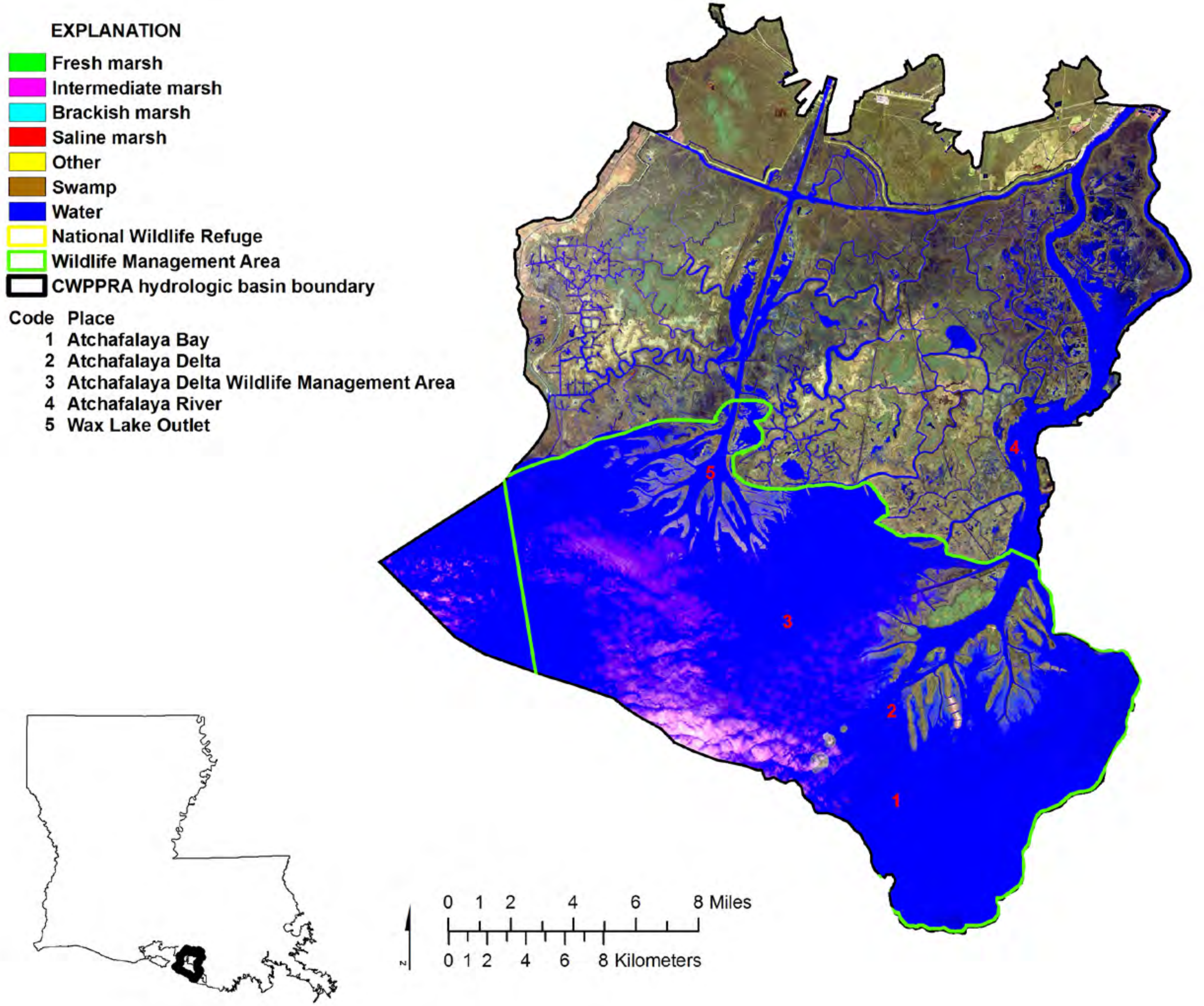
EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Atchafalaya Bay
2 Atchafalaya Delta
3 Atchafalaya Delta Wildlife Management Area
4 Atchafalaya River
5 Wax Lake Outlet
1
2
3
4
5
0 1 2 4 6 8 Miles
0 1 2 4 6 8 Kilometers
N

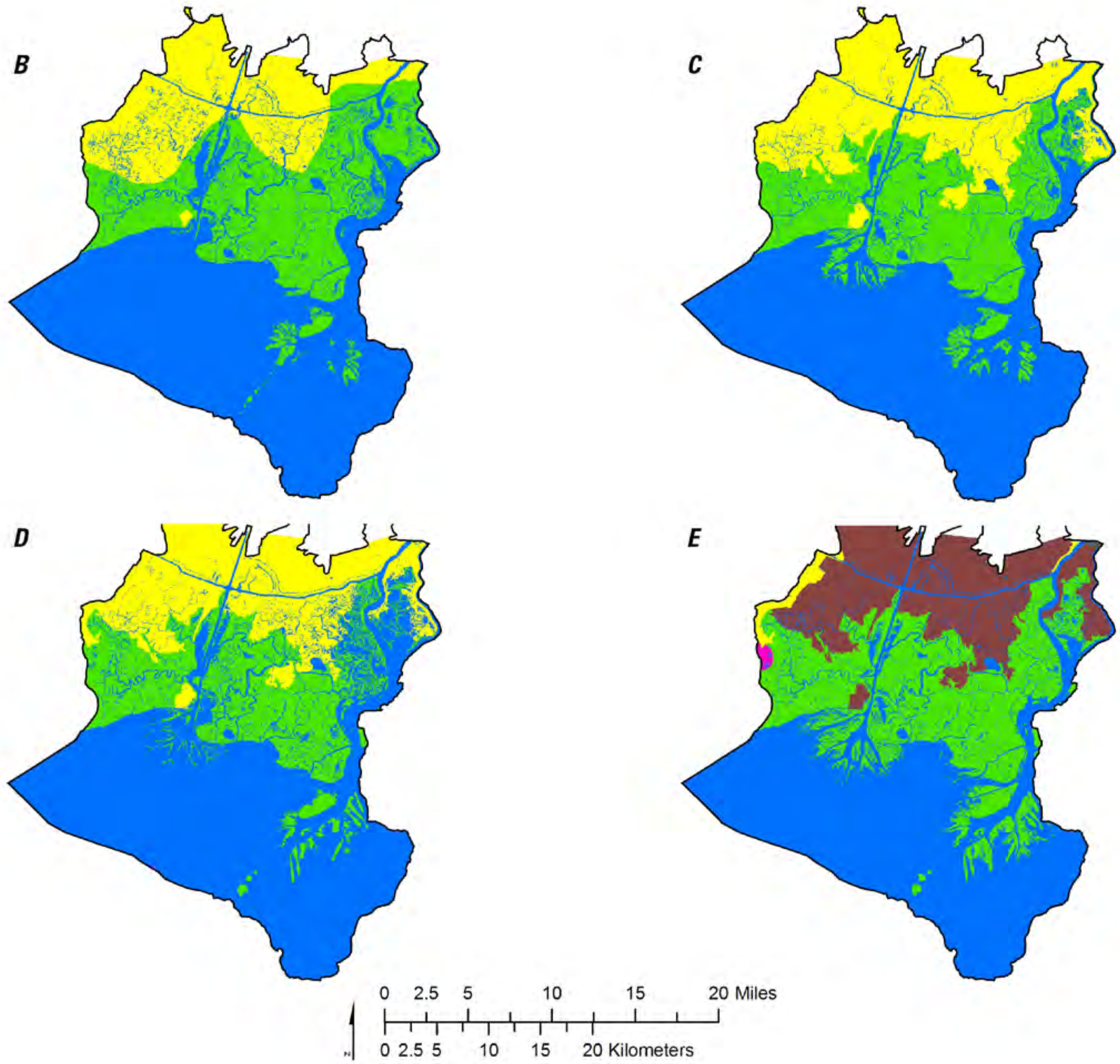

Figure 13. Localities and marsh types in the Atchafalaya basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Atchafalaya basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

Terrebonne Basin

Literature Review

Chabreck and Linscombe (1982) compared changes in marsh types between the 1968 and 1978 surveys and reported an increase of saline (saltwater) marsh types on 82,816 acres (33,516 ha) of the Terrebonne basin. Total area of the Terrebonne basin is 1,712,685 acres (693,124 ha) (table 1).

Comparison of Data for the 1978–88 Study Period

Overview of Marsh Changes

Changes in marsh types during the 1978–88 study period included a minor shift toward fresher marsh types. Fresh marsh increased from 35 to 39 percent; intermediate marsh decreased from 13 to 9 percent; brackish marsh decreased from 24 to 22 percent; and saline (saltwater) marsh increased from 29 to 31 percent. Figure 14 shows the changes in percentages of marsh types calculated during this study for the Terrebonne basin for the four survey periods.

Figure 15 shows a narrowing of the band of intermediate marsh in the Terrebonne basin during the 1988 vegetation survey as compared to the survey in 1978. During the interval, fresh marsh moved southward along the shoreline of Atchafalaya Bay; however, during the 1988 survey, we observed that brackish marsh also had moved northward on both the eastern and western sides of the Houma Navigation Canal, indicating that this area was not influenced by river discharge or precipitation. An area of intermediate marsh was identified, replacing brackish marsh, on the eastern side of the central portion of Point Au Fer Island (fig. 15).

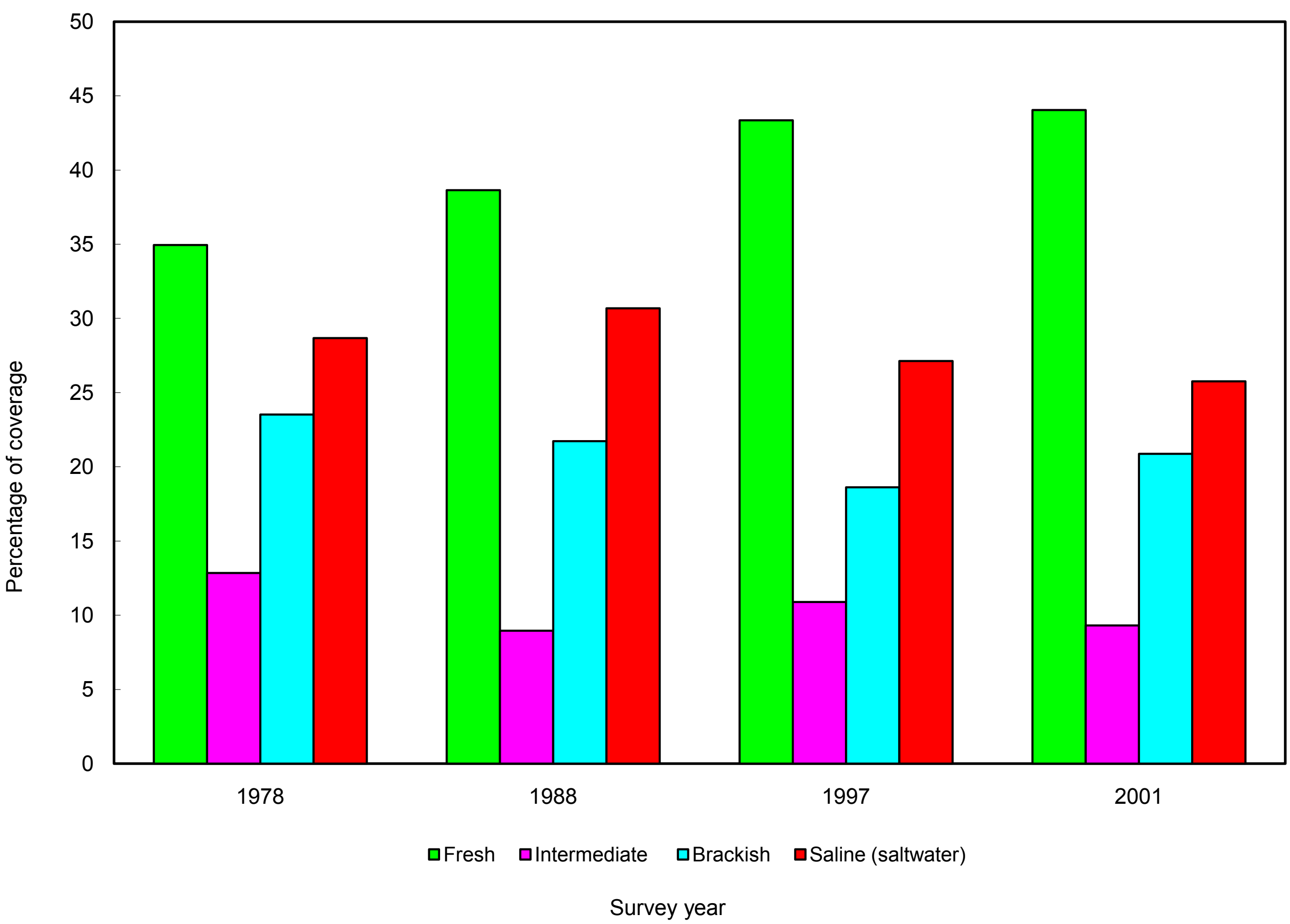

Figure 14. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Terrebonne basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

Precipitation

The Terrebonne basin falls partly within Louisiana climate division 8 of the NCDC but mostly within climate division 9. Climate data for this period in division 8 are shown in figure 11 and table 2 and have already been discussed in previous sections covering this period in the Teche/Vermilion and Atchafalaya basins. Division 9 climate data for this period are shown in figure 16 and table 2. According to division 9 records leading up to the 1978 vegetation survey, the precipitation in 1977 was 68.96 inches (175.16 cm), a 7.83-inch (19.88-cm) departure from normal, and the January–June 1978 period was also wet, with a 4.14-inch (10.52-cm) departure from normal. Figure 16 shows PDSI values above 2 during 11 of the 18 months prior to the 1978 survey.

Precipitation in 1986 (leading up to the 1988 vegetation survey) was 51.30 inches (130.30 cm), a -9.88-inch (-25.09-cm) departure from normal (table 2). During January–June 1987, precipitation was 7.27 inches (18.46 cm) from normal. Figure 16 show that PDSI values were drier than -1 from January through September 1986 but were wetter from January through June 1987. In addition to local precipitation levels, flow from the Atchafalaya River had an influence on changes in marsh types in the western portion of the Terrebonne basin during the approximate 18-month periods leading up to the vegetation surveys. As previously discussed, the sum of daily river discharge in 1986 was higher than during 1977 (U.S. Army Corps of Engineers, 2010). This increased river flow during 1986 accounts for the expansion of fresh marsh along the shoreline of Atchafalaya Bay and the appearance of intermediate marsh on Point Au Fer Island.

Salinity

The salinity in the northeastern corner of Lake Mechant in western Terrebonne Parish averaged 7.4 ppt from January 1977 to June 1978. A pattern of similar salinities were also evident in the Caillou Lake area (known locally as Sister Lake) (fig. 15), with values of 13.5 ppt from 1977 to 1978 and 12.6 ppt from 1986 to 1987. These salinities do not explain the movement of brackish marsh northwestward of the Houma Navigation Canal or north of Lake Boudreaux, which may have been a result of marsh loss and a resulting change in hydrology in those areas due to the canal.

Comparison of Data for the 1988–97 Study Period

Overview of Marsh Changes

Figure 14 shows an increase of fresher marsh types during the 1988–97 study period. Fresh marsh increased from 39 to 43 percent; intermediate marsh also increased from 9 to 11 percent; brackish marsh decreased from 22 to 19 percent and saline (saltwater) marsh also decreased from 31 to 27 percent.

Figure 15 shows spatial changes within the marsh types between the surveys. There was a dramatic shift of fresh and intermediate marsh to the south in western Terrebonne Parish. Fresh marsh moved southward to the southern shoreline of Carencro Lake. Intermediate marsh moved southward to the northern shoreline of Lost Lake and Lake Mechant. The area of intermediate marsh on Point Au Fer Island increased in size and moved northward. Brackish marsh moved southward to the northern shoreline of Caillou Lake, replacing saline (saltwater) marsh east of Lake Mechant. Intermediate marsh replaced brackish marsh to the west of the Houma Navigation Canal and to the north of Lake Boudreaux. Intermediate marsh also replaced fresh marsh between the Point-Aux-Chenes ridge and Bayou Lafourche (fig. 15).

Precipitation

Climate data for this period in division 8 are shown in figure 11 and table 2 and have already been discussed in previous sections covering this period in the Teche/Vermilion and Atchafalaya basins. Division 9 climate data for this period are shown in figure 16 and table 2. Division 9 records indicate that precipitation in 1996 was 54.52 inches (138.48 cm), a -7.11-inch (-18.06-cm) departure from normal, resulting in the designation of a dry year. Precipitation from January to June 1997 was wet, with a 3.44-inch (8.74-cm) departure from normal. Data provided in figure 16 indicate dry conditions during the first 5 months of 1996 and normal to wetter conditions from June 1996 through June of 1997.

Salinity

As it did during the 1978 and 1988 survey periods, discharge from the Atchafalaya River influenced salinities during the 1997 survey period. In 1996, discharge from the Atchafalaya River at Simmesport was 88,171,000 ft^3/s (2,496,725 m^3/s), and in 1997 it was 93,818,000 ft^3/s (2,656,630 m^3/s) (U.S. Army Corps of Engineers, 2010). This discharge was much greater than during any other survey period discussed in this report. Salinities in the Terrebonne basin reflected the shifts to fresher marsh types that are illustrated in figures 14 and 15. In the northeastern corner of Lake Mechant, the average salinity decreased from 7.4 ppt from the span of 1986–87 to 4.2 ppt in the span of 1996–97. Further to the south, at the northern end of Caillou Lake, the average salinity decreased from 12.6 to 7.6 ppt. To the west of the Houma Navigation Canal in Bayou Rambio (fig. 15), the average salinity decreased from 5.4 ppt in the span of 1986–87 to 3.0 ppt in the span of 1996–97. The average salinity to the southwest of Cocodrie decreased from 20.8 ppt in the span of 1986–87 to 15.2 ppt in the span of 1996–97.

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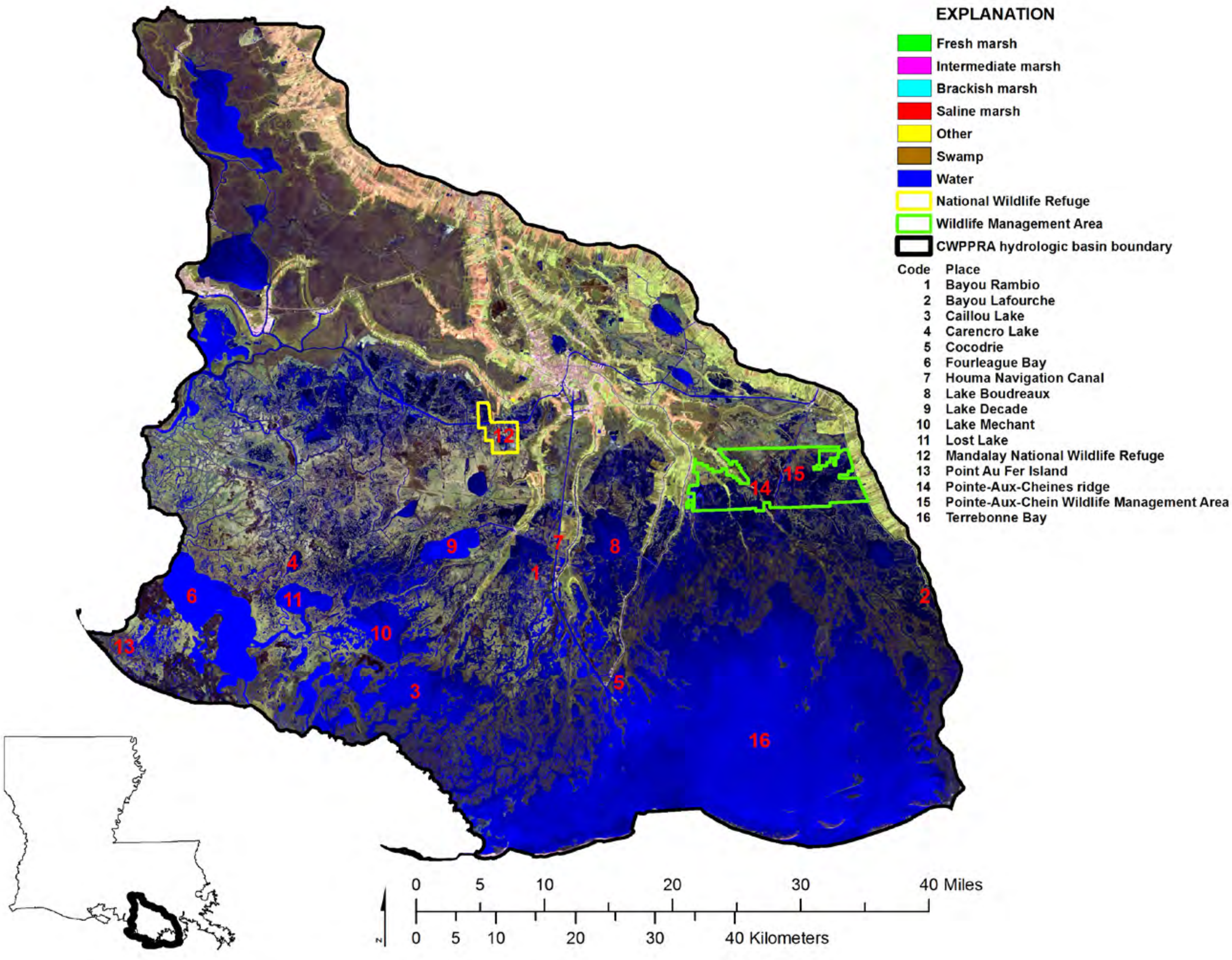
EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Bayou Rambio
2 Bayou Lafourche
3 Caillou Lake
4 Carencro Lake
5 Cocodrie
6 Fourleague Bay
7 Houma Navigation Canal
8 Lake Boudreaux
9 Lake Decade
10 Lake Mechant
11 Lost Lake
12 Mandalay National Wildlife Refuge
13 Point Au Fer Island
14 Pointe-Aux-Cheines ridge
15 Pointe-Aux-Chein Wildlife Management Area
16 Terrebonne Bay
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
N

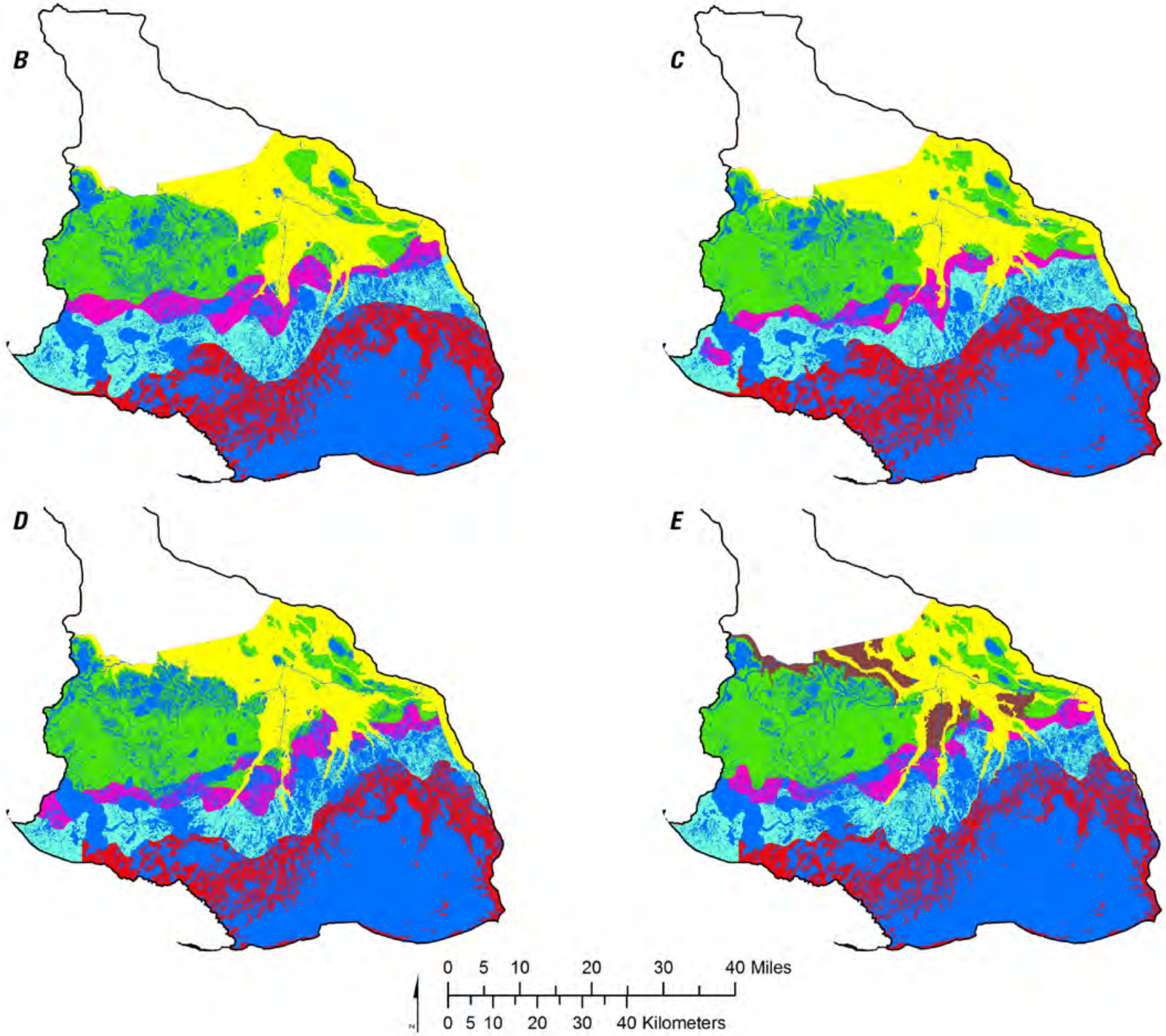

Figure 15. Localities and marsh types in the Terrebonne basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Terrebonne basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

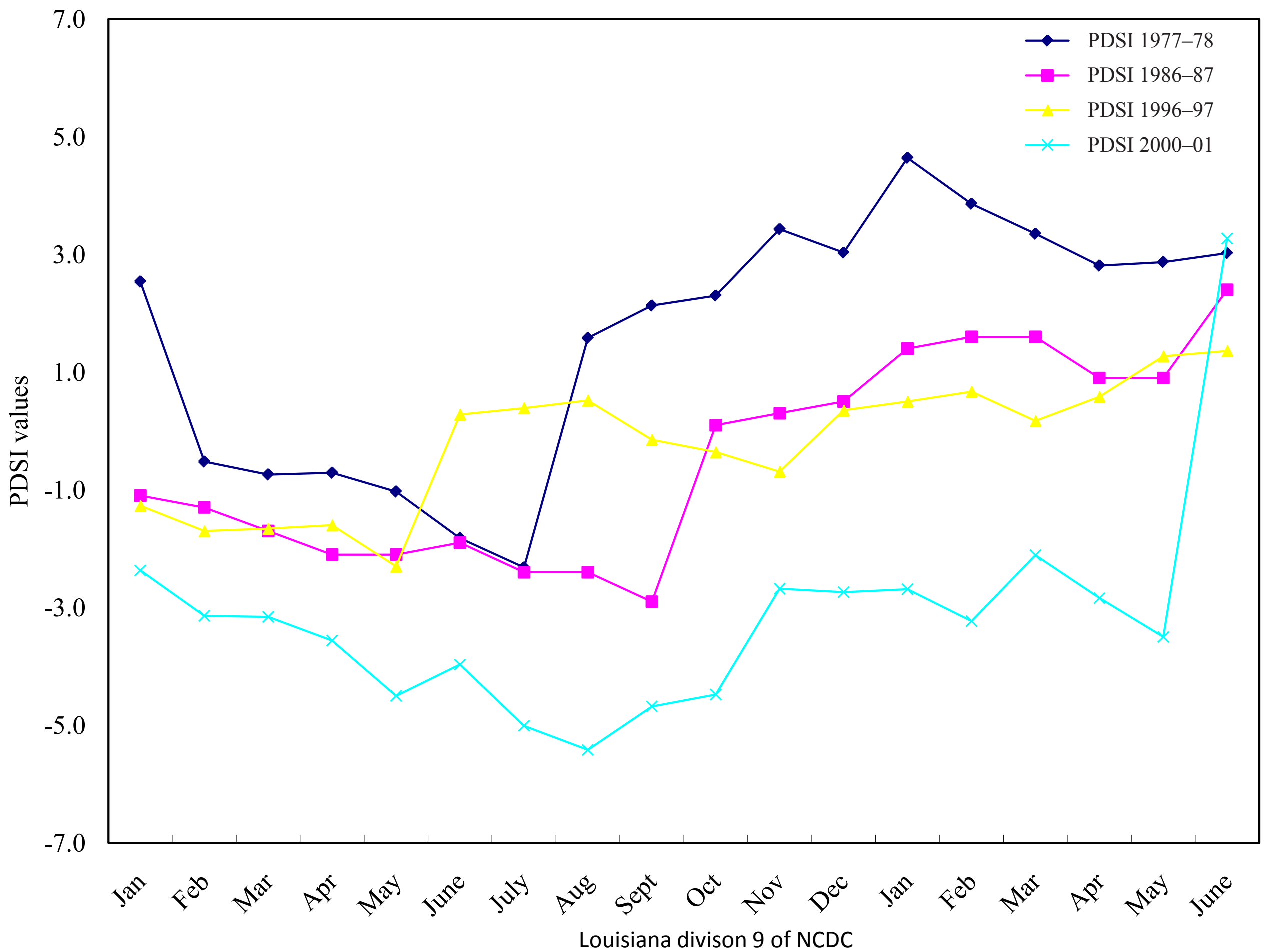

Figure 16. Palmer Drought Severity Index (PDSI) values for Louisiana climate division 9 (fig. 2) of the National Climatic Data Center (NCDC) during survey periods from January 1977 to June 2001. Normal values = 0.5 to -0.5; incipient drought values = –0.5 to –1.0; extreme drought values = < -4.0), incipient wetness values = 0.5 to 1.0; extreme wetness values = >4.0.

Comparison of Data for the 1997–2001 Study Period

Overview of Marsh Changes

Figure 14 illustrates that marsh type changes were not significant within the Terrebonne basin when comparing the results of the 1997 and 2001 vegetation surveys. Fresh marsh was 43 percent in 1997 versus 44 percent in 2001; intermediate marsh was 11 percent in 1997 versus 9 percent in 2001; brackish marsh was 19 percent in 1997 versus 21 percent in 2001; and saline (saltwater) marsh 27 percent in 1997 versus 26 percent in 2001.

Although changes in vegetation coverage were small during this period, there were some obvious spatial changes within the marsh types (figure 15). In 2001, intermediate marsh on Point Au Fer Island was replaced by brackish marsh. Intermediate marsh moved northward, displacing fresh marsh along the Atchafalaya Bay shoreline. Fresh marsh was also replaced by intermediate marsh around Carencro Lake and to the southeast of Lake Decade. Brackish marsh replaced intermediate marsh to the west of the Houma Navigation Canal and to the north of Lake Boudreaux.

Precipitation

Climate data for this period in division 8 are shown in figure 11 and table 2 and have already been discussed in previous sections covering this period in the Teche/Vermilion and Atchafalaya basins. Division 9 climate data for this period are shown in figure 16 and table 2. Division 9 records indicate that precipitation in 2000 was 45.89 inches (116.56 cm), a -15.74-inch (-39.98-cm) departure from normal, but the period from January to June 2001 was wet, with a 14.54-inch (36.93-cm) departure from normal. Figure 16 shows that 17 of 18 monthly PDSI values were below -2.

Salinity

Discharge from the Atchafalaya River at Simmesport during 2000 was 65 percent of the average from 1969 to 2000 (U.S. Army Corps of Engineers, 2010). Average salinity in the northeastern corner of Lake Mechant increased from 4.2 ppt during 1996–97 to 10.7 ppt during 2000–2001. Salinity further to the south in Caillou Lake increased from 7.6 ppt during 1996–97 to 15.2 ppt during 2000–01. The average salinity to the southwest of Cocodrie (fig. 15) increased from 15.2 ppt to 22.7 ppt between the 1996–97 and 2000–01 periods. The average salinity to the west of the Houma Navigation Canal also increased from 3 ppt to 8.5 ppt between the 1996–97 and 2000–01 periods.

Barataria Basin

Literature Review

Chabreck and Linscombe (1982) compared changes in marsh types between the 1968 and 1978 vegetation surveys and reported that vegetation shifts in the Barataria basin were of the greatest magnitude compared to the other basins. During that time period, saline (saltwater) marsh types covered 132,544 acres (53.641 ha) within the total basin area of 1,607,065 acres (650,379 ha) (table 1).

Comparison of Data for the 1978–88 Study Period

Overview of Marsh Changes

Figure 17 shows changes in percentages of marsh types calculated during this study for the Barataria basin, while table 1 shows the acreage changes. Changes in marsh types during the 1978–88[3] study period were minor. Fresh marsh increased from 29 to 33 percent; intermediate marsh decreased from 17 to 14 percent; brackish marsh increased from 22 to 23 percent; and saline (saltwater) marsh decreased from 32 to 30 percent.

In terms of spatial changes within the marsh types, figure 18 shows fresh marsh replacing intermediate marsh along the northern shoreline of Lake Salvador. Fresh marsh also replaced

[3] The 1988 aerial vegetation survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.

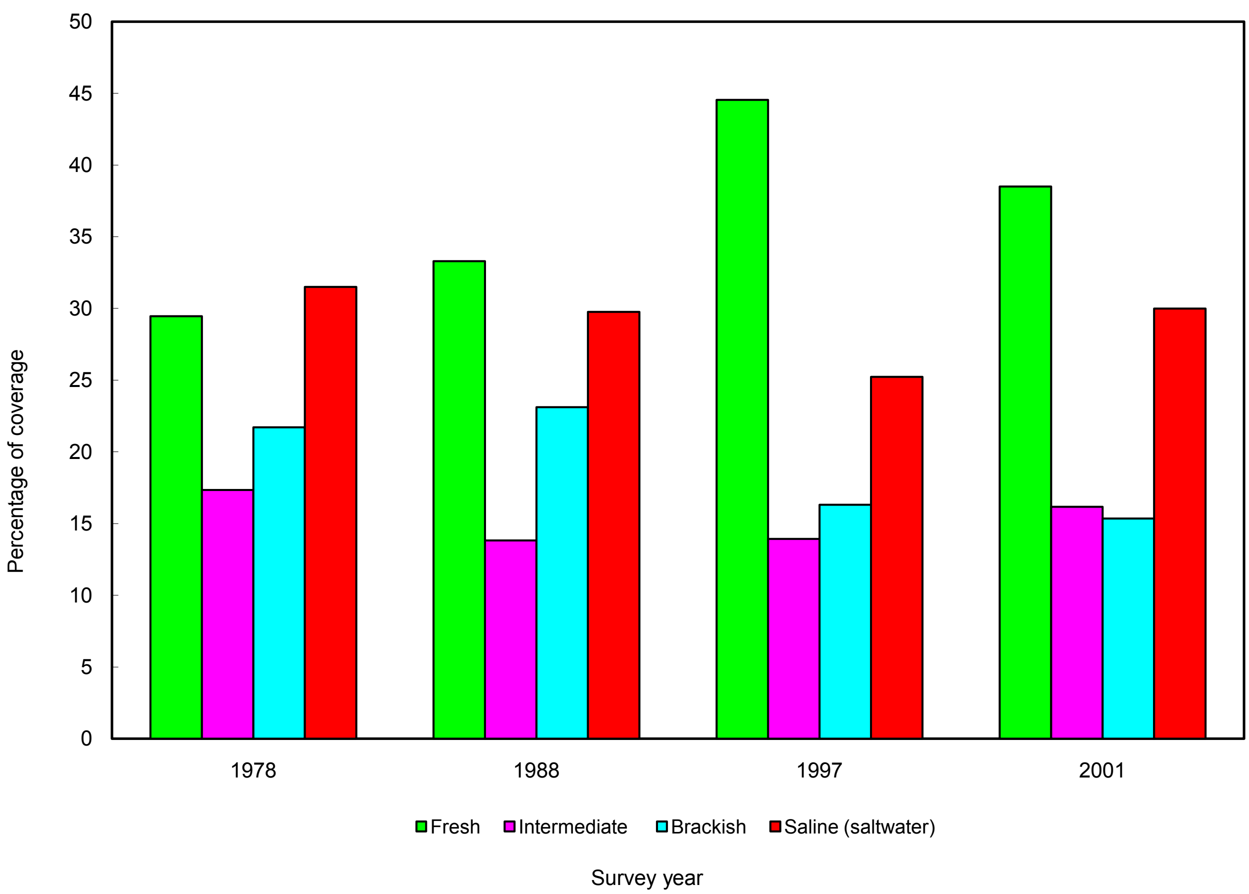

Figure 17. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Barataria basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

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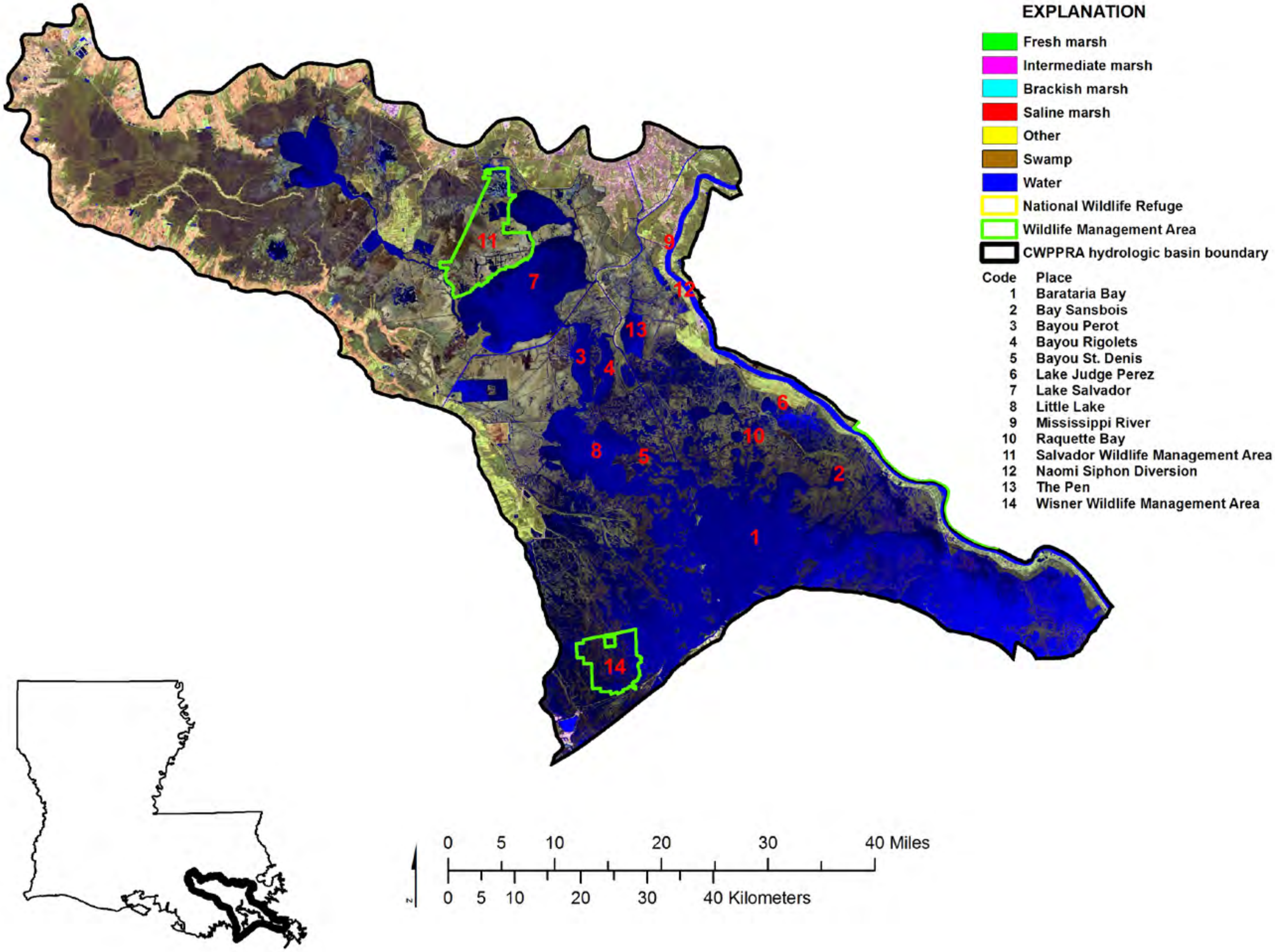
EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Barataria Bay
2 Bay Sansbois
3 Bayou Perot
4 Bayou Rigolets
5 Bayou St. Denis
6 Lake Judge Perez
7 Lake Salvador
8 Little Lake
9 Mississippi River
10 Raquette Bay
11 Salvador Wildlife Management Area
12 Naomi Siphon Diversion
13 The Pen
14 Wisner Wildlife Management Area
1
2
3
4
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6
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0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
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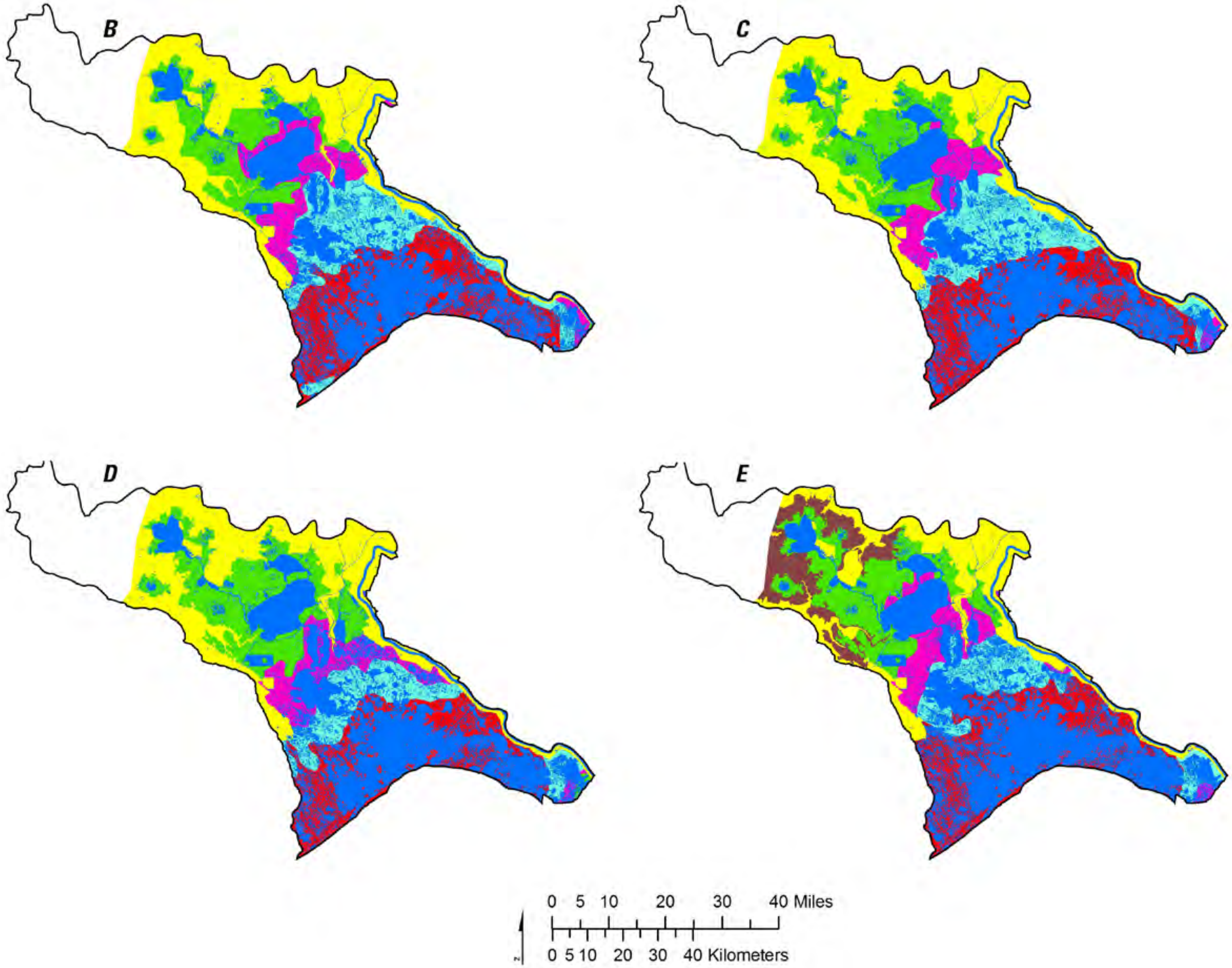


Figure 18. Localities and marsh types in the Barataria basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Barataria basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

intermediate marsh and intermediate marsh replaced brackish marsh to the west of Bayou Perot. Brackish marsh moved southward, replacing saline (saltwater) marsh, from Lake Judge Perez to Bay Sansbois (fig. 18).

Precipitation

The Barataria basin falls mostly within Louisiana climate division 9 of the NCDC, but a relatively small portion falls within division 8. Figure 11 shows PDSI values in division 8, which have already been discussed in previous sections covering this period in the Teche/Vermilion, Atchafalaya, and Terrebonne basins. In division 9, records indicate that the precipitation in 1977 was 68.96 inches (175.16 cm), a 7.83-inch (19.88-cm) departure from normal, and the January–June 1978 period was also wet, with a 4.14-inch (10.52-cm) departure from normal (table 2). Figure 16 shows PDSI values above 2 during 11 of the 18 months leading up to the 1978 vegetation survey.

Precipitation in 1986 was 51.30 inches (130.30 cm), a -9.88-inch (-25.09-cm) departure from normal (table 2). Precipitation from January to June 1987 was a 7.27-inch (18.46-cm) departure from normal. Figure 16 shows PDSI values that were drier than -1 from January through September 1986 but were wetter from January through June 1987.

Salinity

Salinity data for the central or northern end of this basin, where spatial changes were observed, were not available. The average salinity at the mouth of Bayou St. Denis, at the northern end of Barataria Bay (fig. 18), was 14.1 ppt during 1977–78 and 14.6 ppt during 1986–87. Average salinity at Raquette Bay was 9.9 ppt during 1986–87. These data were from areas too far south to reflect vegetation changes in the central and northern parts of the basin.

Comparison of Data for the 1988–97 Study Period

Overview of Marsh Changes

Figure 17 shows fresh marsh increasing from 33 to 45 percent between the 1988 and 1997 vegetation surveys. Intermediate marsh remained constant at 14 percent; brackish marsh decreased from 23 to 16 percent; and saline (saltwater) marsh decreased from 30 to 25 percent.

Figure 18 shows spatial changes within these marsh types. There was a dramatic shift to fresher marsh during the interval. Fresh marsh moved southward, replacing intermediate marsh along the eastern side of The Pen. Intermediate marsh moved southward, replacing a large area of brackish marsh along the eastern side of Bayou Rigolets, and eastward to the Mississippi River in an area to the south of The Pen.

Precipitation

Figure 11 shows PDSI values for division 8, which have already been discussed in previous sections covering this period in the Teche/Vermilion, Atchafalaya, and Terrebonne basins. In division 9, precipitation was 54.52 inches (138.48 cm) in 1996, a -7.11-inch (-18.06-cm) departure from normal (table 2), resulting in the designation of a dry year. Precipitation from January to June 1997 was wet, with a 3.44-inch (8.74-cm) departure from normal. The PDSI values presented in figure 16 indicate dry conditions during the first 5 months of 1996 and normal to wetter conditions from June 1996 through June of 1997.

Salinity

The approximate 18-month average salinity at the mouth of Bayou St. Denis ahead of the 1988 vegetation survey was 14.6 ppt, but by the 1997 survey, it dropped to 8.6 ppt. The average salinity at Bay Raquette was 9.9 ppt before the 1988 vegetation survey and dropped to 4.8 ppt before the 1997 survey. These decreases in salinity may reflect the flow of river water from the Naomi Siphon Diversion (fig. 18), which is a structure that moves water from the Mississippi River into the adjacent marshes.

Comparison of Data for the 1997–2001 Study Period

Overview of Marsh Changes

Figure 17 shows a shift to increasing saline (saltwater) marsh types during the 1997–2001 study period in the Barataria basin. Fresh marsh decreased from 45 percent to 39 percent; intermediate marsh increased slightly from 14 to 16 percent; brackish marsh remained almost the same, with a minor decrease from 16 to 15 percent; and saline (saltwater) marsh increased from 25 to 30 percent.

Figure 18 shows spatial changes within the marsh types. Saline (saltwater) marsh replaced brackish marsh to the north of Bay Sansbois. Intermediate marsh was replaced by brackish marsh northward to The Pen. Fresh marsh was replaced by intermediate marsh along the northern and southern shorelines of Lake Salvador and to the northeast of The Pen.

Precipitation

Climate data for this period in division 8 are shown in figure 11 and table 2 and have already been discussed in previous sections covering this period in the Teche/Vermilion, Atchafalaya, and Terrebonne basins. In division 9, precipitation in 2000 was 45.89 inches (116.56 cm), a -15.74-inch (-39.98-cm) departure from normal. The period from January to June 2001 was wet, with a 14.54-inch (36.93-cm) departure from normal, but this wet period could not make up for the extended drought in this basin. Figure 16 shows PDSI values below -2 during 17 of the 18 months leading up to the 2001 vegetation survey.

Salinity

Average (approximate) 18-month salinities at the northern end of Little Lake increased from 4.2 ppt ahead of the 1997 survey to 12 ppt ahead of the 2001 survey. The approximate 18-month average salinity at Bay Raquette increased from 4.8 to 12.2 ppt during the interval, and the average salinity in northern Barataria, at the mouth of Bayou St. Dennis (fig. 18), increased from 8.6 to 16.9 ppt. These shifts in salinities explain the observed shifts in marsh types.

Mississippi River Delta Basin

Literature Review

Chabreck and Linscombe (1982) compared changes in marsh types between the 1968 and 1978 aerial surveys and reported that marsh coverage in the Mississippi River Delta basin generally changed to increasing saline (saltwater) types covering 4,928 acres (1,994 ha). Total area of the Mississippi River Delta basin is 403,888 acres (163,453 ha) (table 1).

Review of Data for the 1978, 1988, 1997, and 2001 Study Periods

Overview of Marsh Changes

As is the situation in the Atchafalaya Basin, the Mississippi River Delta Basin is largely influenced by Mississippi River discharge. Figure 19 shows changes in percentages of marsh types calculated during this study for the Mississippi River Delta basin, while table 1 shows the acreage changes. Coverage of fresh marsh remained constant at 55 percent during the 1978–88[4] study period. In 1997, coverage of fresh marsh increased to 66 percent, and in 2001 it had increased to 77 percent. Intermediate marsh coverage was 39 percent during the 1978 survey, 43 percent during the 1988 survey, 34 percent during the 1997 survey, and 23 percent during the 2001 survey. Coverage of brackish marsh was 5 percent during the 1978 survey and 1 percent during the 1988 survey, and it completely disappeared from 1997 to 2001. Coverage of saline (saltwater) marsh was 1 percent during the 1978 and 1988 surveys, and there was no saline marsh in 1997 or 2001.

Figure 20 shows slight spatial changes between 1978 and 1988 surveys. In the extreme northern delta, fresh marsh expanded, and intermediate marsh replaced brackish, but in the southeastern delta, intermediate marsh replaced fresh marsh. Fresh marsh expanded in all directions, except to the northeast; during the 1997 and 2001 surveys, we observed that intermediate marsh had been replaced by fresh marsh, except at the outer reaches of Pass A Loutre, Southeast Pass, Main Pass, and along the edges of Southwest Pass (fig. 20).

[4] The 1988 aerial vegetation survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.

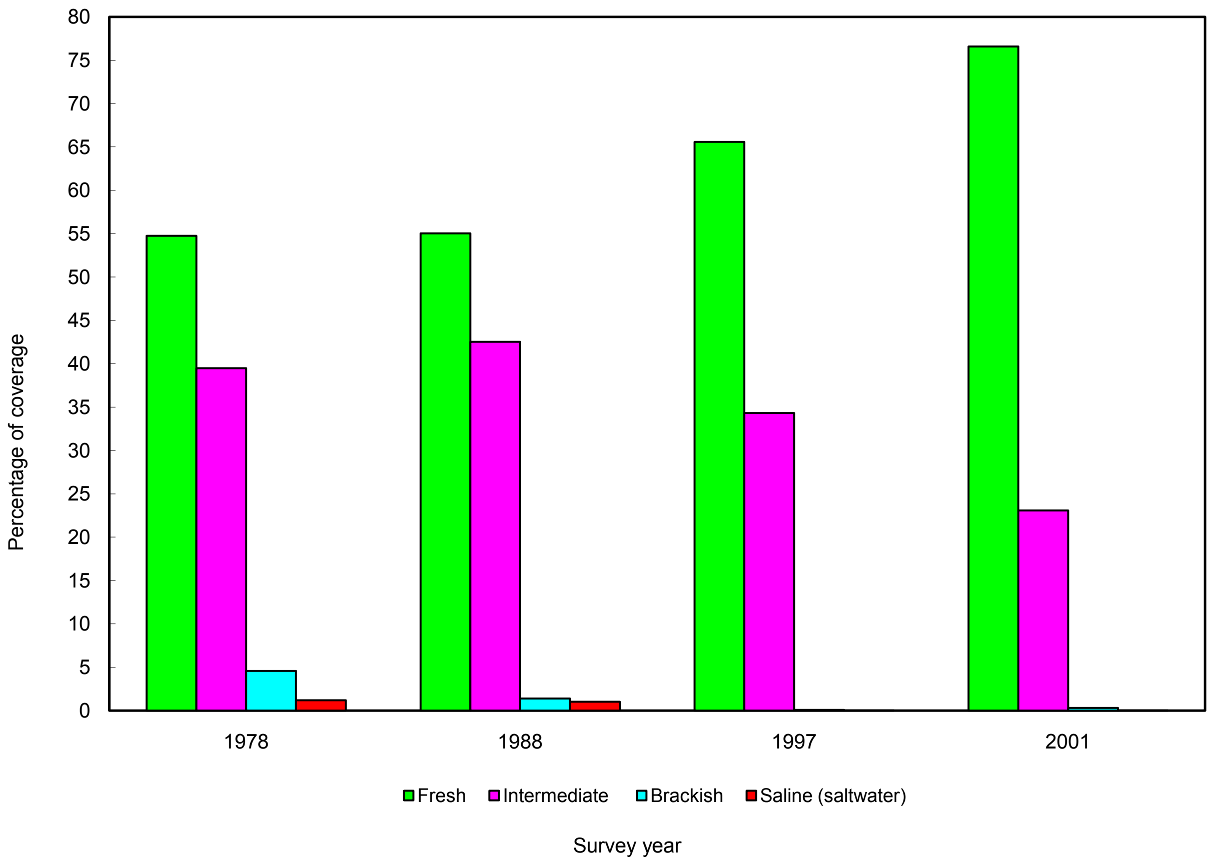
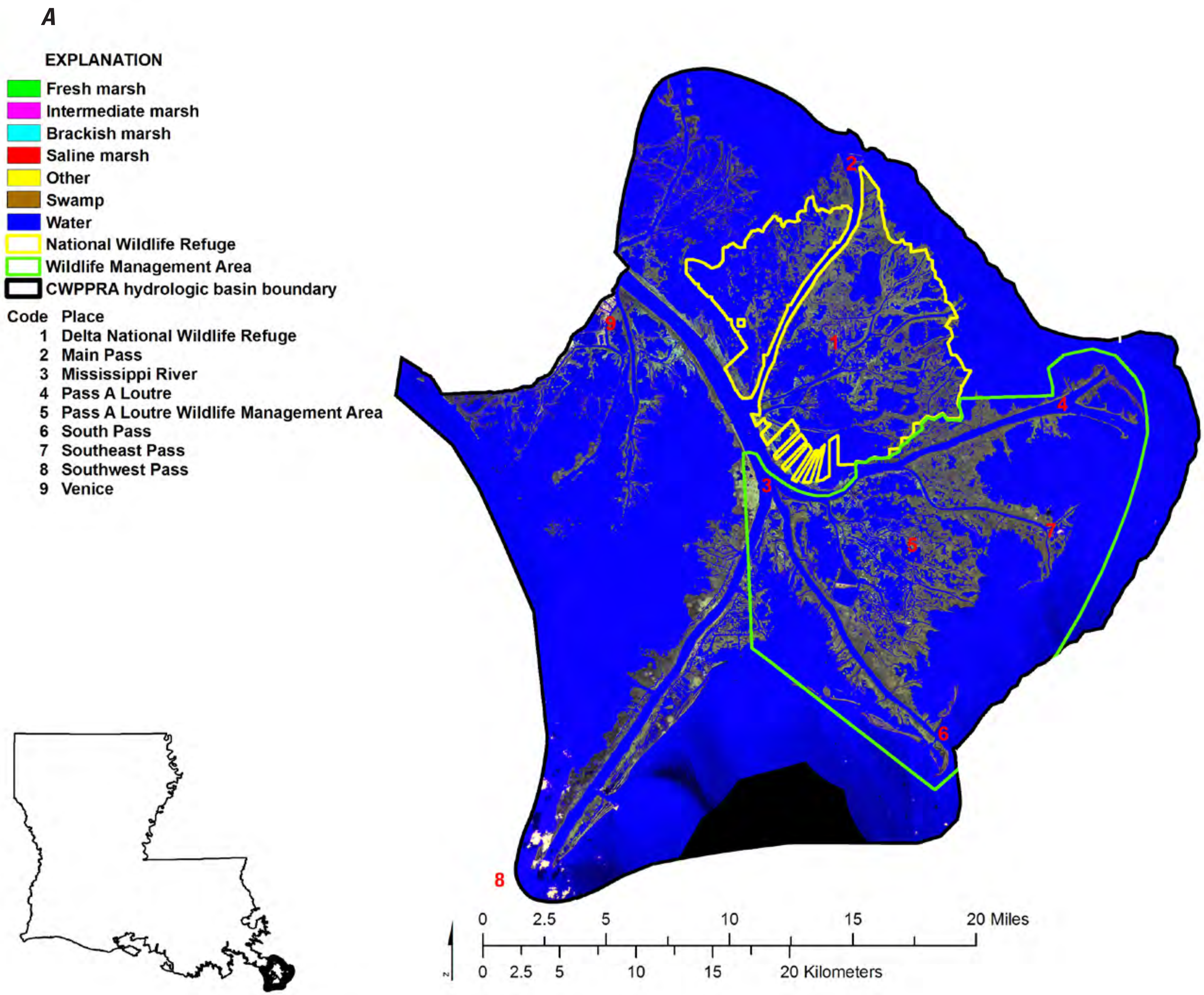


Figure 19. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Mississippi River Delta basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)


A
EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Delta National Wildlife Refuge
2 Main Pass
3 Mississippi River
4 Pass A Loutre
5 Pass A Loutre Wildlife Management Area
6 South Pass
7 Southeast Pass
8 Southwest Pass
9 Venice
1
2
3
4
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0 2.5 5 10 15 20 Kilometers
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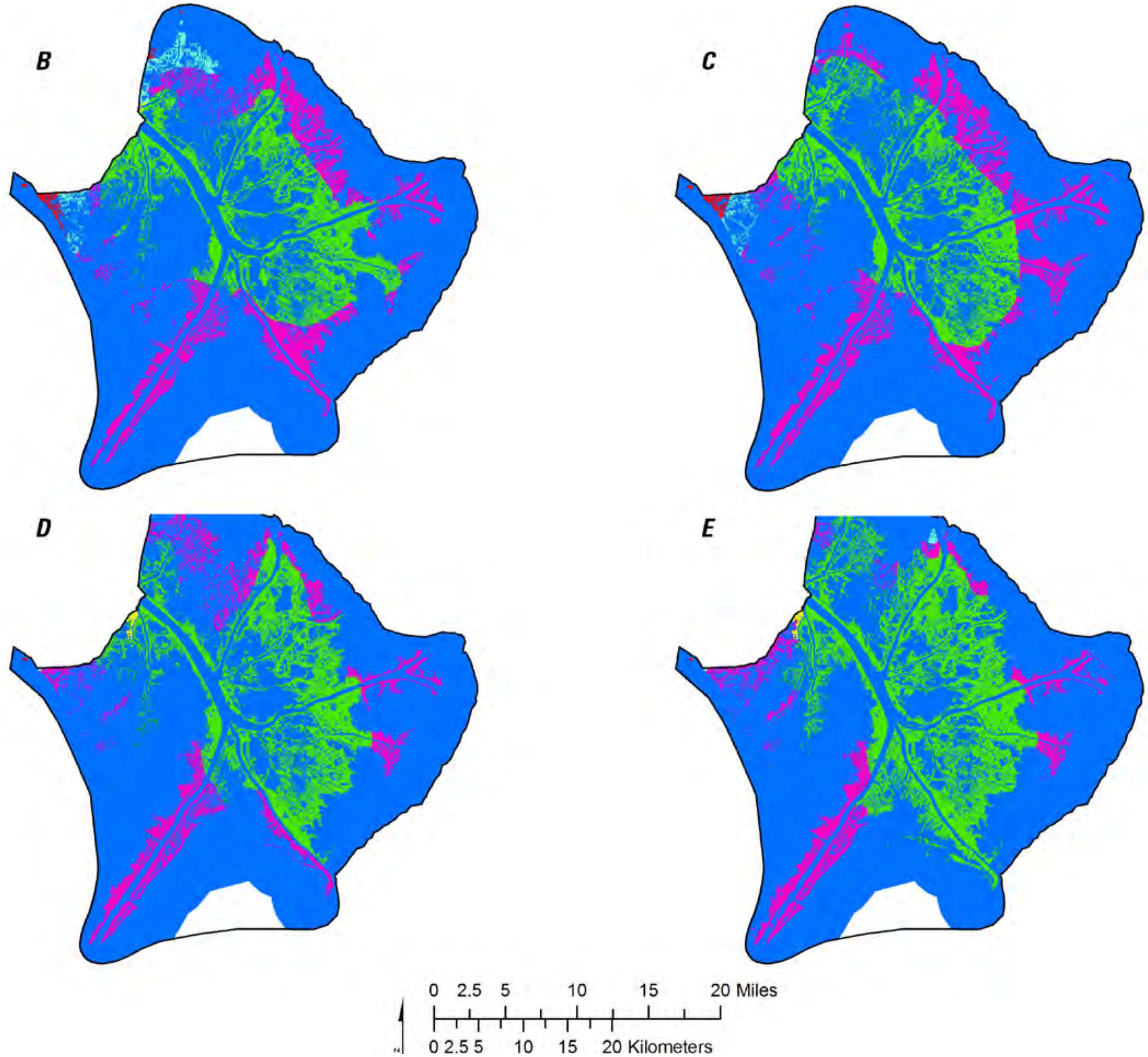

Figure 20. Localities and marsh types in the Mississippi River Delta basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Mississippi River Delta basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

Because conditions in this basin were relatively static, we have elected to discuss all the survey periods collectively rather than individually (as we have done for other basins).

Precipitation

The Mississippi River Delta basin is located completely within Louisiana climate division 9 of the NCDC. Division 9 climate data for all the survey periods are shown in figure 16 and table 2. These data have already been discussed in sections covering precipitation and PDSI values in the Terrebonne and Barataria basins. Precipitation for this basin did not appear to be the controlling factor determining salinity, but river discharge did explain changes in some survey periods.

Salinity

As in the case of the Atchafalaya basin, coverage of marsh types in the Mississippi River Delta basin is determined by discharge levels of the Mississippi River. River discharge ahead of the 1978 and 1988 vegetation surveys was below the 32-year average from 1969 to 2000 but was similar. This similarity might explain the stability of marsh types during these two survey periods. The level of river discharge ahead of the 1997 survey was much higher than it was ahead of the previous survey (U.S. Army Corps of Engineers, 2010), and the higher discharge clearly explains the expansion of fresh marsh; however, the increased expansion of fresh marsh in 2001 is not explained by heightened river discharge, especially in consideration of the very low flow in 2000.

Breton Sound Basin

Literature Review

Chabreck and Linscombe (1982) compared changes in marsh types between the June 1968 and 1978 aerial surveys and reported that there was decreasing coverage of saline (saltwater) marsh types over a combined area of 65,344 acres (26,445 ha) in the Breton Sound and Pontchartrain basins; however, the net change to less saline types in the Breton Sound basin was only 2,432 acres (984 ha). Total area of the Breton Sound basin is 605,327 acres (244,976 ha) (table 1).

Comparison of Data for the 1978–88 Study Period

Overview of Marsh Changes

Figure 21 shows that during the 1978 vegetation survey there was no fresh marsh in the Breton Sound basin, and by the 1988[5] survey, fresh marsh covered only 1 percent of the area. Intermediate marsh was also insignificant during the 1978 (with only 3 percent) and 1988 (with only 1 percent) surveys. Brackish marsh was dominant during the 1978 (with 68 percent) and 1988 (with 64 percent) surveys. Saline (saltwater) marsh occurred on 28 percent of the basin area during the 1978 survey and on 34 percent during the 1988 survey.

Spatial changes within marsh types are shown in figure 22. During the 1978 survey, intermediate marsh was present in the area adjacent to Big Mar, but most of this area was covered by brackish marsh during the 1988 survey. Along the Mississippi River, northeast of Venice, a small crevasse accounted for the appearance of fresh marsh in 1988. Saline (saltwater) marsh moved westward replacing brackish marsh between Lake Jean Louis Robin and Lake Ameda (fig. 22).

Precipitation

Breton Sound basin falls completely within Louisiana climate division 9 of the NCDC. Division 9 climate data for all the survey periods are shown in figure 16 and table 2. These data have already been discussed in sections covering precipitation and PDSI values in the Terrebonne and Barataria basins. Precipitation for this basin does not appear to be the controlling factor determining salinity.

Salinity

Salinity levels at Bay Gardene at the outer edge of the basin averaged 9.8 ppt during the 1977–78 period, and during the 1986–87 period, salinity averaged 11.4 ppt at Bay Gardene. This increase in salinity might explain the spatial increase in saline and brackish marsh. Changes in the small crevasse near Venice were more related to river discharge and local conditions.

Comparison of Data for the 1988–97 Study Period

Overview of Marsh Changes

Figure 21 shows a dramatic increase in lower salinity marsh types between the 1988 and 1997 vegetation surveys. Fresh marsh increased only slightly from 1 to 2 percent; however, intermediate marsh increased from 1 to 48 percent. Also, brackish marsh was reduced from 64 to 33 percent, and saline (saltwater) marsh decreased from 34 to 17 percent. These transitions represent the greatest changes seen in marsh types during any of the survey periods.

Figure 22 shows spatial changes within the marsh types during this period. Fresh marsh replaced intermediate and brackish marsh in the area adjacent to Big Mar, near the outflow site of the Caernarvon Freshwater Diversion structure. Intermediate marsh replaced brackish marsh as it moved eastward into the Breton Sound basin, surrounding Lake Lery.

[5] The 1988 aerial vegetation survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.

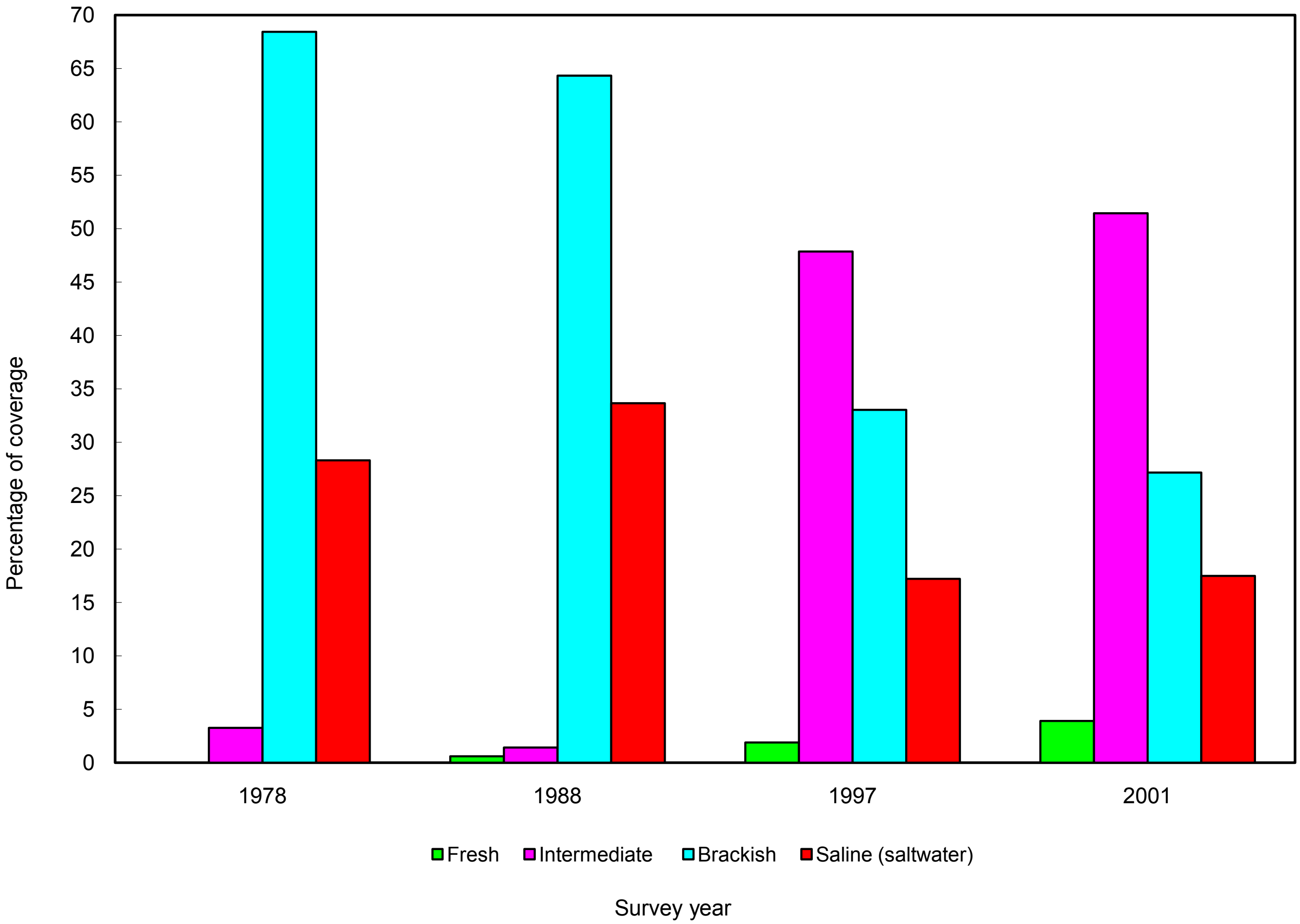

Figure 21. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Breton Sound basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

Further to the south, intermediate marsh moved eastward beyond Petit Lake. Saline (saltwater) marsh was replaced with brackish marsh pushing eastward to Lake Jean Louis Robin, Lake Campo, and Bay La Fourche (fig. 22), leaving only peninsulas of saline (saltwater) marsh.

Precipitation

Climate data for this period in division 9 are shown in figure 16 and table 2 and have already been discussed in the section covering this period in the Terrebonne, Barataria, and Mississippi basins. Although precipitation levels are not consistent with the trend of freshening marsh types during this period, this trend is explained by river discharge due to the operation of the Caernarvon Freshwater Diversion structure.

Salinity

Salinity levels at Bay Gardene in the southwest region of the basin averaged 11.4 ppt from January 1986 to June 1987 and 3.4 ppt from January 1996 to June 1997. In the northern end of the Breton Sound basin, south of Lake Lery, salinities averaged 9.9 ppt in the span of 1986–87 and 1 ppt in the span of 1996–97. These salinities explain the freshening of marsh types in the basin following the operation of the Caernarvon Freshwater Diversion structure.

The initiation of the Caernarvon Freshwater Diversion project of the USACE occurred in 1991, and the flow of river water from this water-control structure into the Breton Sound basin began reducing salinities from west to east, with marsh types beginning to change during the middle of the 1990s. The first significant discharge

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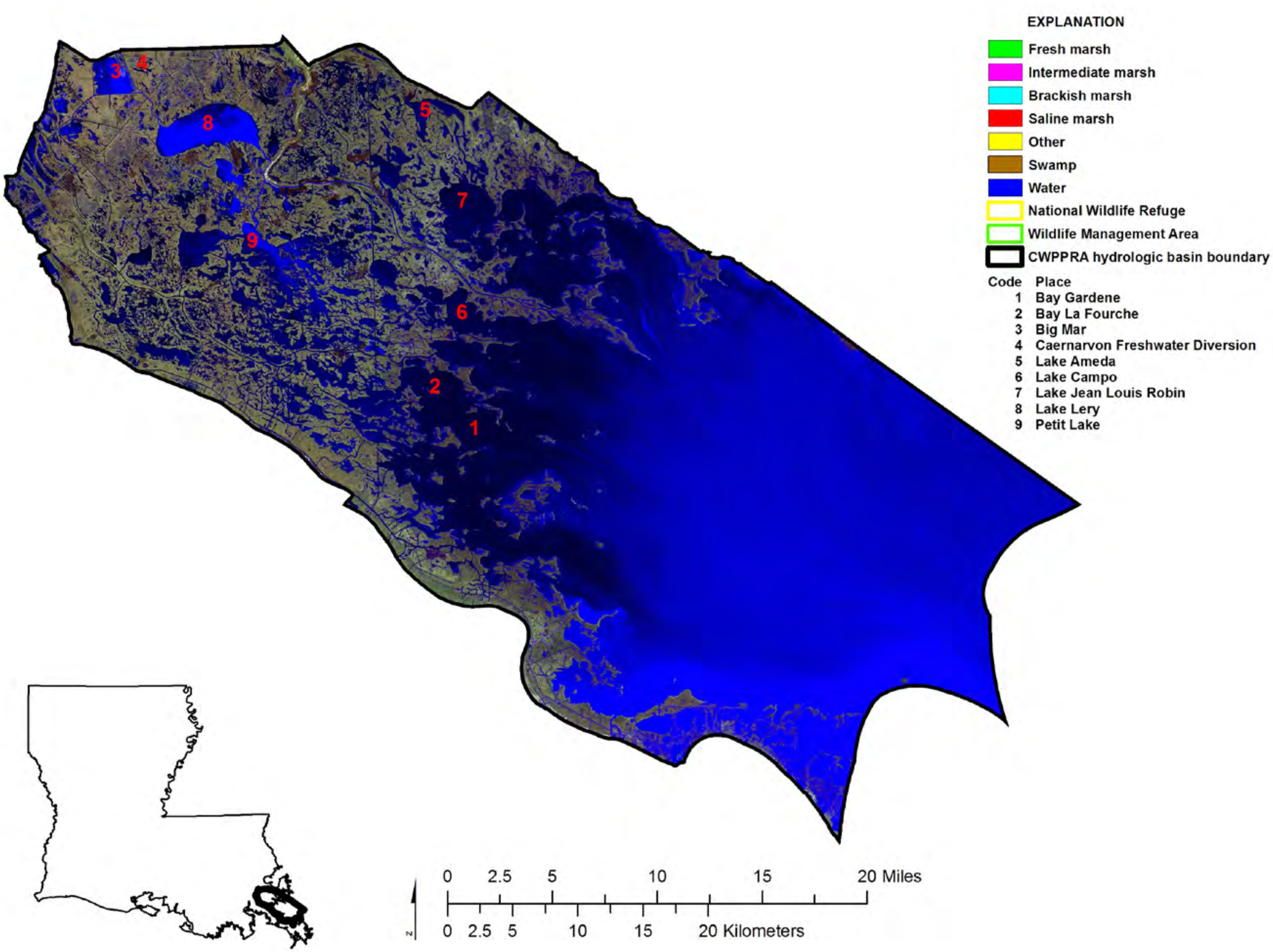

EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Bay Gardene
2 Bay La Fourche
3 Big Mar
4 Caernarvon Freshwater Diversion
5 Lake Ameda
6 Lake Campo
7 Lake Jean Louis Robin
8 Lake Lery
9 Petit Lake
1
2
3
4
5
6
7
8
9
0 2.5 5 10 15 20 Miles
0 2.5 5 10 15 20 Kilometers
N

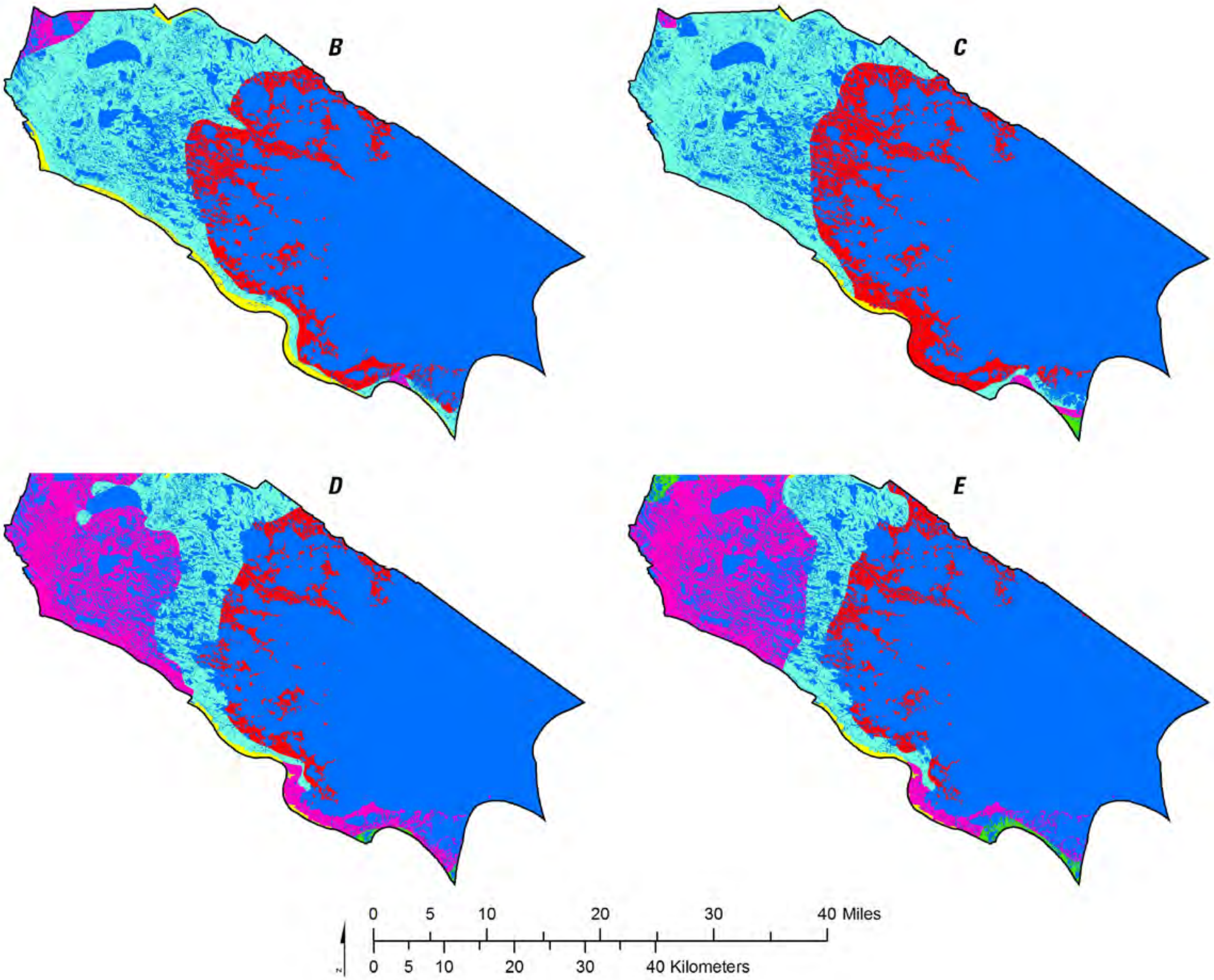


Figure 22. Localities and marsh types in the Breton Sound basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Breton Sound basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

(approximately 7,000 ft^3/s [198.2 m^3/s]) from the Caernarvon structure was in December 1993 (U.S. Army Corps of Engineers, 2010). During 1994, the approximate discharge from the structure was recorded as 5,800 ft^3/s (164.3 m^3/s) in January, 7,000 ft^3/s (198.2 m^3/s) in February, 3,800 ft^3/s (107.6 m^3/s) in July, and 4,600 ft^3/s (130.3 m^3/s) in December. Similar discharges occurred in 1995, 1996, and 1997.

Comparison of Data for the 1997–2001 Study Period

Overview of Marsh Types

Figure 21 shows that fresh marsh increased from 2 to 4 percent between the June 1997 and 2001 surveys. Intermediate marsh also increased slightly from 48 to 51 percent; brackish marsh decreased from 33 to 27 percent; and saline (saltwater) marsh remained constant at 17 percent.

Spatial changes within the marsh types during this period are shown in figure 22. Fresh marsh increased to the west of Big Mar by the 2001 survey. Intermediate marsh moved eastward, replacing brackish marsh, around and to the east of Lake Lery by 2001. Intermediate marsh also moved eastward into the southwestern corner of the Breton Sound basin, thus narrowing the band of brackish marsh in this region.

Precipitation

Climate data for this period in division 9 are shown in figure 16 and table 2 and have already been discussed in earlier sections covering this period. Despite dry conditions, river discharge resulting from operation of the Caernarvon water-control structure continued to reduce salinities in the northern basin, thus influencing marsh changes during this period.

Salinity

During the 2000–01 period, salinity increased slightly from 3.4 to 5.1 ppt on the outer edge of the basin at Bay Gardene. In the northern end of the basin, more under the influence of the Caernarvon water-control structure, salinity only increased from 1 to 1.5 ppt.

Pontchartrain Basin

Literature Review

Chabreck and Linscombe (1982) compared changes in marsh types between the June 1968 and 1978 surveys and reported that there was a decrease in coverage of saline (saltwater) marsh types over 9,536 acres (3,859 ha). Total area of the Pontchartrain basin is 2,704,537acres (1,094,526 ha) (table 1).

Comparison of Data for the 1978–88 Study Period

Overview of Marsh Changes

Figure 23 shows changes in the percentages of marsh types calculated during this study for the Pontchartrain basin for the four survey periods, while table 1 shows the acreage changes. Changes in marsh types between the 1978 and 1988[6] vegetation surveys included freshening in some areas of the basin but shifts to more saline conditions in other areas. Fresh marsh increased from 3 to 11 percent; intermediate marsh increased from 10 to 12 percent; brackish marsh decreased from 62 to 46 percent; and saline (saltwater) marsh increased from 25 to 32 percent.

Figure 24 shows spatial changes within marsh types during this period. Between the surveys, fresh marsh replaced deteriorated swamp in the western end of the Pontchartrain basin and replaced brackish marsh on the southeastern shoreline of Lake Pontchartrain. This latter change was likely related to marsh restoration projects on Bayou Sauvage National Wildlife Refuge (fig. 24). Saline (saltwater) marsh replaced brackish marsh along the southern shoreline of Lake Borgne. This change was likely related to shoreline erosion and a hydrologic connection to the Mississippi River-Gulf Outlet Canal that allowed water with higher salinity to move in from Breton Sound.

[6] The 1988 aerial vegetation survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.

Precipitation

Part of the Pontchartrain basin falls within Louisiana climate division 9 of the NCDC, and other portions fall within climate division 6. Very little marsh occurs within division 6; therefore, those data are not discussed within this report. Division 9 climate data for this period are shown in figure 16 and table 2 and have already been discussed in the section covering this period in the Terrebonne, Barataria, and Breton Sound basins. The records show a wetter period in 1977–78 as compared to 1986–87.

Salinity

Ahead of the 1978 vegetation survey, the average salinity in the eastern portion of the basin (at Treasure Pass) was 16.3 ppt, and ahead of the 1988 survey, it was 13.2 ppt. During the interval, average salinity on the northern side of the Biloxi Wildlife Management Area at Nine Mile Bayou (fig. 24) increased from 7.1 to 9.1 ppt. Average salinity at Bayou Bienvenue, west of Lake Borgne, increased from 7.8 to 9.6 ppt. Average salinities at The Rigolets, on the northern side of Lake Borgne, increased from 4.8 to 5.3 ppt. These fluctuations in salinity do not explain the minor marsh changes seen around Lake Borgne. These changes were likely more of a result of erosion or changes in hydrology, similar to the ongoing processes at Bayou Savage National Wildlife Refuge.

Comparison of Data for the 1988–97 Study Period

Overview of Marsh Types

Figure 23 shows that there was no clear trend of change in marsh types between the 1988 and 1997 vegetation surveys. Fresh marsh decreased from 11 to 9 percent; intermediate marsh increased from 12 to 18 percent; brackish marsh decreased from 46 to 41 percent; and saline (saltwater) marsh increased slightly from 32 to 33 percent.

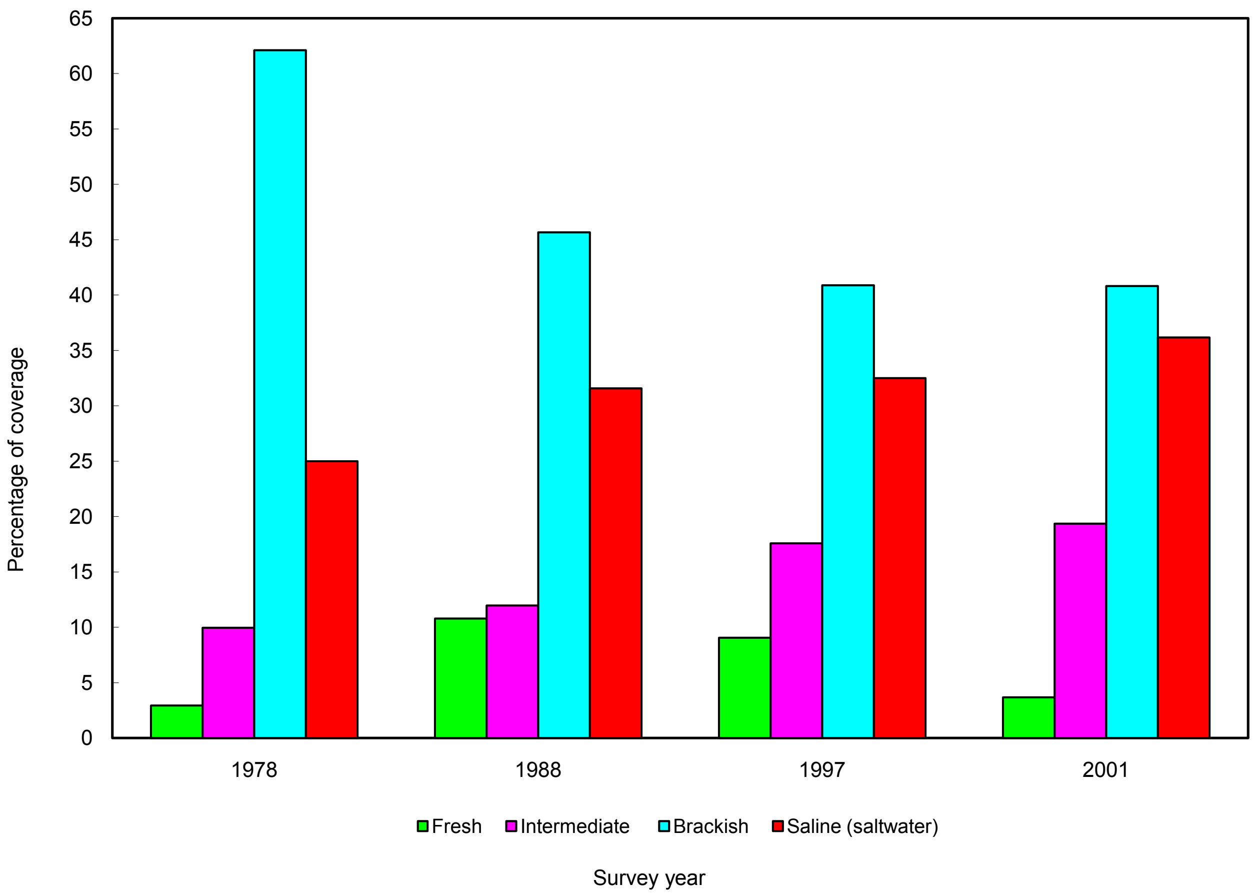
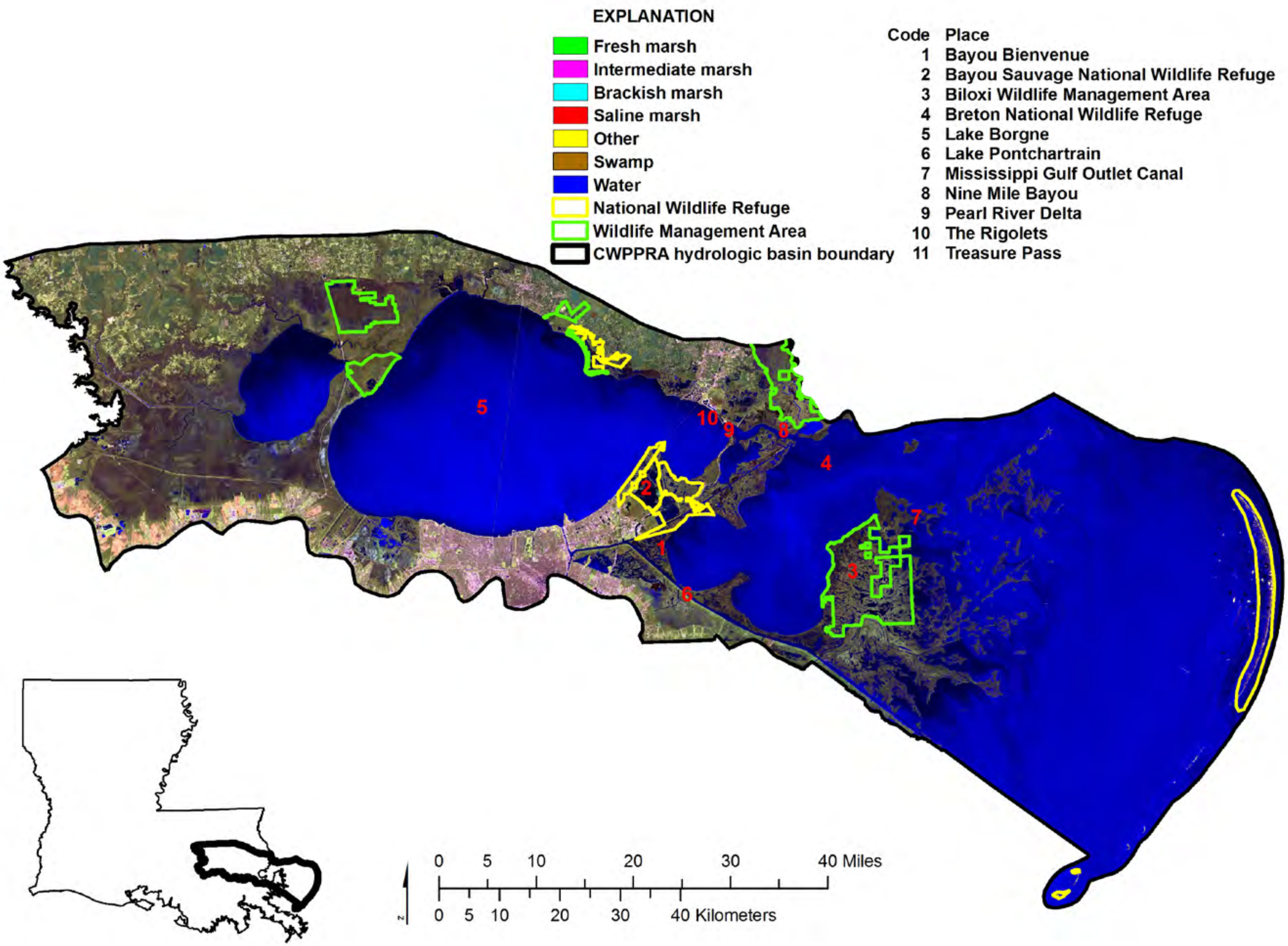


Figure 23. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in the Pontchartrain basin during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

A


EXPLANATION
Fresh marsh
Intermediate marsh
Brackish marsh
Saline marsh
Other
Swamp
Water
National Wildlife Refuge
Wildlife Management Area
CWPPRA hydrologic basin boundary
Code Place
1 Bayou Bienvenue
2 Bayou Sauvage National Wildlife Refuge
3 Biloxi Wildlife Management Area
4 Breton National Wildlife Refuge
5 Lake Borgne
6 Lake Pontchartrain
7 Mississippi Gulf Outlet Canal
8 Nine Mile Bayou
9 Pearl River Delta
10 The Rigolets
11 Treasure Pass
0 5 10 20 30 40 Miles
0 5 10 20 30 40 Kilometers
N

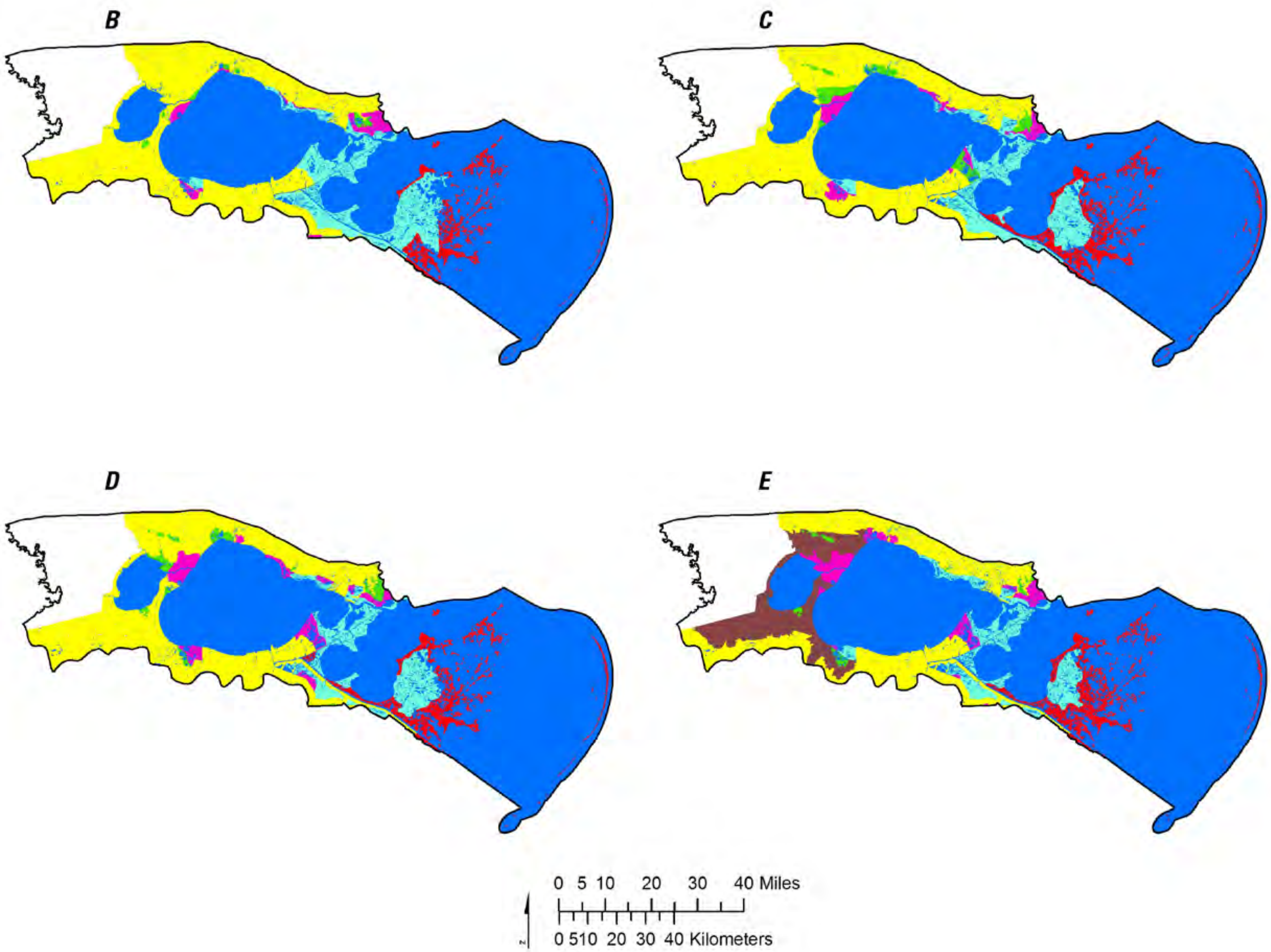


Figure 24. Localities and marsh types in the Pontchartrain basin during aerial vegetation surveys, 1978–2001. *A*, Localities within the Pontchartrain basin. *B*, 1978 survey. *C*, 1988 survey. *D*, 1997 survey. *E*, 2001 survey. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

Figure 24 shows spatial changes within marsh types during this period. There was an increase of intermediate marsh in the western end of the Pontchartrain basin, and fresh marsh was replaced by intermediate marsh along the southeastern shoreline of Lake Pontchartrain. Fresh marsh replaced intermediate marsh in the Pearl River delta.

Precipitation

Climate data for this period in Louisiana division 9 of the NCDC are shown in figure 16 and table 2. The periods of 1986–87 and 1996–97 were drier than normal years during the first portion of each period and wetter than normal during the last 6 months.

Salinity

During the interval, average salinity values in the southeastern corner of Pontchartrain basin at Treasure Pass (to the north of the Mississippi River-Gulf Outlet Canal) increased from 13.2 to 14.9 ppt. Average salinity values on the northern side of the Biloxi Wildlife Management Area at Nine Mile Bayou decreased from 9.1 to 8.9 ppt. Average salinity values at Bayou Bienvenue, to the west of Lake Borgne (fig. 24), decreased from 9.6 ppt to 8.9 ppt. At The Rigolets, on the northern side of Lake Borgne, average salinity values were nearly static, with a slight increase from 5.3 to 5.4 ppt. Again, there is no clear pattern of salinity change to support the observed, minor spatial changes in marsh types. The Bonnet Carré Spillway in the upper end of this basin was opened for 31 days in March and April of 1997. This could have influenced some spring and summer salinities in a basin.

Comparison of Data for the 1997–2001 Study Period

Overview of Marsh Changes

Figure 23 shows a slight trend indicating an increase of saline (saltwater) marsh types during the survey of 2001 as compared to that of 1997. Between the surveys, fresh marsh decreased from 9 to 4 percent; intermediate marsh increased from 18 to 19 percent; brackish marsh remained constant at 41 percent; and saline (saltwater) marsh increased from 33 to 36.

Spatial changes within the marsh types during this period are shown in figure 24, which indicates that there was a decrease in fresh marsh in the Pearl River delta and in the western end of the Pontchartrain basin. Some brackish marsh was replaced by saline (saltwater) marsh in the Biloxi Wildlife Management Area.

Precipitation

Division 9 climate data for this period are shown in figure 16 and table 2. As previously discussed, the 1996–97 period started out dry and ended up wetter than normal. Precipitation in 2000 was 45.89 inches (116.56 cm), a -15.74-inch (-39.98-cm) departure from normal, but the period from January to June 2001 was wet, with a 14.54-inch (36.93-cm) departure from normal. Figure 16 shows PDSI values below -2 during 17 of 18 months leading up to the 2001 survey.

Salinity

Average salinity in the southeastern corner of the Pontchartrain basin at Treasure Pass (to the north of the Mississippi River-Gulf Outlet Canal) increased from 14.9 to 19.6 ppt during the 1997–2001 study period. Average salinity on the northern side of the Biloxi Wildlife Management Area at Nine Mile Bayou increased from 8.9 to 14.5 ppt. Average salinity at Bayou Bienvenue, to the west of Lake Borgne, increased from 8.9 to 12.8 ppt. At The Rigolets, on the north side of Lake Borgne, average salinity values increased from 5.4 to 9.7 ppt. These changes in salinity, which appear to be related to below-normal levels of precipitation, explain the observed changes in marsh types.

Summary

Figure 25 summarizes changes in the percentages of marsh types calculated during this study (spanning all four surveys) for coastal Louisiana. The general trend across coastal Louisiana was a shift to increasingly fresh marsh types. Although fresh marsh remained almost the same, with only a small increase from 29 to 30 percent during the 1978–88 study period, there were greater increases during the 1988–2001 study periods (with coverage of 37 percent during the 1997 survey and 36 percent during the 2001 survey). Intermediate marsh followed the same pattern, with coverage of 18 percent during the 1978 and 1988 surveys and 26 percent during the 1997 and 2001 surveys. Brackish marsh showed a reverse (decreasing) pattern, with coverage of 35 percent during the 1978 survey, 32 percent during the 1988 survey, and 21 percent during the 1997 and 2001 surveys. Changes in saline (saltwater) marsh were minimal, with coverage of 18 percent during the 1978 survey, 19 percent during the 1988 survey, 17 percent during the 1997 survey, and 16 percent during the 2001 survey.

The value of comparing the surveys is greater when examining individual basins as compared to viewing coastwide changes. Also, during the 23 years we analyzed (1978–2001), total marsh acreage decreased, with conversion

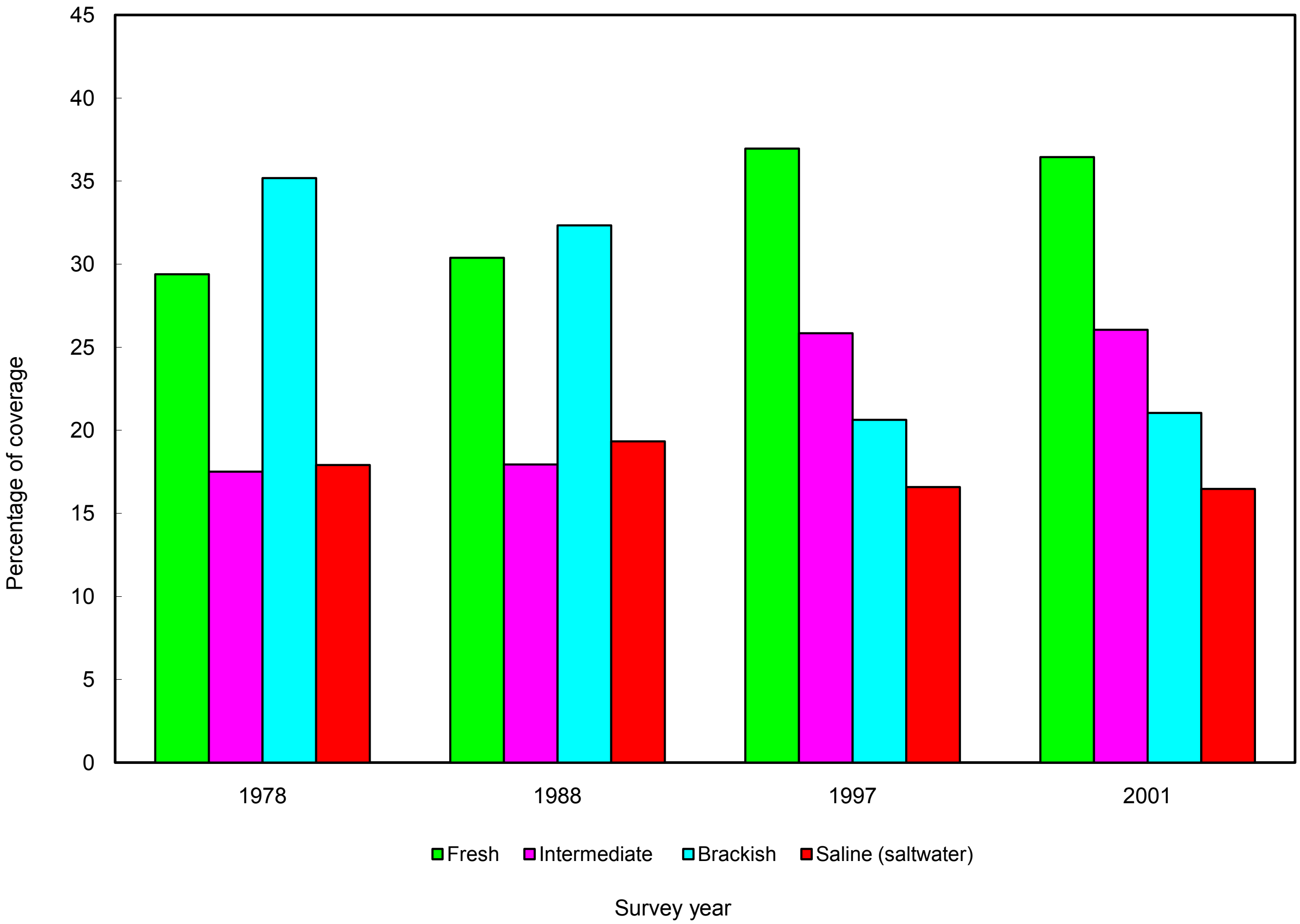


Figure 25. Percentages of fresh, intermediate, brackish, and saline (saltwater) marshes in coastal Louisiana (all basins combined) during aerial vegetation surveys in 1978, 1988, 1997, and 2001. (The 1988 survey was conducted in September 1987, but resulting maps were printed and dated August 1988; therefore, both the aerial survey and the vegetation data are noted as 1988.)

of marsh to open water. With the loss of marsh and resultant changes in hydrology, it is likely that changes in marsh type may show greater variation in the future, even if given only minor changes in precipitation levels. By analyzing marsh changes in the context of fluctuating precipitation and salinity data within individual basins, we hope to provide a better understanding of these spatial changes. Such information may help researchers and coastal resource managers forecast future changes in marsh types and areas of likely change and thus improve planning for coastal protection and restoration.

Salinity measurements now available from the Coastwide Reference Monitoring System will make future comparison of marsh type changes much easier to interpret. Precipitation rates prior to vegetation surveys indicated that precipitation fluctuations impacted salinities differently across the coast. For example, a wet 6 months prior to the survey may or may not have made up for a dry period during the earlier 12 months. More research is needed to better understand precipitation periods and how they affect salinity changes.

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