DETECTING CHANGE IN A LOUISIANA GULF COAST MARSH USING REMOTE SENSING

By

AMANDA LU FRICK

Bachelor of Science

University of Michigan - Flint

Flint, Michigan

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Thesis Approved:

Stephen J. Walsh
Thesis Adviser

John D. Vitek

Stephen J. Stadler

Paul A. Nauke

Norman N. Durham
Dean of Graduate College

PREFACE

This study is concerned with detecting change in a Louisiana Gulf Coast marsh, and citing possible causes for the change. The primary objectives are to determine the amount, location and nature of change over a nine year period, utilizing Landsat data. Salinity, precipitation, water level and the distance of change-to-water are examined to determine their contribution to the alteration of this ecosystem.

The author wishes to express her appreciation to her major adviser, Dr. Stephen J. Walsh, for his guidance, assistance, and understanding throughout this study. Appreciation is also expressed to the other committee members, Dr. David A. Francko, Dr. Stephen J. Stadler and Dr. John D. Vitek, for their comments and patience, and for their invaluable assistance in the preparation of the draft and final manuscripts.

Thanks are also extended to the National Aeronautics and Space Administration personnel at the Earth Resources Laboratory for allowing me to complete my data processing using their facilities, utilization of in-house data, and for appointing me to a position where I could be exposed to the goings on at the cutting edge of remote sensing research. Special thanks go to: Director, Mr. Wayne Mooneyhan, for giving me the chance; Ms. M. Kristine Butera for letting me assist in wetlands research,and for her guidance throughout; Mr. James Anderson, Dr. Ken Langran, Dr. Brad Musick, Mr. Dale Quattrochi, Dr. Doug Rickman and Mr. Eugene Zetka, for their assistance in processing data and understanding the 'why's'; Ms. Maria Kalcic and Mr. Ronnie Pearson for their aid in understanding ELAS and BMDP statistical software, and; Mr. Tony Blanchard, at Oklahoma State University, who helped spark my interest in wetlands and NASA. Thanks are also extended to all of the LEMSCO personnel for their assistance against all 'system level' odds, and for cartographic assistance and suggestions form Mr. Gary Stover, to Ms. Jackie Wall, for typing early drafts of the manuscript, to Ms. Janet Austill, who pulled me through when I was near the end, and to Janet and Ms. Nan Touchard for helping me prepare the final manuscript.

Compilation of ancillary data involved many agencies. A note of thanks goes to those individuals who gave friendly, helpful assistance, including: Mr. Eric Knudsen, and other Louisiana State University personnel in Creole, who helped in field sampling; Mr. Barton Rogers, for being in the right place at the right time, compiling salinity data, and sharing ideas; Mr. John Walthers, for release of the Sabine salinity data; Mr. Eric Swenson, for helping analyze the tidal model; Mr. Michael Materne, for sharing his personally acquired, unpublished, salinity data; and Mr. Quinn Humphreys, for his assistance in obtaining Cameron water level data.

Finally, heartfelt thanks go to Beth and Susan for being friends and being there, and offering the positive stroking that drove me to keep climbing out of the hole. No amount of thanks can adequately express the depth of love and appreciation to Mom, for helping me get from point A to point B, and continual encouragement from Dad and the rest of the family who were always behind me, though hundreds of miles away.

I love you all.

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CHAPTER I

INTRODUCTION

General

The Study of Wetlands

In recent years, the nations wetlands have attracted a great deal of interest from scientists, land managers, and property owners alike. Wetlands, that took centuries to evolve, are changing so rapidly that it has been deemed necessary to conduct a national inventory: determine their areal extent and wetland type; and establish a basis to assess their value (Cowardin et al., 1979). The value of a wetland depends upon the point of view of the user. Hunters, fishermen, trappers, and wildlife managers find these ecosystems invaluable and highly productive habitats. Industrial canals and channels through wetlands provide access to remote areas. Wetlands are valuable even to those who don't directly use them. Wetland vegetated areas act as a buffer zone for coastal urban developments: by absorbing the initial shock of hurricanes and severe storms. Wetland vegetation also absorbs chemicals, acting as a filtering system for polluted water entering the estuary (Kibby, 1978).

Human impact upon wetlands is complicated by numerous environmental variables. Many researchers are currently studying various aspects of wetland systems and the forcing functions of their change

(Gosselink et al., 1979). The complexity of wetland ecosystems requires extensive efforts by the research community to understand wetland dynamics.

Wetlands: A Definition

> A wetland is land where water is the dominant factor in determining the nature of soil development and the types of plant and animal communities growing at the soil surface. It spans a continuum of environments where terrestrial and aquatic systems intergrade (Cowardin, 1978, p. 667).

This fragile ecosystem produces more biomass (primary energy) than most other aquatic communities (Wetzel, 1983). Numerous physical, chemical, and biological variables control wetland dynamics. Society does not appreciate the delicate balance of these variables nor the vulnerability of these vast areas, as evidenced by the rapid deterioration of the wetland environment. Nearly one-third of the nation's population is distributed along the coastal regions. Intense human interaction with the coastal environment requires that high regard is placed on proper management of these areas if people are to reap the benefits. Louisiana's coast, almost entirely composed of marshes and swamps, makes up 30 percent of the nation's coastal wetlands.

Louisiana's coastal wetlands are unique in comparison with marshes along ocean coasts and inland marshes. Although both oceanic and Gulf coast marshes support similar vegetative types, the hydrologic factors differ. Oceanic tides have a broader vertical flux, on the order of meters, and flush a greater area of marsh on a daily basis. The tidal range in Louisiana's marshes, may only vary by centimeters, as the configuration of the Gulf dramatically attenuates ocean tides. The tides, however, are an important component in horizontal and vertical mixing of the shallow waters of the marsh. Tidal mixing is entirely lacking in inland marshes, which are fresher on the whole and have greater species diversity (Charbreck, 1972). Successional trends in coastal marshes from fresh to saline vegetative communities normally require hundreds of years to complete transition (Teal and Teal, 1969). Along the Louisiana Gulf Coast, the literature has noted that rapid deterioration and transition from fresh to saline marshes has only taken 15 to 50 years, and is still proceeding.

Utilizing Remotely-Sensed Data to Analyze Wetlands

Remote sensing provides techniques for the inventory of wetlands. Considering that marshes may change rapidly, remote sensing offers a fast, repetitive procedure by which the composition of plant species, and areal extent of wetlands can be analyzed (Link and Long, 1977). Because many wetlands are often inaccessible by car or boat, and costly to sample by helicopter or airboat, remote sensing may offer the only feasible techiques by which information can be obtained. Remote sensing also provides a cost-effective method to study these sometimes inhospitable environments without using traditional ground survey techniques (Butera, 1979 and 1983, and Klemas et al., 1974).

Detection of water salinity levels based on the spectral reflectance of indicator plant species can be accomplished using satellite remote sensing techniques (Butera, 1977a, 1977b, 1978, 1983 and Gammon and Carter, 1976). Actual water salinity data, however, will be used in this study, because MSS sensor information has been unsuccessful. Some research has shown that false color infrared (CIR) aerial photographs are best for delineation of wetlands (Gammon et al., 1977, and Lillesand and Kiefer, 1979). While most aerial photography has greater resolution than satellite data, photography cannot be statistically manipulated as easily as Landsat digital data and does not have the spectral advantages of Landsat data. The distinct MSS wavelength regions of the electromagnetic spectrum respond differently to vegetation and water, thus enhancing contrast between these cover types. Landsat can be used to effectively monitor changes in marshes and open water (Anderson et al., 1982, Gammon et al., 1977 and Rose and Rosendahl, 1980). The utility of Landsat data has other advantages over photography: edge distortion is minimal because the sensor orbits at a high altitude; and coverage is provided over a large geographic area. One scene of data may be sufficient to cover a study area with Landsat, whereas, the same areal coverage would require several hundred frames of photography, depending upon the scale. Landsat data, however, is not without limitations. Aside from poor resolution and atmospheric interference, scan-line overlap and other radiometric noise, can cause problems for the investigator. In this study, satellite data was chosen on the basis of proven feasibility and ease of digital manipulation.

Hypothesis

Vegetated marsh in the coastal areas of the Louisiana Chenier Plain are believed to have deteriorated by 6.4 per cent over the last 25 years (Gosselink et al., 1979). Deterioration is not the same as succession. Succession from fresh to more saline vegetation occurs naturally as water salinity levels increase, although this process may be accelerated by human activity. The term deterioration, as used in this study, refers to loss of vegetated wetland acreage to open water bodies. A marsh goes through various stages as it deteriorates. Thickly vegetated areas break up, becoming heavily dissected, and small ponds form which increase in size until the marsh is open water. Baumann et al. (1983) determined that a portion of the area for this study, identified as the saline vegetative zone by Gosselink et al. (1979), was 4.5 percent open water in 1954, 7.5 percent in 1963, and has been nearly doubling every six years since then (Figure 1).

Utilizing remote sensing techniques, targeted at a distinct hydrologic basin, it is hypothesized that the nature of change in cover-type as a marsh moves into advanced stages of deterioration can be detected for a nine year period. A study conducted over the Chenier Plain region by O'Neil (1949) showed that the majority of the wetlands were fresher than they are now. A later report published by Gosselink et al., in 1979 showed the area studied ranged from fresh to salt marsh. As shown by these two works, the salinities in most Louisiana coastal marshes have increased in the past 30 years. Assuming the salinities have also increased in the study site, one would expect that vegetation growing in different salinity regimes, would have different tolerance to this increase. This study attempts to explain the nature and degree of change in each salinity zone (saline, brackish, intermediate, and fresh) for the nine-year period, by using available precipitation, salinity, water level data, and the extent of water bodies and shoreline.

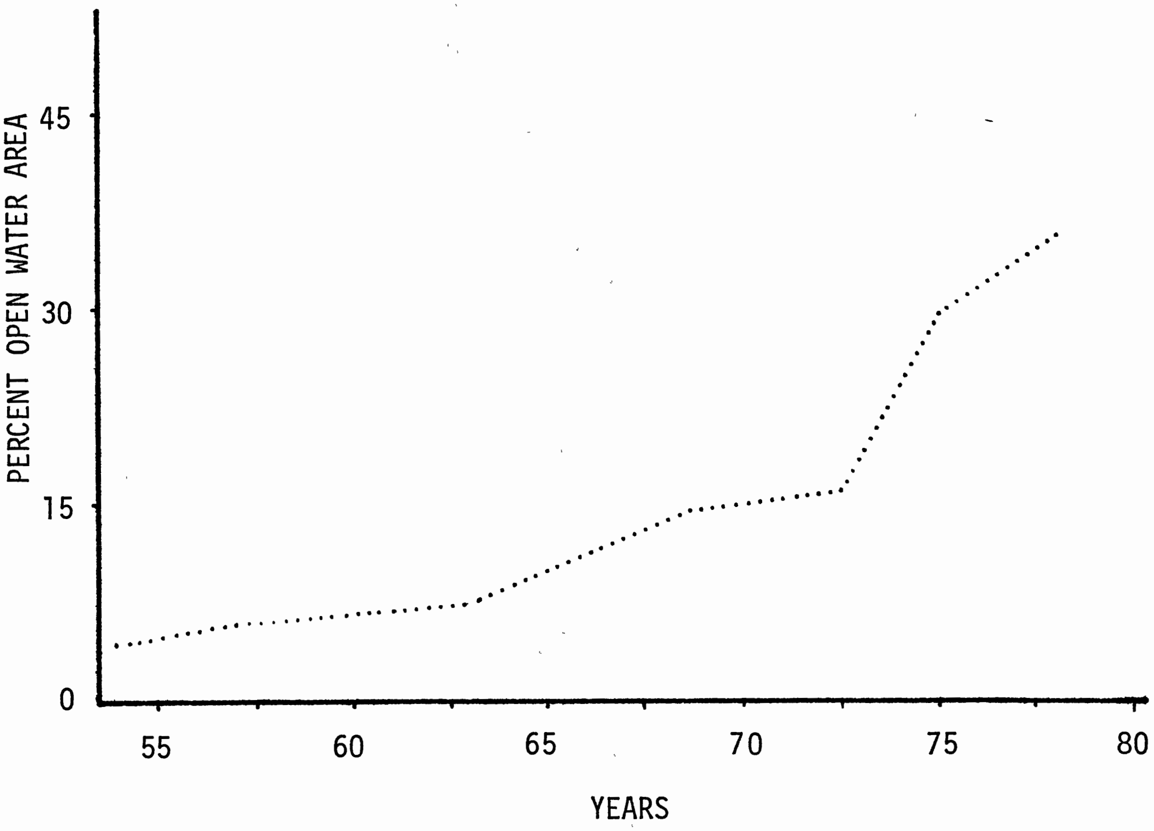


Figure 1. Percent Open Water in a Portion of the East Cove Marsh Over Time, After Baumann et al., 1983

Methodology

Although salinity appeared to be an obvious agent of change operating in the basin, other environmental variables and human activities must be considered. Precipitation and water level may have affected salinity: concentration; rate of change; deviation from normal; and seasonal or annual trends. Salinity, precipitation and water level will be the only ancillary data analyzed in this study. In addition, field data and observations (ground-truth) from July of 1982 through April of 1983 will aid in understanding hydrological and climatological processes operating in the study site. The lack of suitable historical data for velocity of marsh currents, biological activity, geomorphic processes, and geologic activity during this study period, eliminate these environmental variables from my analysis. They will be briefly discussed, however, as possible agents of change.

Human induced changes also have not been documented specifically for the study area. The dates, however, for increased waterborne commerce and related dredging activities will be compared to changes in general salinity concentrations. Water and mineral extraction, and burning practices also have not been historically documented. Grazing, agricultural activity, and recreational uses within the study site were minimal, though the uses were only documented for a large area surrounding the study site (Gosselink et al., 1979).

Two scenes of digital data derived from the Landsat multispectral scanner (MSS) sensor will be employed to document change in cover-type from October 1972 to October 1981. The specific cover-types will be land, water, and transitional: transitional being areas of 50 percent land and 50 percent water, ± 10 percent. At the time of the acquisitions of the satellite data, water levels in the marsh were not identical. A water model was used to determine if the water level varied enough to affect the amount of open water calculated. Furthermore, a linear relationship was assumed for rates of change in cover-type classes between 1972 and 1981. This assumption was made because no major storm events that might have significantly contributed to changes in the marsh, have taken place since 1957 (Hurricane Audrey). Finally, salinity zones were plotted on the Landsat data from an existing map (Gosselink et al., 1979). The amount and nature of change was calculated in each salinity zone. The spatial relationship of change versus distance to water, and shoreline length and density was determined for each vegetative zone. An analysis of the types of change in relation to the climatic, chemical, and hydrologic variables was conducted in order to aid in the understanding and explanation of the change in different regions.

Objectives and Considerations

The purpose of this study is to detect deterioration in a coastal Louisiana marsh, spatially and temporally (over a nine year period). An attempt is made to determine if salinity, precipitation, water level, and spatial relationships of water to land could explain changes in salinity-based vegetative zones. Subsidence, accreation, erosion, wind, and tidal flux are only a few of the other simultaneously occuring natural events taking place. Human activity also has an impact on the marsh. It is important to understand how each variable operated to change the basin, and to determine why and how changes occurred in specific locations. Unfortunately, data are presently unavailable for those analyses.

Given the importance of Louisiana's coastal wetlands to the state and nation as a whole, this research attempts to deduce why a portion of this ecosystem is deteriorating so rapidly, and provide a basis for future management of this valuable resource.

Chapter Organization

Chapter II includes a description of the study area location, historical changes in plant species, and the affect of salinity on wetland plants. A historical summary of the activities within the basin emphasizes natural and human induced factors of change. A brief discussion follows of studies in Louisiana's wetlands and studies in other states that relate to change.

The methods used for analysis of Landsat and ancillary data are discussed in Chapter III. Each source and type of data are identified and areal coverage is indicated. The methodology for processing the ancillary and digital image data is discussed in detail and analytical procedures are presented.

Chapter IV includes the results and discussion of the processing of ancillary data, Landsat digital data, and the comparison of the two data sets. The differences and similarities of results obtained in this study are compared with related investigations.

Chapter V reports the findings and limitations of this investigation and provides recommendations for future research.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

Location

The study area lies in the Chenier Plain of coastal southwest Louisiana. This 28,500 ha marsh is located on the east side of Calcasieu Lake and is known locally as East Cove (Figure 2). Grand Bayou and its North, South, and East Prongs divide the basin into sectors and facilitate water movement. The hydrologic unit known as the East Cove Marsh is bounded on its north side by an upland prairie terrace extending east to the Gulf Intracoastal Waterway (GIWW). The levees along this transportation route are well above water level, and thus effectively restrict the mixing of marsh and GIWW waters. Along the east boundary, the Creole Canal levee acts in the same manner. Some fresh marsh water is allowed into the canal, although flap gates reportedly do not allow any canal water back into the marsh. The southern boundary of this basin is topographically controlled by the chenier ridges and Calcasieu Lake lies along the west side. The interior region of this hydrologic unit is of nearly uniform relief.

General depths in Grand Bayou and its prongs ranged from .45 to 1.37 meters in 1970 (Barrett). The location of sampling stations for this study coincided with those for a NASA/National Marine and Fisheries Service, Joint Research Project, and Sabine National Wild-

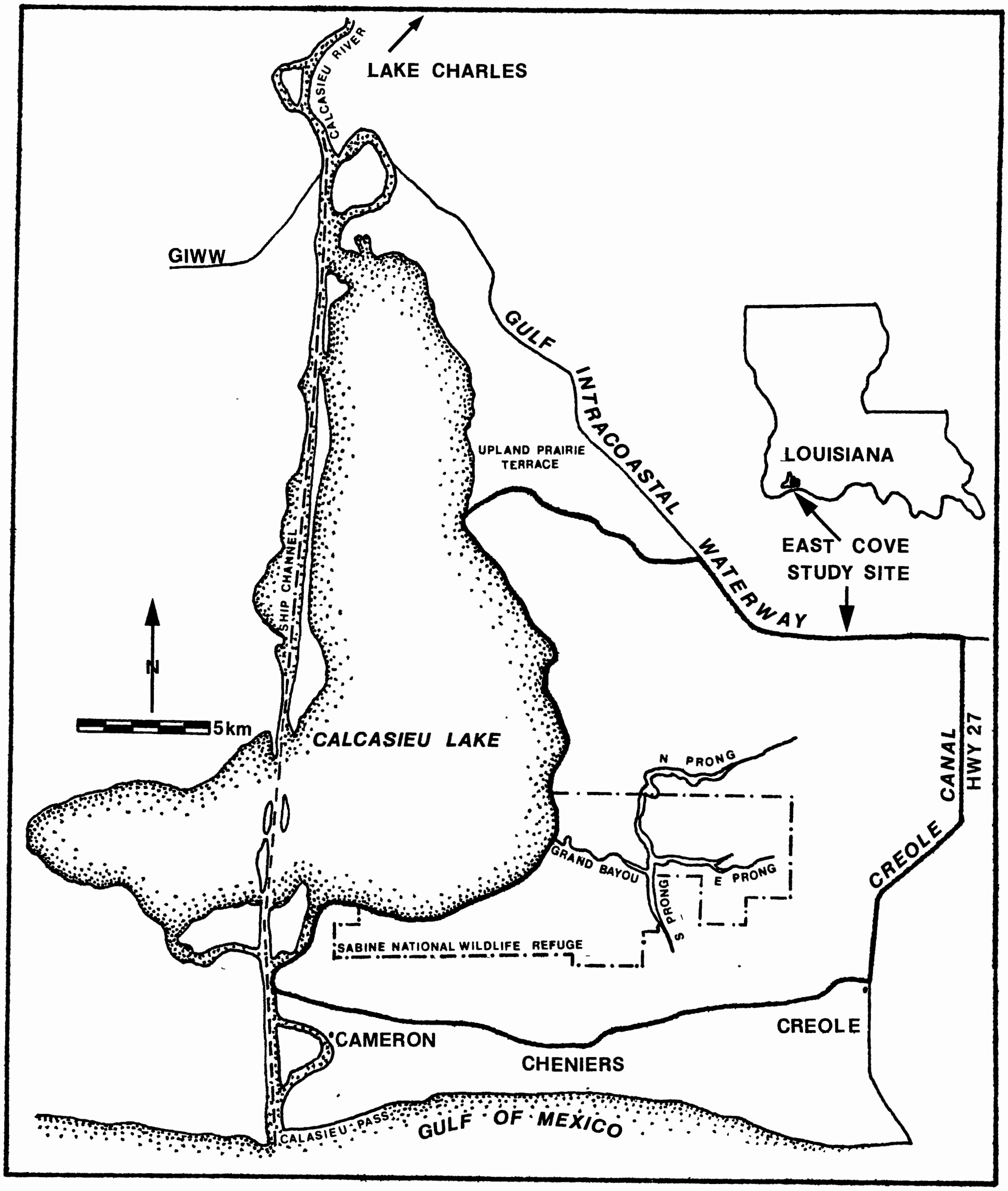


Figure 2. East Cove Marsh Study Site

life sampling stations. Measurements taken during this study more precisely detected depths from less than 1 to 4.5 meters (Figure 3). Because the water is shallow, little energy is needed to effectively mix it from top to bottom, therefore, stratification caused by salinity and temperature gradients is minimal for the majority of the marsh.

Calcasieu River feeds into the north side of Calcasieu Lake. A ship channel extends along the entire west side of the lake and Calcasieu Pass connects the lake to the Gulf of Mexico. Aside from precipitation falling directly within the basin, Calcasieu River is the only other source of fresh water to the marsh. The main artery to deliver fresh water to the interior of the marsh is Grand Bayou.

A large portion of the East Cove marsh lies within the Sabine National Wildlife Refuge. The remainder is privately owned by cattle ranchers and the Miami Corporation, a mineral exploration company. The majority of data collected for this study were taken within refuge boundaries.

Vegetative Condition of the Study Area

Previous Condition

The Mississippi River has historically occupied several positions, as a naturally meandering river diverts to paths of least resistance. The Chenier Plain, the oldest coastal ecosystem in Louisiana, was created by 5,000 years of sediment deposition from the Mississippi. As the river repeatedly shifted to the east, approximately 3,000 years B.P., recessional beachridges (cheniers) were formed. As a result of the lack of sediments to maintain delta building in western Louisiana,

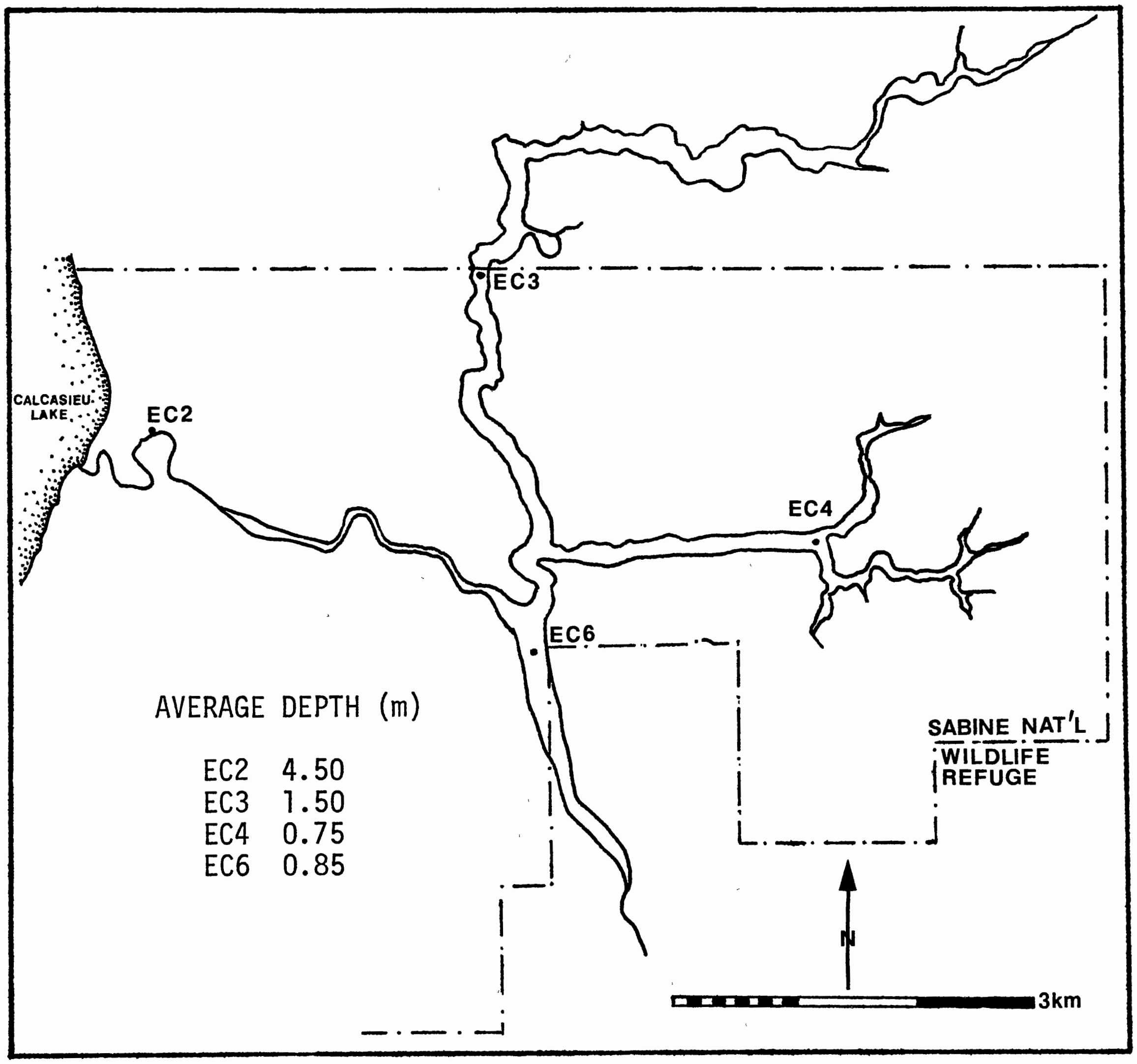


Figure 3. East Cove Marsh Sample Sites for Water Depth and Salinity

a ridge developed at the mouth of the coastal streams. During the latest glacial period, the coastal streams cut valleys into Pleistocene-age deposits. During the Holocene, sea level rose to its current level, and sediments, deposited on the eroded surface, formed the substrate of the present-day marsh (Russell and Howe, 1935 and Gosselink et al., 1979). The sill at the mouth of the Calcasieu Pass (part of the Chenier complex) was an effective barrier to the denser saline Gulf waters, until it was dredged in 1967.

Table I presents the vegetative salinity zones determined by coastal marsh investigators. Penfound and Hathaway (1938) found the Louisiana coastal marshes generally fresher than their present condition. In 1949, O'Neil published a study of muskrat habitats. In his work, he classified the East Cove Marsh vegetation (Figure 4) as predominantly intermediate to brackish, and fresh. He based his conclusions on vegetative types and samples which were collected by boat. He indicated that a change in hydrologic conditions would usually result in a change in plant species. Fogarty (1965) noted that the East Cove Marsh was once dominated by sawgrass (*Cladium jamaicensis*), a fresh to intermediate species. At the time of his study, however, the marsh was 30 per cent salt meadow cordgrass (*Spartina patens*), a predominantly brackish and salt marsh species. He also indicated that a wide, fresh water vegetation zone, including the greatest number of plant species, existed parallel to the Creole Canal. His vegetative samples were taken every 100 yards (91.44 m) along four transects spanning east to west across the East Cove Marsh. In 1968 Chabreck identified this same area as a brackish marsh. His field observations, taken from a helicopter, were made along north-

TABLE I

VEGETATIVE SALINITY ZONES LISTED BY INVESTIGATOR (AFTER WICKER, 1981)

	Salinity (in ppt) of Marsh Types			
Investigator	Fresh	Intermediate	Brackish	Saline
Penfound and Hathaway, 1938	<5	NA	5-20	>20
O'Neil, 1949	<5	NA	0.7-18.0	>18
Chabreck, 1968	1.09-6.66	2.71-2.77	4.67-18.39	10.63-29.57
Gosselink et al., 1979	0.5-2	1-4	1-9	4.5-21

NA - Not Available

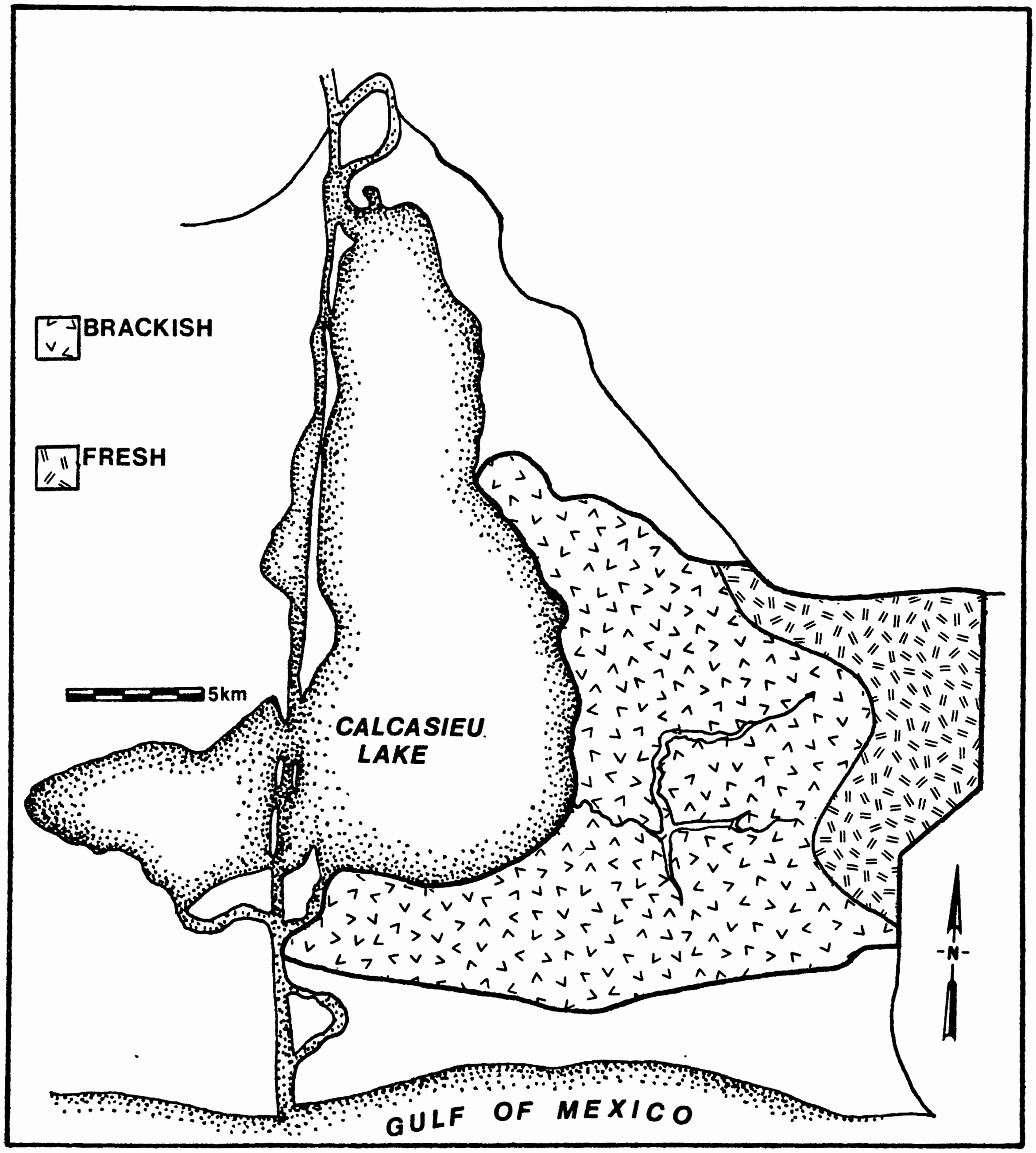


Figure 4. Vegetative-Type Map, After O'Neil, 1949

south , parallel transect lines. Plant species, recorded at spot locations, were used to determine vegetation salinity boundaries (Figure 5).

Current Condition

Using Chabreck's vegetative characterization zones and 1974-1975 U.S.G.S. orthophoto quad maps, a 1968 map of coastal Louisiana was updated for the Chenier Plain region by Gosselink et al., 1979, and again by Chabreck in 1978 for a Louisiana Wildlife and Fisheries publication (Figure 6). These maps indicate that the marsh has become progressively brackish. Gosselink et al., (1979), identified the western portion of the basin, nearest the Pass, as salt marsh. A narrow zone along the eastern edge was identified as fresh and the area between the east and west extremes ranged from intermediate to brackish (Figure 7). This map illustrates that less of the marsh is vegetated compared to older maps. Open water bodies appear in areas that were once totally vegetated. This supports the claim of natives in the vicinity, that they once walked through head high Roseau Cane (Pharagmites communis), an intermediate to fresh water species, so thick that visibility was only a few meters (Richard, 1982). Now visibility extends for miles over open water and salt meadow cordgrass.

The Effect of Salinity on Wetland Plants

Many experiments and observations have been completed dealing with the effect of salinity concentration on North American wetland

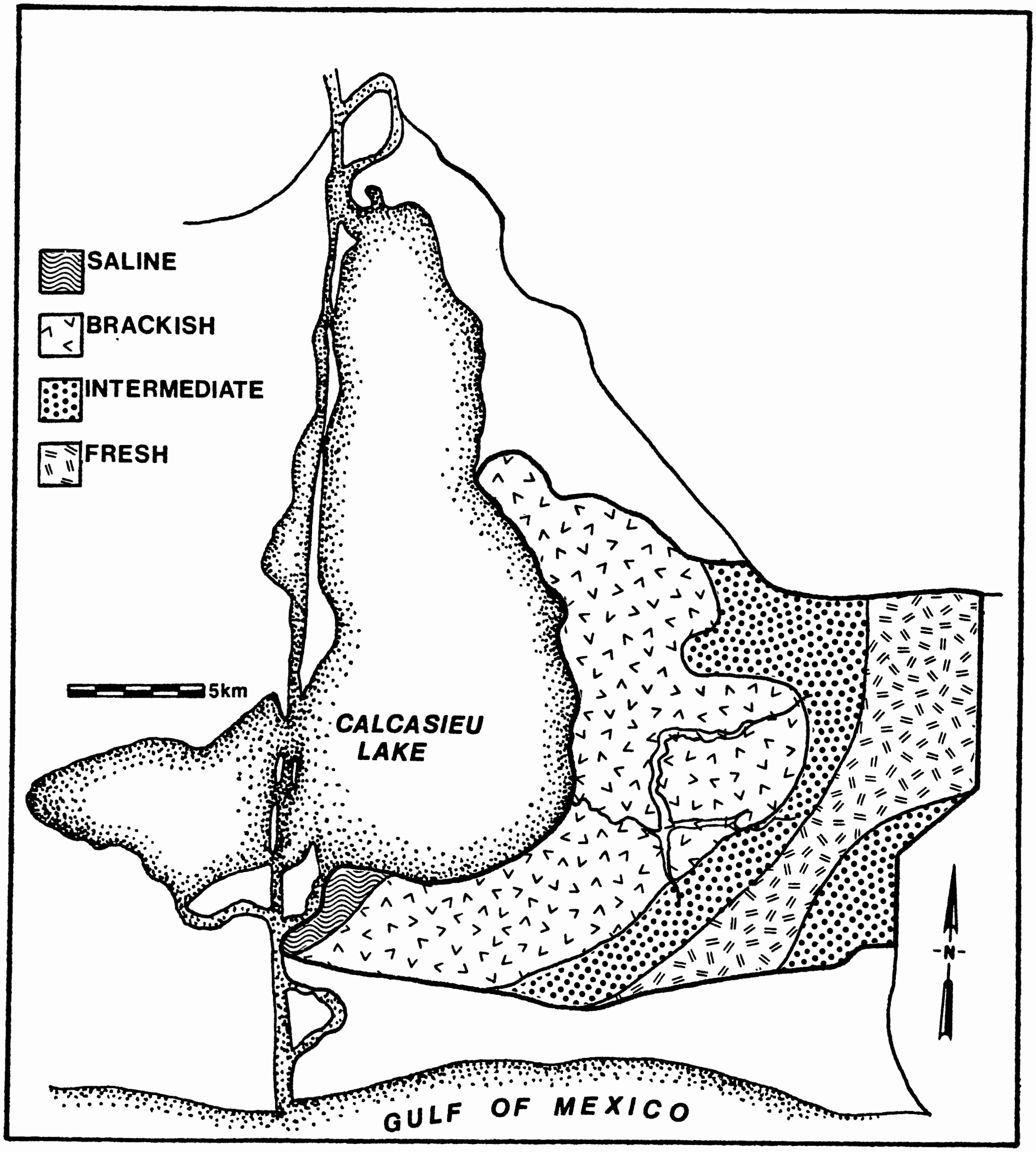


Figure 5. Vegetative-Type Map, After Chabreck, 1968

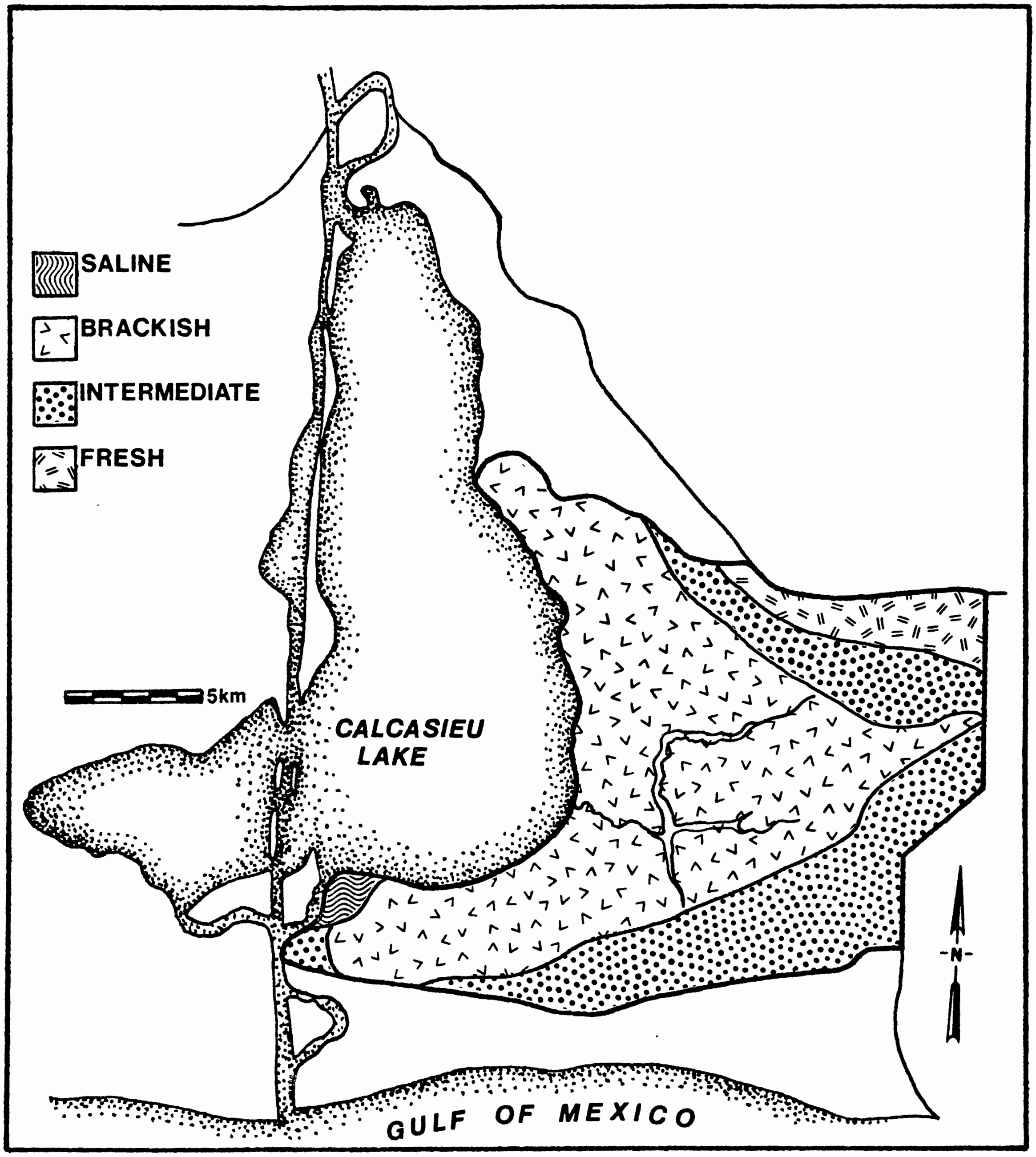


Figure 6. Vegetative-Type Map, After Chabreck, 1978, Determined by Helicopter Observations

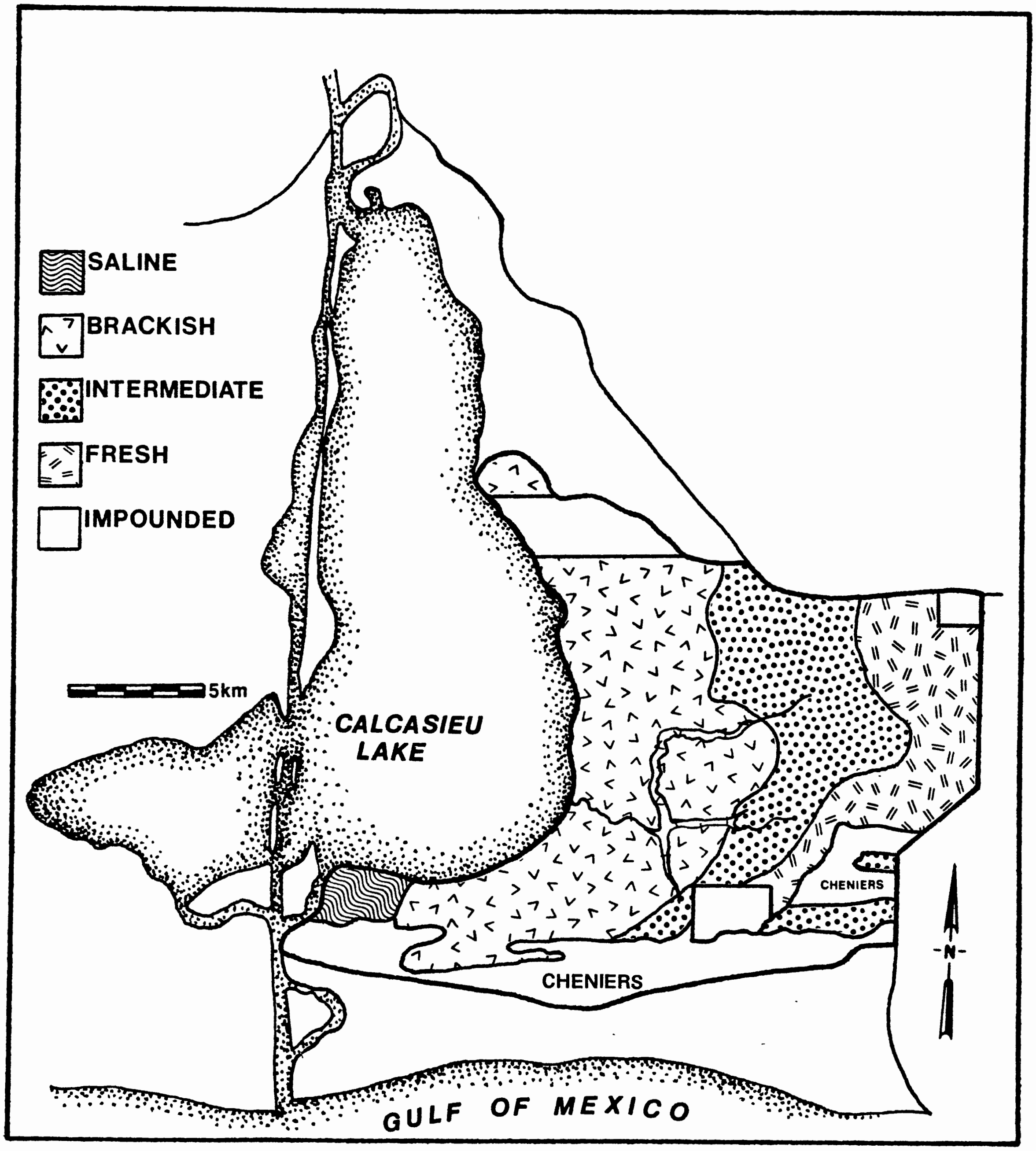


Figure 7. Vegetative-Type Map, After Gosselink et al., 1979, Determined from Helicopter Observations and Vegetation Samples

vegetation. In 1911, Harshberger determined that salt-tolerant species could withstand wide ranges in salinity levels better than fresh-water marsh species could withstand salt water. He noted that in some freshwater species, the heights of the plants decreased as salinity increased.

Generally, the type of vegetation growing in the marsh depends on the length of time and the amount of salt water introduced into an area. Plants adjust slowly to changes in salinity conditions (Brupbacher, 1973, McMillan, 1974 and Mudie, 1974) and grow more slowly in more saline waters. In areas where salt water has been intruding gradually, species composition has also changed gradually regardless of tolerance levels (Palmisano, 1970). It is not common, therefore, to find plants growing outside of their salinity niches. Mudie also suggested that some species may be more sensitive to salt at certain growth stages. Palmisano (1970) tested a number of different marsh species with varying degrees of salt tolerance. He concluded that the germination of all the species tested was greatly reduced in waters of increasing salinities. He also noted that Spartina patens, the most dominant species in the East Cove marsh, grew under the broadest variation of salt and water level conditions of any species tested.

O'Neil (1949) noted that in some low marsh areas in East Cove where more saline tidal waters became trapped, vegetation would rot and produce large scalded areas denuded of vegetation. If the rot was severe enough to destroy the root systems, these areas became open ponds and lakes. The bayous in East Cove facilitate the movement of saline tidal waters on a daily basis. The interior of the marsh, however, is not actively flooded, except during maximum high tides. Fresh water flushing may only occur during rains, abruptly decreasing the shallow water salinities. Good (1965, p. 10) has pointed out that this characterizes a habitat subject to "rapid change" and the "greatest extremes". He reported high estimates of standing crop in the well mixed areas and low estimates in the areas with the widely ranging salinities. These observations are further supported by an experiment conducted by Weiss et al., (1979) where he determined that salinity was the most limiting factor for vegetation located nearest to open water. Vegetated areas located further inland were effected by factors such as elevation and standing water, more than salinity.

Basin History

Louisiana's coastline, particularly the East Cove Marsh, has evolved over thousands of years. Natural processes including: geologic activity, erosion, climatic processes, tidal fluctuation and other hydrologic parameters, as well as, human activity are a few of the phenomena that have physically, chemically, and biologically altered this environment. This study requires knowledge of the role played by each factor. Because data are lacking for many of the factors, their role can only be hypothesized until further studies are conducted. The variables for this study, which have sufficient data for analysis, are precipitation, water level, and salinity.

Naturally Induced Factors of Change

Natural processes have molded the East Cove Marsh into its present condition. The extent of the impact of the geological, climatological, hydrological, and biological phenomena depends upon soil composition, basin shape, weather patterns, seasonal trends and their departure from normal. The impact that each process has had on changing the East Cove Marsh is independently complex and overwhelming in combination.

Geologic and Geomorphic Processes. Sea level has been rising, slowly and irregularly, along the Gulf coast (Bruun, 1962). On a global basis, the rise averages 1.2 mm annually, and on Florida's gulf-side, west coast the rise is 1.4 mm annually (Baumann et al., 1983). Subsidence has been attributed to down warping (isostatic adjustment) from sedimentary loading, compaction of sediments, tectonic activities within the sedimentary layer, and eustatic sea level changes (Coleman et al., 1969 and Craig et al., 1979).

Coastal submergence has been measured near the city of Cameron (Figure 2), on the southwest side of the site, at 1.20 cm per year, while accretion is only 0.8 cm per year (Baumann et al., 1983, p. 148). Baumann refers to submergence as "all factors which appear to elevate the sea in relation to the land as depicted by tide gauges". At one time, sedimentary deposition kept pace with subsidence (Gould, 1970 and Morgan, 1970), but canals have attributed to the decrease in the sediments available for Louisiana's land building.

O'Neil (1949) claims that subsidence is not as important in areas with a firmer chenier foundation. The ecology of these marshes, he claims, is not affected by subsidence compared to the newer marshes in eastern Louisiana. Recent studies have emphasized subsidence as the major factor controlling the deterioration of coastal wetlands.

Erosion of the soft marsh substrate appears to be controlled by two hydrologic forces: wind driven currents and tidal fluctuation. The extent of erosion may vary depending upon the soil composition and properties. Brupbacher (1973) has determined the soil composition and texture for the Louisiana coast. Seven sampling sites in the East Cove Marsh indicated a range of mineral clay soils through organic mucks and peats. The same soil types are shown on a Soil Conservation Service map (Figure 8). Peat has recognizable plant parts present, weak adhesion and high water holding capacity. Muck is highly decomposed peat that has no recognizable plant parts, a lower water absorption capacity and has more adhesive components than peat. Depending upon the original composition of the plants, muck may even form a coherent, sticky, plastic mass (Dachnowski-Stokes, 1940). Brupbacher's research showed that fresh-water marsh areas had the highest amount of organic matter and higher decomposition rates than brackish or saline marshes. Lytle and Dirskell's (1954) analysis of the Louisiana coastal marshes indicated that marsh substrates were subject to shrinkage and subsidence when drained. This shrinkage occurs during deficit rainfall periods in the East Cove Marsh. Peats were observed to have the greatest shrinkage and subsidence, then mucks, and the same processes in clays were not significant. If allowed to drain and dehydrate, dessication cracks form in muck through the hard, usually more saline crust, hindering plant growth.

Atmospheric Processes. Weather and climate of the Chenier Plain area can be inferred from data from the three closest stations. While wind and precipitation are of specific interest in this study, only the precipitation data were available at all three stations. The

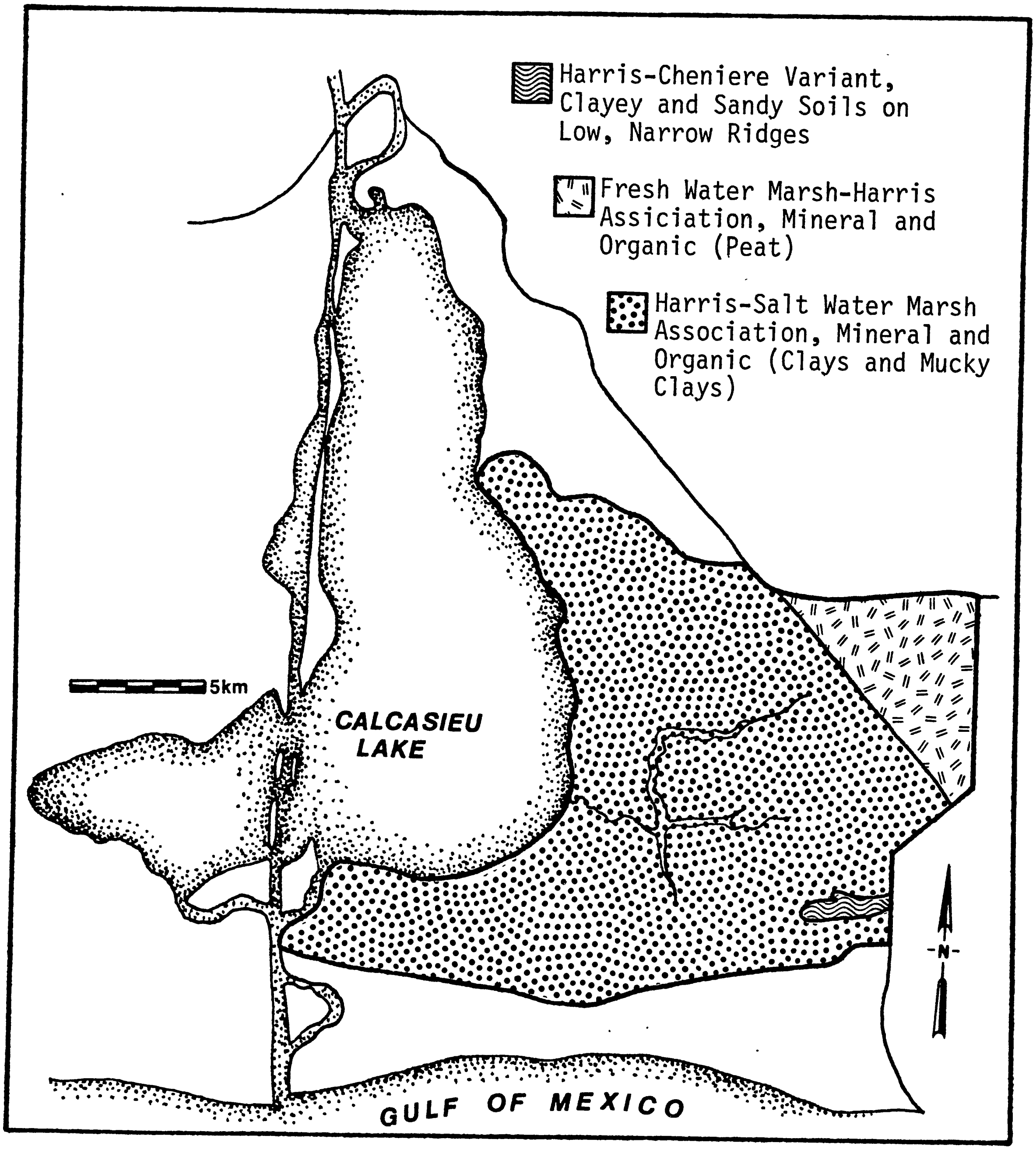


Figure 8. Soil Map, U. S. Department of Agriculture, Soil Conservation Service, 1971

closest wind observations were from the Lake Charles station, 20 miles to the north of the study site. Wind data were not considered because of the lack of sample stations in the area.

The Chenier Plain area receives in excess of 130 cm of average rainfall annually. The amount of precipitation affects the flushing rate within the marsh. Some areas are only inundated during periods of the highest tides and water levels. Precipitation reduces salinity concentrations, and helps transport dead vegetative material, from areas which are out of normal tidal range to open water.

Precipitation also affects other parameters of the hydroclimate in East Cove. During extended periods of heavy rains, the hydraulic pressure builds up in the interior of the marsh causing continued outgoing flows even after the rain subsides. The reverse occurs when high temperatures combine with high evapotranspiration rates. In an unusually dry year, rainfall deficit causes a die-back of aquatic vegetation. Annual extremes during the study period include a low of 36 cm below the mean in 1976, and highs 56 cm above the mean in 1973 and 1979.

Winds in the Chenier Plain region have a southerly component during most of the year. North winds occur, on the average, 16 percent of the time from October through March and are strongest during the winter, coinciding with the high frequency of north and northeasterly winds (Gosselink et al., 1979, p. 15). Information from the Lake Charles station agrees with this trend during the 1982-1983 sampling period. If summer winds are sustained for a long period of time, the fetch is significantly increased and more water is pushed into the wetlands. In summer months when winds originate in the south, a rainfall deficit can occur. Less fresh water is available to the hydrologic system and more Gulf tidal waters are brought in which multiplies the effects of the salinity concentration. During winter months, observers have noted that winds may push the water off of the interior marsh entirely, leaving mudflats and normally shallow water areas high and dry (O'Neil, 1949 and Knudsen, 1982). The salts in the water are deposited on the surface and crusty, cracked layers form preventing most vegetative forms from becoming easily established. Statistical documentation of the effect that wind may have on change in the East Cove Marsh is not presented in this study. Muller and Wax (1977) have determined that wind, as well as air and water temperatures, and other climatic parameters may be affected by variability in water level, which is subject to analysis in this paper.

Hurricanes bring extremes in both wind and rain. Because they are so extreme, they may inflict more damage than more frequent storms of lower magnitude. The extent of the damage for any one hurricane cannot be predicted. Hurricane Audrey, in 1957, extensively damaged the Chenier Plain. The amount of damage has not been observed since, but the damage was poorly documented.

The relationship between precipitation and water salinity levels has not been statistically proven, though it would seem that they are inversely related. Monthly water salinity concentrations will be analyzed to determine the relationship to the amount of precipitation received over the same time period.

Hydrological Processes. Water circulation in the East Cove Marsh is a function of tidal fluctuation, wind and at times a hydraulic pressure head. Tides in the Gulf of Mexico, as mentioned earlier, are minimal compared to the east or west coast of the United States (Morgan, 1970). At Calcasieu Pass, the mean tidal range is 75 cm and attenuates upstream (Gosselink et al., 1979). Field measurements taken during 1982-1983 indicated the tidal ranges at Grand Bayou averaging 15 cm, significantly decreased from those observed at Calcasieu Pass. Current velocity was rarely greater than 0.5 m/s.

The tides do not follow a predictable cycle. Generally, one ebb and flood tide occur daily (diurnal), though two each (semidiurnal), or a mix of both can occur depending on weather conditions. Winds influence tidal currents by creating a drag on the water surface, and also aid vertical and horizontal mixing of the waters. Water movement in the East Cove Marsh does not appear to be topographically controlled although it has not been extensively surveyed. One bench mark, at an elevation of two feet, is located in the center of the marsh, and the Creole Canal levee has been maintained at four feet. Considering the height of the levee, the horizontal gradient for the marsh is so low that in-coming and out-going tides should dominate the direction of current flow.

During field sampling in East Cove, it was noted that after one and one-half inches of rain fell in 24 hours, the water flow was continually outgoing for a number of days, only slowing during what would normally be flood tides. Presumably, this was a result of the freshwater pressure head built up within the interior of the study area, abruptly lowering water salinities and removing plant debris from higher marsh areas not affected by normal tidal fluctuation. During major Gulf storms, the reverse occurs, a surge of saline waters is pushed onto the marsh by tides and winds. Some of this more saline water may be trapped inside the elevated banks of the bayous, thus aiding formation of or feeding already existing tidal channel lakes (Fogarty, 1965). Depending upon the salt tolerance of the species present in these areas and the duration of the increased water levels, the lakes could continue to grow in size.

Biological Processes and Activities. The competition of plant species and wildlife activity within the study area was apparently influential in the formation of the present day marsh. As East Cove became more and more saline, some fresher plant species could not tolerate the change and eventually were replaced by more tolerant species, as shown by published vegetative maps. Spatina patens is one such species that, once established, will tolerate a wide range in salinities from fresh to saline. It is a stoloniferous plant which forms dense communities, spreading by rhizomes to form huge mats (Godfrey and Wooten, 1979). The leaves are tough and leathery and do not break easily when inundated by tides or storm waves. It seems well adapted to the changing environment in East Cove.

In times past, the marsh was predominantly three-cornered grass (Scirpus olneyi), a rush identified by O'Neil (1949) as one of the best muskrat habitats. If an area became overpopulated, the vegetation might virtually be stripped. If this 'eat out' condition occurred, it could lead to permanent root damage and prevent replacement by new vegetation. Geese can do similar vegetative damage. Most researchers agree that 'eat outs' have damaged some small areas in East Cove, through documentation of locations or extent of marsh lost appears to be on the eastern side of the Creole Canal, which is not within the study area.

Human Activity Within the Basin

Modifications of the East Cove Marsh by human activity have varied in purpose, impact, and location. Although many of the activities have not taken place within the marsh boundaries, they were influential in determining its present condition. Louisiana's Gulf coast supports many forms of activity including recreational and commercial hunting, fishing and trapping, refuge management, waterborne commerce, mineral and water extraction, grazing and agricultural practices. Some activities, such as recreational uses and agricultural and grazing activities, have had little if any part in altering the ecosystem in East Cove, while others, including dredging to facilitate waterborne commerce, have been a major agent of change.

Waterborne Commerce and Related Activities. Since 1871, the Calcasieu Pass, a natural feature between the Gulf of Mexico and Calcasieu Lake, has been dredged continuously to allow ship traffic easy access to the lake and the city of Lake Charles. In 1937 a ship channel was dredged along the western edge of the lake from the pass to Lake Charles. The naturally sinous Calcasieu Pass at the city of Cameron was bypassed, and dredging extended into the Gulf across a shallow sill that had acted as a constraint to the salt water wedge (Gosselink et al., 1979). Fogarty (1965) believed this to be a major factor in the salt water intrusion in East Cove. The dredge spoil was banked on either side of the channel, retaining the sediment from Calcasieu River. The dredging was completed in 1940 and formed a channel approximately 10 m deep by 75 m wide. In later years, the channel proved to be inadequate for increased traffic of post World War II tankers (U. S. Army Corps of Engineers, 1950). Another extensive dredge was conducted from 1946 to 1953 as a result of the passage of the River and Harbor Act of 1945. The River and Harbor Act of 1960 specified that the dimensions from the pass to Lake Charles should be modified to approximately 12 m by 120 m. This latest major dredge, initiated in 1962, was completed in the fall of 1968, four years prior to initiation of Landsat coverage over the study area. Maintenance dredging continues on an annual basis. The ship channel is necessary for safe passage of waterborne commerce destined for Lake Charles or the GIWW. Waterborne commerce in the Calcasieu basin is greater than any other basin in the Chenier Plain region (Gosselink et al., 1979).

The ship channel is not the only dredged waterway affecting the East Cove Marsh. Creole Canal, which runs along the east side of the marsh along Highway 27, empties into the Gulf at the Mermentau River (Figure 2). The levee containing Creole Canal inhibits this waterway as a sedimentary source, though it is not always effective when eroded down to water level. Gosselink et al. (1979, p. 120) suggest this canal acted as a "salt water pump". Denser salt water pushes the fresher water across the marsh and into the canal which then flows into the Gulf and is replaced by salt water entering at Calcasieu Pass.

Many smaller canals, used for access to oil and gas sites, have also affected the hydrology of the area (Gagliano, 1973). Canals have been claimed to be responsible, directly and indirectly, for 69 percent of the total wetland loss in the Calcasieu Lake basin (Craig et al., 1980 and Gosselink et al., 1979). Deepening the channels may affect the constituents in the water, as did the ship channel (U.S.

Army Corps of Eng., 1950). By channelizing the water, it flows faster in directed paths instead of its normal laminar sheet flow. The nutrient input from and to the marshes is therby greatly reduced as is the filtering effect of wetland vegetation (LaRoe, 1977).

Water and Mineral Extraction. The Hackberry Salt Dome, which exists on the northwest side of Calcasieu Lake outside of the study area, has been mined to create storage for fossil fuels. The brine from the dome is pumped directly into nearby Black Lake (Gosselink and Baumann, 1980), and piped to a brine diffuser located 9.6 km offshore into the Gulf. When flood tide occurs, a higher salt concentration is available for intrusion.

Numerous petroleum industries have wells located in the lake and the Grand Bayou basin. Disregarding the effect of access canals, the wells are still considered environmentally damaging (White, 1982). As a part of the pumping process, brine is discharged at the well sites, and becomes more concentrated as the wells age. Brine varies from ocean salt water in chemical makeup and ratio of components. Sea water normally has 36 ppt of salts, while an average of 110 ppt is released from oil wells. Because freshwater marsh vegetation has the lowest tolerance range for salinity, these areas incur the most damage, because few plant species can endure salts combined in highly toxic ratios (McMillan, 1974). At least two well sites, located in the fresh area of the East Cove Marsh, have been operational since 1977, though the effect upon the immediate area has not been documented.

Aside from surface disturbance, mining petroleum products and salts and withdrawing groundwater affects the subsurface. As minerals and water are extracted, voids are created. The sedimentary particulates then sink and subside to fill these voids. On the surface, these areas may lower and collect water during high tides and rains. Some drawdown occurred from increased pumping of groundwater, but considerable recharge was contributed by rainfall. Locations or rates of subsidence because of removal of subsurface mineral or ground-water deposits are difficult to document.

Grazing and Agricultural Practices. Grazing has occurred for many years (O'Neil, 1949) though most of it takes place on the higher land of the cheniers. If left uncontrolled, the vegetation that is stripped within the wetland, may not be reestablished, contributing to direct loss of vegetation. Conversely, as more of the marsh becomes open water, less good grazing land is available. The portion of the East Cove Marsh used for grazing is minimal, so its impact is considered unimportant.

Large scale farming has all but ceased in the study area. Abandoned rice fields remain in the northern portion of the marsh where leveed areas were once flooded with the fresh marsh waters. Rice growers attributed dredging of the ship channel to the loss in suitable areas to farm (U.S. Army Corps of Engineers, 1950). Present salinity levels prohibit the growth of rice or other agricultural plants.

Hunting, Fishing and Fur Harvesting Activities. These activities do not directly contribute to wetland loss in most cases. On the contrary, the condition of the marsh greatly influences their success. The majority of the marsh is privately owned, so hunting, fishing or fur harvesting is done so with the permission of the owner, or with a collectors permit in the refuge. The Sabine Wildlife Refuge was established in 1937 as one of the primary wintering sites for waterfowl. Waterfowl hunters and managers prefer a more open, fresh water environment (Shaw, 1956) as it attracts migrating ducks and geese.

The trappers prefer quite a different environment, because muskrat and nutria prefer a more highly vegetated, slightly brackish marsh for their homes and food (O'Neil, 1949). Trapping activity has slowed considerably in the study area, a reflection of the less desireable dominant vegetation now present, and extent of open water. The trapping route canals may have contributed to marsh degradation.

Commercial and recreational harvesting of shrimp, crabs and fish have become big businesses and sport in the lake basin. Major fisheries are located around the lake and shrimping has been booming for the past few years (White, 1982). The Calcasieu Lake basin has the highest shrimp harvest of any basin on the Chenier Plain (Gosselink et al., 1979). Research has indicated that as salinities increase, so do shrimp harvests (Faller, 1979 and Barrett, 1971). For this reason fishermen and commercial businesses in the area have favored the increased lake salinity levels. Though most fishing is prohibited in the Wildlife Refuge, this area serves as a nursery for juvenile finfish and shell fish which move to the lake or Gulf when grown. If the trend toward open water continues, the East Cove Marsh will export more and more nutrients for fish to feed upon.

<u>Burning Activities</u>. Controlled burns take place regularly in the East Cove Marsh with the objectives being: promoting new plant growth and its availability; improvement of habitat; and facilitating trapping and protecting against uncontrolled fires (Lynch, 1941). Daiber

(1974) identified two types of controlled burns: cover burns, which remove accumulated dead vegetation; and root burns, which are conducted during dry periods for removal of dense climax vegetation. The latter burn type often removes accumulated peat, and leads to a condition which may hinder immediate revegetation. This practice may initiate a sequence of irreversible events ultimately creating open water areas. The burns conducted by the refuge managers have been documented and appear to have been controlled, and subsequently revegetated. Land owners of the remainder of the study area have not published burn locations, and it is not known what type of burns occurred.

Recreational Activities and Research. These two activities may seem unrelated, though people in each group are the few who are actually in the marsh observing, collecting data, or simply enjoying the aesthetics. These activities may have little physical effect upon altering the environmental conditions in the marsh, but are significant nonetheless. Birdwatchers or other outdoor enthusiasts consider the marsh an invaluable habitat to maintain, and have expressed their opinions concerning coastal legislative matters. Researchers have found the complexities of marsh life to be neverending and dynamic. Continuous research has been conducted over the past few years by numerous institutions and individuals attempting to document the changes that affect life in the marsh.

Previous Studies Relating to Change

Change detection using remote sensing techniqes has been conducted for a number of purposes for many years. Louisiana coastal studies have employed aerial photography in combination with U.S.G.S. quadrangle maps to detect various aspects of change in the wetlands. Gagliano et al. (1970) determined the net gain or loss of land in a region of the Mississippi River delta at 4277 ha (16.5 mi^2) per year. At the same time Chabreck (1970) compared his 1968 vegetative type map, produced from data collected via hellicopter, to O'Neil's map (1949), compiled from 1941 to 1945. Chabreck determined that the brackish marshes of the Chenier Plain had decreased by 47 percent. The return to fresh marsh was attributed to management practices in the Sabine Wildlife Refuge. Since O'Neil's study, wetland areas, on the western side of Calcasieu Lake, had been impounded and flooded with fresher water.

The rate of change in the coastal wetlands was becoming increasingly important as it appeared to be deteriorating even to the unenlightened public. Gagliano (1973) compared his previous study with studies done by Barrett (1970) and the aforementioned Chabreck research. Although the rates of change differed, Gagliano concluded that they were exponentially related. The larger the area studied, the greater was the rate of change.

Adams et al. (1976) analyzed change in Louisiana's Barataria basin from a period of 1960 to 1974. His results showed that land loss rates were accelerating, and determined loss of each type of wetland. Later, Craig et al. (1979) combined studies by Adams and Chabreck to determine land loss per vegetative type for the entire Louisiana coastal zone.

Other studies have been conducted in Louisiana's coastal zone with an emphasis on providing a data base for monitoring, inventory and future change. Aerial photography was utilized for a resource inventory of vegetation, soil, water quality, canals, aquatics, and land use (Lewis, Kim and Wilson, 1977). They produced a sequence of accretion maps by comparing available maps and early photography, depicting change from 1917 to 1972.

The use of Landsat digital data as a tool to detect change in wetlands is a relatively new approach. Landsat data has been successfully utilized, for other studies, to determine the best season for remote sensing of wetlands (Butera, 1978), location of habitat types (Cibula, 1976), and their contribution to detrital export (Butera and Seyfarth, 1981). Recently, a Louisiana coastal study utilized Landsat MSS data to detect and map suspended solids and salinity (Hughes, 1982). Although the surface truth data was collected coincidentally with the remotely sensed data, the use of Landsat data for directly mapping salinity was not successful. Few researchers have attempted to employ Landsat data for detecting wetland dynamics. Link and Long (1977) investigated the feasibility of utilizing various sensors for use in rapid change detection of cover types and wetland plant species. Rose and Rosendahl (1980) were successful in detecting the changing land/water interface in a Florida wetland for wet and dry seasons using five Landsat data sets.

Detecting changes in the landscape is rapidly becoming an important aspect in creating a data base for long-term monitoring and managing resources for the future. As shown by the Computer Sciences Corporation (1978) and Nualchawee et al. (1981), Landsat MSS data is a feasible tool to help accomplish this task. The testing of various change detection techniqes for accuracy has been emphasized by

Weismiller et al. (1977), Joyce et al. (1980), Colwell and Weber (1981), Howarth and Wickware (1981) and Burns and Joyce (1982). New technique development is being continued by researchers (Eghbali, 1979, Byrne and Crapper, 1980 and Burns, 1983) who are improving existing change detection techniques or creating techniques applicable to the dynamics of specific surface features.

Landsat digital data is preferred because it covers a large spatial area. Scene to scene registration, collection of ground truth for previously acquired Landsat data, clouds, and poor resolution are a few of the problems to be confronted when dealing with this type of data for a change detection study.

This change detection study was conducted to not only identify where change has occurred in the East Cove Marsh, but also to determine what might have contributed to cause the change. The following chapters include a detailed description of the methods of analysis, results, and conclusions of this investigation.

CHAPTER III

METHODS OF ANALYSYS

Sources, Types and Locations of Data

The analysis of Landsat MSS digital data, in conjunction with noncoincidental aerial potography, for a change detection included the use of many other sources of data. Ground truth cover-type information was not available for previous years, therefore, aerial photography was relied upon to provide the needed qualitative spatial information about the study area. To locate changes in the East Cove Marsh, and identify possible factors leading to change ancillary field data (ground truth and archival) was also necessary.

Aerial Photography

Three sets of color infrared (CIR) aerial photography were used to aid in computer classification of Landsat digital data. All of the photography used was collected by NASA aircraft (Table II). The approximate location of the photography was 30° N latitude and 93° 15' W longitude. The resolution ranged between 3 and 10 meters.

Landsat MSS Data

Two sets of Landsat MSS digital image data were processed for the nine-year change detection. The first Landsat satellite (then termed ERTS-1) was launched in July 1972. This is the earliest available

TABLE II

AERIAL PHOTOGRAPHY SPECIFICATIONS

DATE	MISSION #	SCALE	FRAME #(s)
10/4/74	289	1:123,000	16 and 56 (roll 7)
10/9/78	78-144	1:65,775	128, 130, 241 and 243
9/23/82	285	1:82,000	243, 245, 247 and 248

data after the ship channel was dredged. The specifications of the Landsat MSS data sets are shown in Table III.

Ground Truth and Archival Data

The environmental parameters analyzed in this study include, vegetative zonation, water salinities, precipitation and water level. The sources, dates of collection, and geographic location of the data vary for each parameter. Some water salinity and water level ground truth data were collected, by this researcher, from July, 1982 through April, 1983. The remaining data were derived from alternate sources. Merging data concerning each type of surface variable was a difficult research problem to address, as is the case in many scientific investigations which utilize ancillary data. Spatial and temporal variations of each type of data creates greater uncertainty about their interrelationships. The locations of the environmental data are identified on Figure 9.

Salinity.

"Salinity is a principle factor regulating plant distribution; consequently, the plants that occupy a particular area can be used as indicators of prevailing salinity regimes" (Charbreck and Condrey, 1979, p. 5). Water salinities have broad fluctuations on a daily and seasonal basis, and may greatly differ at any given time from plant zonations. Many vegetative type-maps dating back to 1949 exist that include the East Cove Marsh (see figures 4-7). The original division of Louisiana Marsh-zones were: saline; brackish; slightly brackish (intermediate); and fresh (Penfound and Hathaway, 1938).

TABLE III

LANDSAT SPECIFICATIONS

I Date: 10/3/72 Time: 16:19
Satellite: Landsat I
Scene ID: 81072/16190500
Row: 39 Path: 26 Lat.: N 30° 20' Long.: W 93° 48'
Format: Band Sequential
Density: 1600 BPI
Corrections: Radiometric and Geometric
Sun Elevation: 47 Azimuth: 139

II Date: 10/19/81 Time: 16:03
Satellite: Landsat II
Scene ID: 22462/160324
Row: 39 Path: 26 Lat.: N 30° 12' Long.: W 93° 52'
Format: Band Interleaved
Density: 1600 BPI
Corrections: Geometric
Sun Elevation: 40 Azimuth: 140

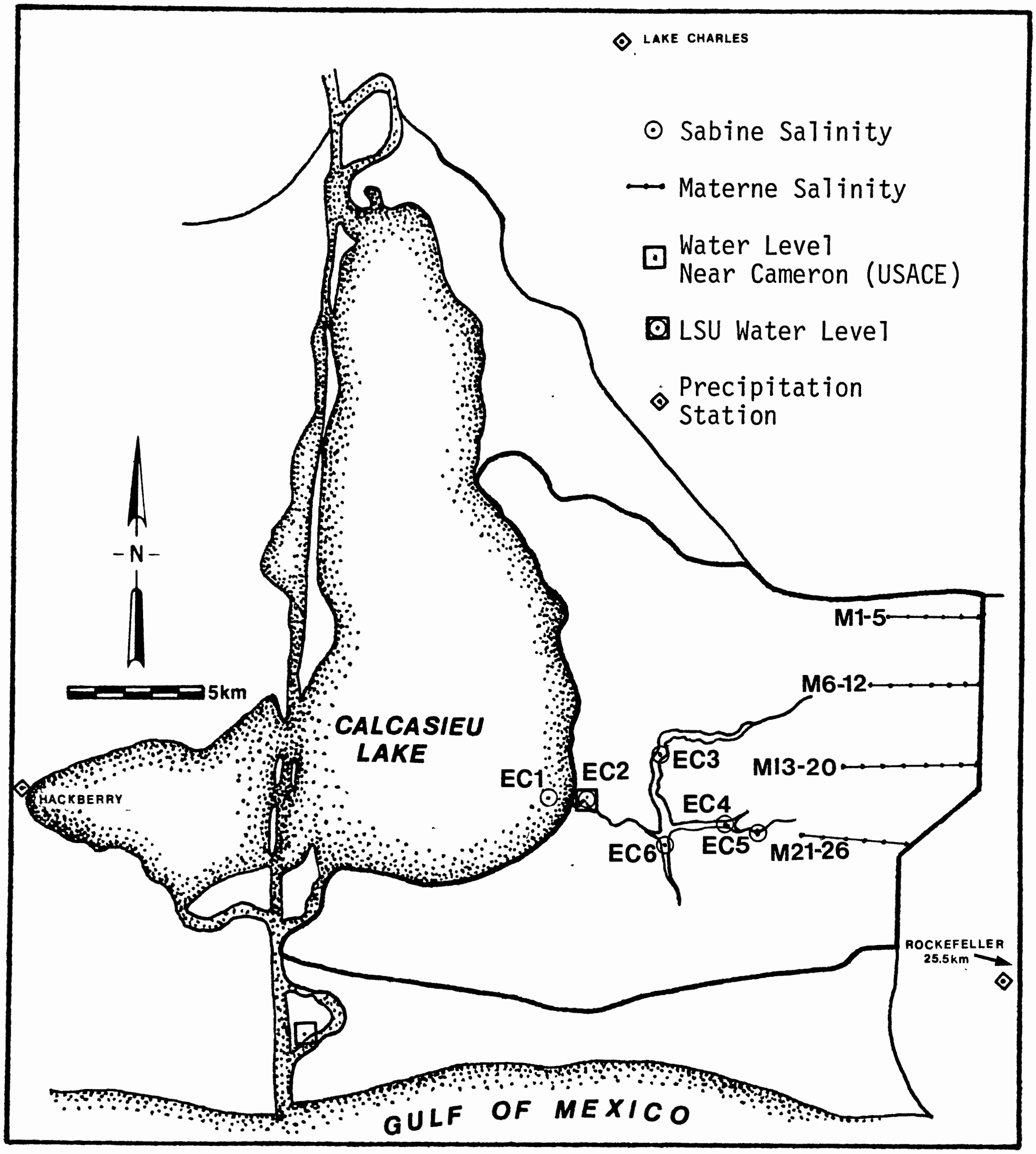


Figure 9. Data Sampling Locational Map

Since 1967, the Sabine National Waterfowl and Wildlife Refuge has collected water salinity samples at the locations depicted in Figure 9. Data collected at the EC1, EC2, EC3, and EC6 locations are useable, while EC4 and EC5 records were too sporatic for sufficient analysis. The data were collected and recorded as parts per million Chloride (ppm CL^-), and converted to parts per thousand (ppt) salinity, by using the following formula (Riley and Chester, 1971):

$$\frac{\text{ppm } CL^-}{1000} \times 1.80655 = \text{ppt salinity}$$

The readings were taken on a monthly basis, though the exact day of collection was not recorded.

The limits of the Refuge boundary do not include the entire East Cove Marsh hydrologic unit. Interior water salinty data were obtained for six months by Materne, (1983), who collected samples at 1200 foot (368 m) intervals along four transect lines during 1982, on 23 March, 26 April, 24 May, 24 June, 29 July, and 26 August (Figure 9). The water salinity data obtained, covers the major water bodies which are open to the estuary, and influenced by the more saline Gulf waters. Water salinity information was not available for other closed water bodies within the study area.

Precipitation. Daily precipitation data is available from the National Climatic Data Center in Asheville, North Carolina (U.S. Dept. of Commerce, 1967 - 1982). Daily data for three stations, located outside the marsh, were used to interpolate precipitation values, using Thiessen polygons, in the East Cove area: Hackberry 8, SSW, no. 3979; Lake Charles WSO AP, no. 5078; and Rockefeller Wildlife Refuge, no. 7932 (Figure 9).

Water level. Water level data has been collected by the U.S. Army Corps of Engineers (1967 - 1982) at Calcasieu River and Pass near Cameron since 1939 (station 735022). Using a Leupold and Stevens model, continuous recording gauge positioned in a well, data were collected. These data, obtained from the New Orleans district office, were graphically recorded at mean low gulf (MLG), which is 0.78 feet higher than sea level.

Currently, a tide level study is being conducted in East Cove by Louisiana State University (LSU), School of Forestry and Wildlife Management (1982). These data have been collected since December, 1981, at the Sabine Salinity Station, EC2 (Figure 9). A Leupold and Stevens digital tape, continuous water level recorder (model 7001) was positioned approximately half the distance to the bottom (2 meters).

Mean marsh level (MML) was measured relative to water level, using a line leveling device, during the spring 1983 sampling mission at the EC2, Sabine and NASA project sampling station, shown on Figure 9. This measurement indicates the level of the marsh bank adjacent to the sampling stations (Figure 10). If the water rises above this level, large areas of the marsh behind the natural levees (or banks) can become flooded, and greatly affect the water area calculated for the Landsat data sets.

Processing Methodology

Landsat digital data were processed to detect wetland change from 1972 to 1981. Ground truth and archival data were incorporated and analyzed to determine the factors leading to change shown by the Landsat data.

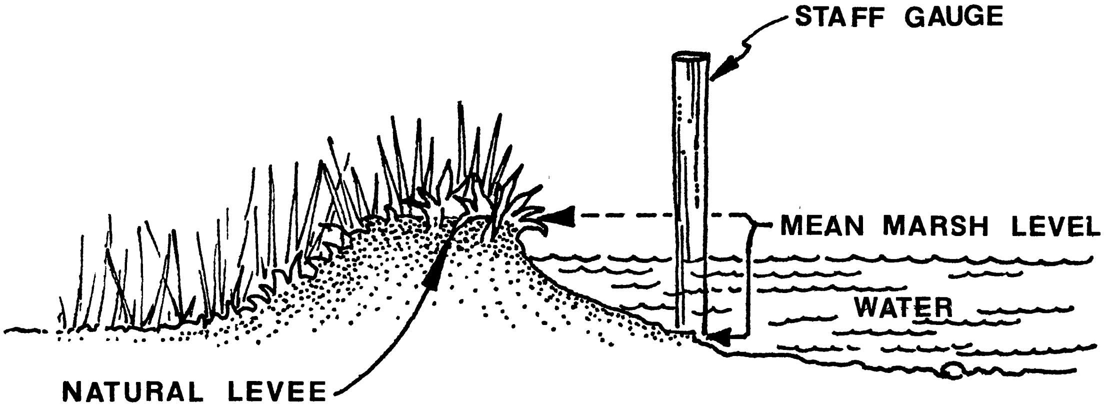


Figure 10. Determination of Mean Marsh Level (Cross-Sectional View)

Landsat Data Processing for Change Detection

Digital Landsat data were processed on Perkin-Elmer 8/32 and 3240 computers, interfaced with a Comtal image display device, and a Versatec electrostatic plotter. The processing was completed at the NASA/Earth Resources Laboratory, National Space Technology Laboratories, Mississippi, and at the Oklahoma State University, Center for Applications of Remote Sensing (CARS), Stillwater, Oklahoma. ELAS (Earth Resources Laboratory Applications Software) was used at both locations to process the Landsat data. ELAS is a geobased information system for use in processing remotely sensed data and integration of environmental data (Junkin et al., 1981). The ELAS software routines (four letter acronyms) are divided into pre-classification, classification and post-classification procedures in Figure 11.

Pre-Classification Procedures. Pre-classification of MSS digital data included all procedures that prepared the data for classification. The Landsat Computer compatible tapes (CCT) were reformated so that digital data could be viewed as an image. Banding or other parities in the data were corrected and in this instance, the data were georeferenced prior to classification. The methodologies for the 1981 and 1972 Landsat digital image data were identical, for all but the initial georeferencing procedures. To geographically reference the '81 data to the Universal Transverse Mercator (UTM) grid, control points were located, using a X-Y digitizer, from USGS 7.5' topographic quadrangle maps. Mapping coefficients (linear functions) were computed between the Landsat coordinates (scans and elements) and UTM coordinates (eastings and northings). This process was accomplished

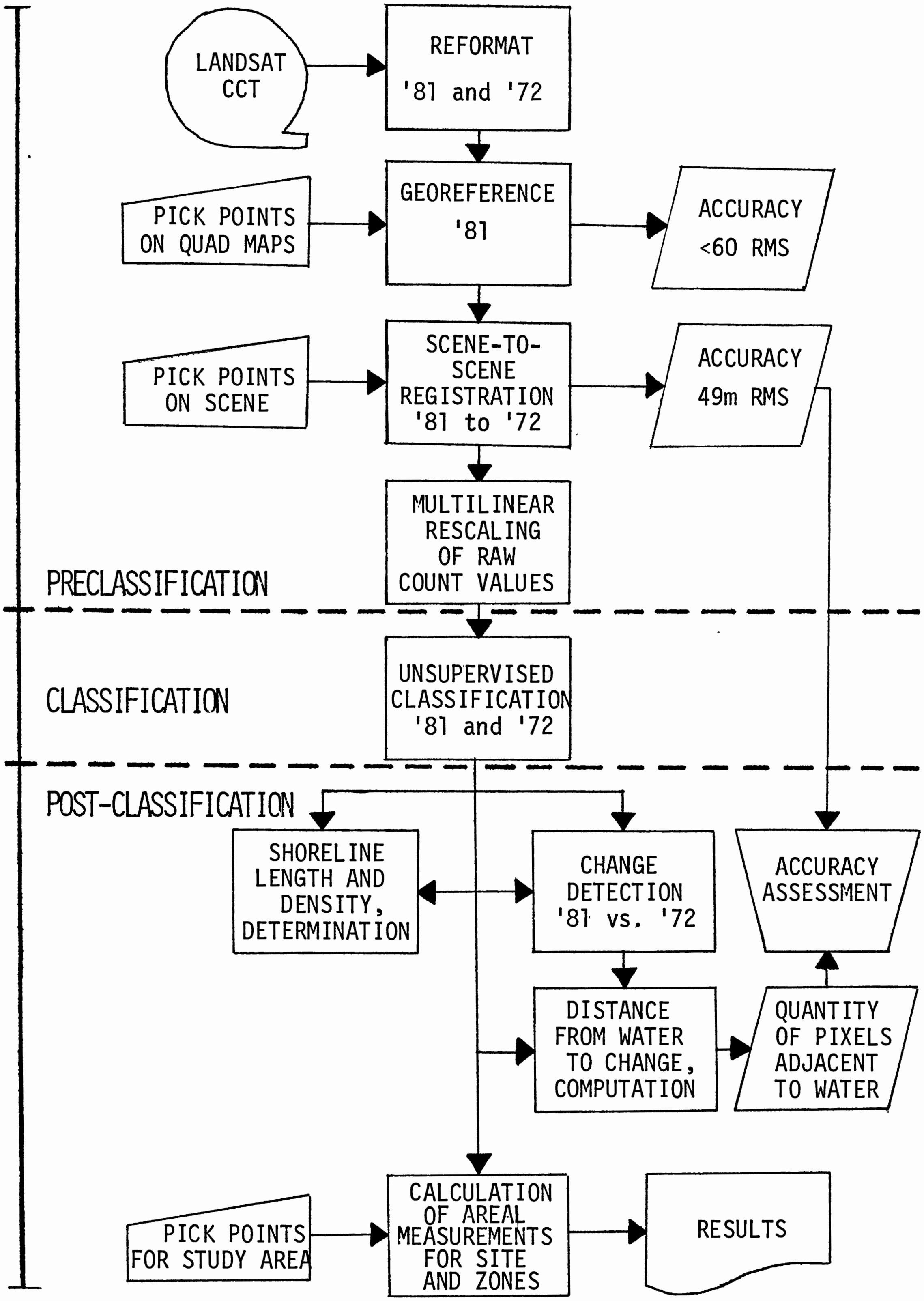


Figure 11. Analysis Procedures for Digital Change Detection

by using overlay PMGC (Georef Constants), which corrected the skew, scan angle and mirror velocity of the scanner. The corrections were necessary because Landsat sensors collect data on a non-orthogonal basis, and so, if uncorrected, would result in a non-linear map product. Overlay PMGE (Georef) uses the coefficients developed in PMGC to resample the Landsat data to the UTM grid on a cell-by-cell basis. The accuracy of the corrected image was within 60 meters root mean square (rms). This error approximated the size of a pixel (79 m by 59 m).

The 1972 data set was not georeferenced to USGS quadrangle maps. A scene-to-scene registration of the 1972 data to the georeferenced 1981 data was deemed better for change detection. Georeferencing procedures would entail identifying control points of known coordinates (i.e. roads, or other stable features), which are difficult to accurately locate in the East Cove Marsh. Mappable control points were limited, but approximately 250 common surface points were located on each scene of data. The technique used to conduct an ELAS scene-to-scene registration included: 1) viewing the 1981 data set (referred to as the BASE) and the 1972 data set (referred to as the MAP) simultaneously utilizing multiplex image capabilities; 2) picking spatially corresponding points for use in computing mapping coefficients (OCON); and 3) resampling the MAP data set using the coefficients (OVLA).

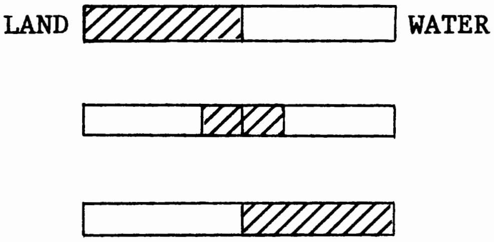
OCON (Compute Mapping Coefficients) is very similar to PMGC, although OCON does not use USGS quadrangle map coordinates. Mapping coefficients were computed, using OCON through the selection of 152 points. The rms error for the scene-to-scene registration, of the study site and its immediate surrounding area, was 49 meters. OVLA (overlay) is a semi-automated module, similar to PMGE, which uses bilinear interpolation for corresponding channels of two data sets (e.g. channel 1, BASE with channel 1, MAP). The data from one Landsat frame are mapped, by element, into the coordinate system of another, one channel at a time. This procedure effectively georeferenced the MAP data set to the BASE data set.

After viewing the georeferenced data sets, it was apparent that the raw spectral reflectance intensities of the two data sets were noticeably different because of varying noise levels. The DIME (Digital Image Enhancement) overlay was used to make the two data sets statistically comparable by rescaling the data for each channel from the normal 0 to 63 into a 0 to 255 (byte) range, using multi-linear scaling. DIME samples the data, generates statistics and histograms of the spectral characteristics, and computes the desired transformations. The original and transformed statistics are presented in Table XV, Appendix A.

Classification Procedures. Classification is the process of grouping pixels into classes which have similar spectral signatures. Classification of the two data sets was accomplished using the SRCH (search) and MAXL (Maximum Likelihood Classification) overlays. Because the raw data values ranged from 0 to 255, standard default procedures designed for data ranging from 0-63, could not be utilized. Parameters for SRCH were derived by comparing the raw and transformed means and standard deviations of count values per channel.

SRCH procedures were developed to separate large homogeneous cover-type training fields, through the unsupervised approach, and generate statistics by sliding a 3 by 3 pixel window through the data. The unique characteristics of this ecosystem, including low tidal range and minimal vertical relief, required further modification of standard procedures. The small, heterogeneous areas of shallow water, mudflats, and heavily dissected land, appeared to reflect nearly the same amount of energy, thus, distinguishing these boundary cover-type classes was complex.

The goal was to optimize land/water discrimination, by spectrally separating these two clusters of classes from transitional classes. The following was the criteria for class cover-type discrimination.



>50% LAND=LAND

50% LAND + 50% WATER ± 10%
= TRANSITIONAL

>50% WATER=WATER

Although choosing training fields was automatic and unsupervised, the SRCH procedure was mathematically supervised. SRCH statistics were derived by locating pixel groups whose standard deviation upper and lower bound (SDUB and SDLB) and coefficient of variation/100 (COV) times the mean of a channel were within specified limits. If the scaled distance (SDIS), a mathematical measure of spectral separability, between each class is greater than a specified minimum distance, a class is produced (Figure 12). The statistics are then gathered and listed as spectrally distinct classes. The modified parameters used to develop SRCH statistics on the rescaled data sets, are presented in Appendix B, along with standard default parameters. The SDLB was lowered and the SDUB was raised, thereby increasing the

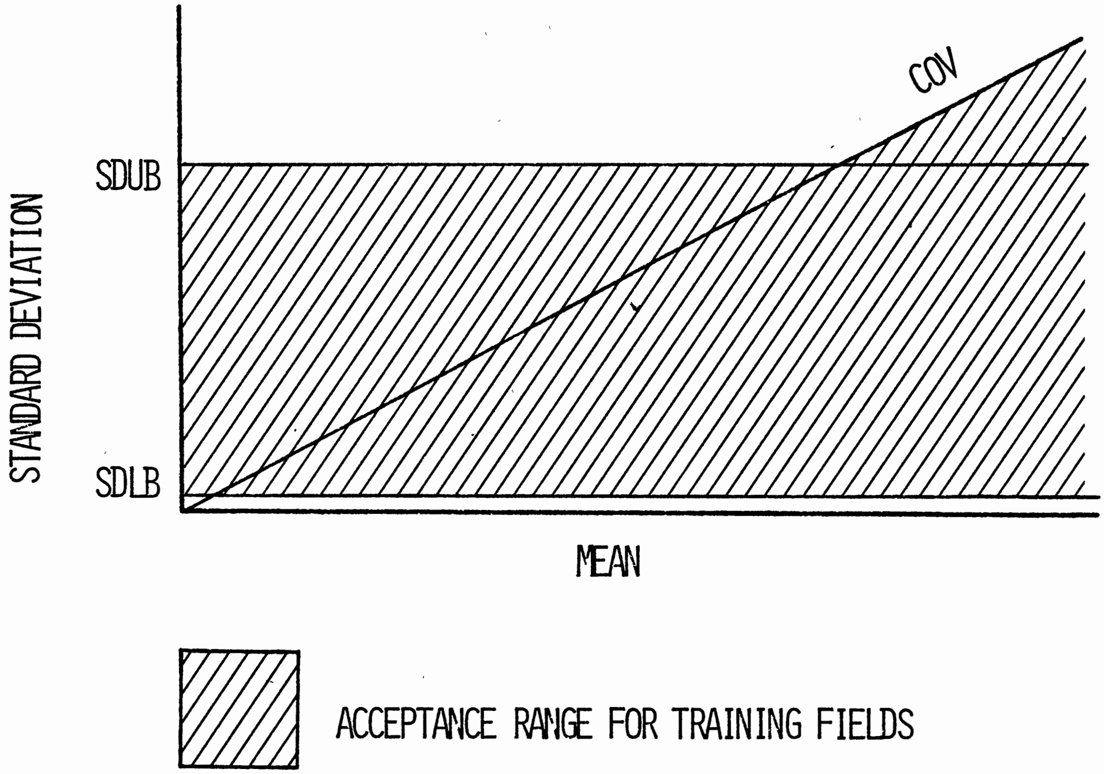


Figure 12. Criteria for Development of Training Fields

number of acceptable pixels which are influenced by water, which generally has lower mean reflectance values with high variablility or standard deviation. The COV was raised because the means and standard deviations were larger after the DIME transformation, as the reflectance values had a much broader range. SDIS was increased to allow class development from smaller pixel groups, like those in transitional zones. Two space plots of channel two versus channel four were produced to aid in identification of cover-type classes, spatially as well as statistically (Figure 37 and 38, Appendix C). Channel two is highly sensative to chlorophyll concentrations and channel four is sensative to plant tissue structure and water content, therefore, plotting two versus four maximizes separability of marsh cover types.

MAXL classification was accomplished using the principle of maximum likelihood (Swain and Davis, 1978) and a threshold of 99 percent (Chi-square value = 13.2767). Each pixel of the data set is assigned to the number of the statistic which it best fits. Unclassified data are data which does not fit any statistic with an acceptable amount of error. Four channels of raw data were used as input, and a single-channel composite classification was output.

The results of the classification procedure were displayed in two products: one for 1981 and one for 1972. Each data set was viewed on the COMTAL and each class was manually identified as either land, water, transitional or unclassified. The identity of each class was determined by analyzing a combination of: 1) photography; 2) observations in the field; and 3) two-space plots of channel two versus channel four. The overlay POLY (Polygon Manipulations) was used to delineate the East Cove hydrologic unit. PLYA (Polygon Acreage) was utilized to extract the area for each class within the East Cove Polygon for both 1981 and 1972.

Post-classification Procedures. Post-classification procedures include several types of manipulations of classified data. DBAS, PLYA, SLIN, SLID and DIST manipulations were used in this analysis. DBAS (Basic Computer language) was employed to assign each class with a value (Unclassified = 0, Water = 1, Land = 2, and Transitional = 3), and to determine the difference between the 1981 (Channel 1) and 1972 (Channel 2) data sets. The first DBAS run was used to determine any change, by subtracting each pixel of the 1981 data set from the corresponding pixel in the 1972 data set (Table XVI, Appendix D for BASIC run-stream). A second DBAS run was used to determine what kind of change had taken place in each cover-type (Table XVII, Appendix D for BASIC run-stream). The value for each 1981 pixel was added to the 1972 pixel value, specifically chosen in order to total a discrete value for each type of change (i.e., a change from a transitional to a water class had a value of 83). The data sets analyzed for change detection were plotted and gridded on the electrostatic plotter (presented in Chapter IV).

SLIN, SLID, and DIST were used to more accurately identify the location of changes in cover-type between 1972 and 1981. SLIN (Shoreline Length) assigns a shoreline length class to land pixels, centered in a 3 by 3 pixel window, depending upon the number of water pixels surrounding it. For this procedure, the transitional classes were grouped with land classes. It is assumed that this method would accurately produce shoreline classes in transitional areas, because they were 50 percent water. The possible output of a SLIN classification is: class 0 = Water; class 1 = Land; and class 2-70 = Shoreline, where the shoreline classes increase in proportion to the shoreline length. In both, the 1972 and 1981 classifications, there were only 2-68 shoreline classes. The actual shoreline length for each class may be calculated by multiplying the coefficient associated with each class (Table XVII, Appendix E) by the spot or pixel size (50 meters), however, the total shoreline length for an area can be generated by the computer. The output for SLIN was in the form of a data file which was used as input for the SLID overlay.

SLID (Shoreline Density) is a program which computes the density of shoreline in a given window size, by using the following formula:

$$\text{SLID} = \frac{\text{SLIN}}{\text{LAND AREA}},$$

where SLID = 2 through 255. A 3 by 3 pixel, search window was used in this study, therfore, the land area used in the above equation could be as much as 22,500 m^2 (50 m x 50 m x 9 pixel), per window. The SLID value was assigned to the center pixel. The output class, is the actual shoreline density in units of m/ha.

The DIST (Distance Between Two Classes) overlay was used to calculate the distance of all pixels to water pixels. Water classes for the 1972 data were used to classify every pixel width away from water pixels. Each DIST class output was consecutively 50 m, 100 m, etc., from the nearest water class. The 1972 DIST output was compared to the DBAS run which determined the type of change between 1972 and 1981. PLYA, multi-channel processing (MULT), was utilized to identify spatial co-occurrences of each DIST class with those of the DBAS run. Implementation of this PLYA option made it possible to identify the nature and quantity of changes which took place at 50 m intervals from water classes.

DIST output was used to calculate the maximum amount of error due to georeferencing. Misregistration can only appear at the boundary of the two input classes for the DIST run (land and water). The rms error was 49 meters, therefore, the area contained in the first distance class (one pixel width from water), conservatively speaking, is the maximum georeference error possible. The total area in class 1 is 2,256 ha, which is 7.9 percent of the total study area.

Analysis of Factors Leading to Change

Ancillary surface data were compiled to better assess the apparent change between the two Landsat data sets. Water salinity and precipitation data were analyzed to determine if salinity had changed over the nine year period. Water level data were analyzed to develop a model which would aid in determining the water level in the marsh during collection of Landsat data and to determine if the water level had changed on a long term basis. Vegetative maps based on salinity regimes were used to locate salinity zones on the Landsat data sets.

Water Salinity. The monthly water salinity data which was, collected by the Sabine National Wildlife Refuge, was used in a linear regression, with time as the independent variable to determine trending. Because the monthly arithmetic means of the four sites were correlated with their individual monthly values, the averages of the four were used to represent the salinity of the area. The monthly salinity data were highly variable and warranted extreme smoothing methods to identify trends. A five-year running average was computed for the mean of the Sabine salinity stations by using two years on either side of the year being averaged. The mean salinity for 1978, for example, was computed by averaging the mean annual salinities for 1976 through 1980. The salinity data collected by Materne (1982), at 26 stations, were intended for use in developing a model to estimate water salinities at each of the 26 sites for 1972 and 1981, based on the Sabine salinities. It was determined that six months of samples, taken once a month at each location, were not enough replicates to accurately predict the variability of water salinities for the nine-year period. A salinity map, presented with the results in Chapter IV, was produced using thirty control points to compare water salinity zones in 1982 with the vegetative zones depicted by Gosselink et al., in 1979.

Salinity and Precipitation. It is hypothesized that salinity and precipitation were inversely related. Both types of data are highly variable annually as well as seasonally. The precipitation for the East Cove basin was calculated by using a modified version of the Thiessen Polygon Method (Oliver, 1973). Three precipitation locations were used to construct Thiessen polygons (Figure 13). The polygons were open because of the absence of a satisfactory number of data collection points, however, this did not affect calculation of the basin precipitation. A planimeter was used to measure each area, and the precipitation for each station was weighted accordingly. Hackberry data was weighted by 59 percent, Lake Charles by 38 percent, and Rockefeller by 3 percent, then summed to obtain the total basin precipitation. The total monthly precipitation data was then averaged on a five-year basis, as was the salinity data. Precipitation data

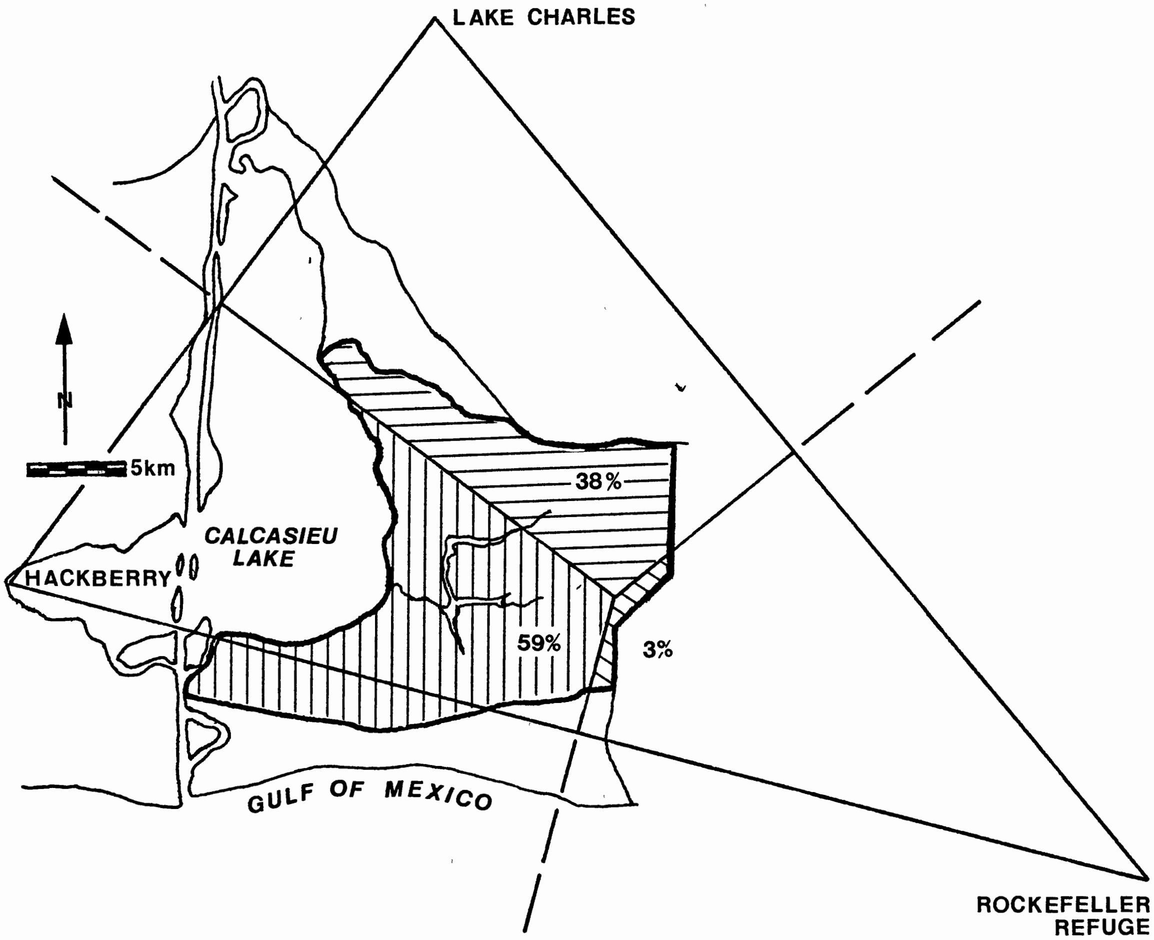


Figure 13. Thiessen Polygons for Precipitation

and the corresponding year were analyzed to determine their correlation to salinty concentrations.

Water Level. At the time the multitemporal MSS data were acquired, water levels at Cameron were not the same. On October 3, 1972 the level at 16:19 was 2.46 feet above mean low gulf and on October 19, 1981, at 16:03 it was 0.92. Water level was important in this study, for if it is above the mean marsh level, a large area of marsh may be flooded, which would increase the amount of open water calculated. This would lead to confusion as to what areas were permanent open water and which were merely being temporarily influenced by high water.

Water level at Sabine EC2 was digitally recorded on an hourly basis, and continuously recorded at Cameron in graphic form. Graphic data for the time period of Landsat over passes were compared to graphic data for the time period in which data were collected at EC2. This procedure helped eliminate some of the variability in the model because of variance in tidal patterns. Data values were picked from the Cameron graph at one-hour intervals, for the period from October 14 through 25, 1982. The digital data recorded at EC2 was graphed for the same time period. Figure 14 shows graphs of Cameron tide patterns for October 18-20, 1981, and October 14-25, 1982 and the EC2 tide pattern for the 1982 October dates. It was noted that a 3 to 6 hour lag existed between the two sampling points, and that the vertical range at East Cove was approximately half that of Cameron. EC2 data was lagged by 3, 4, 5, and 6 hours to determine the best correlation when regressed against the Cameron data.

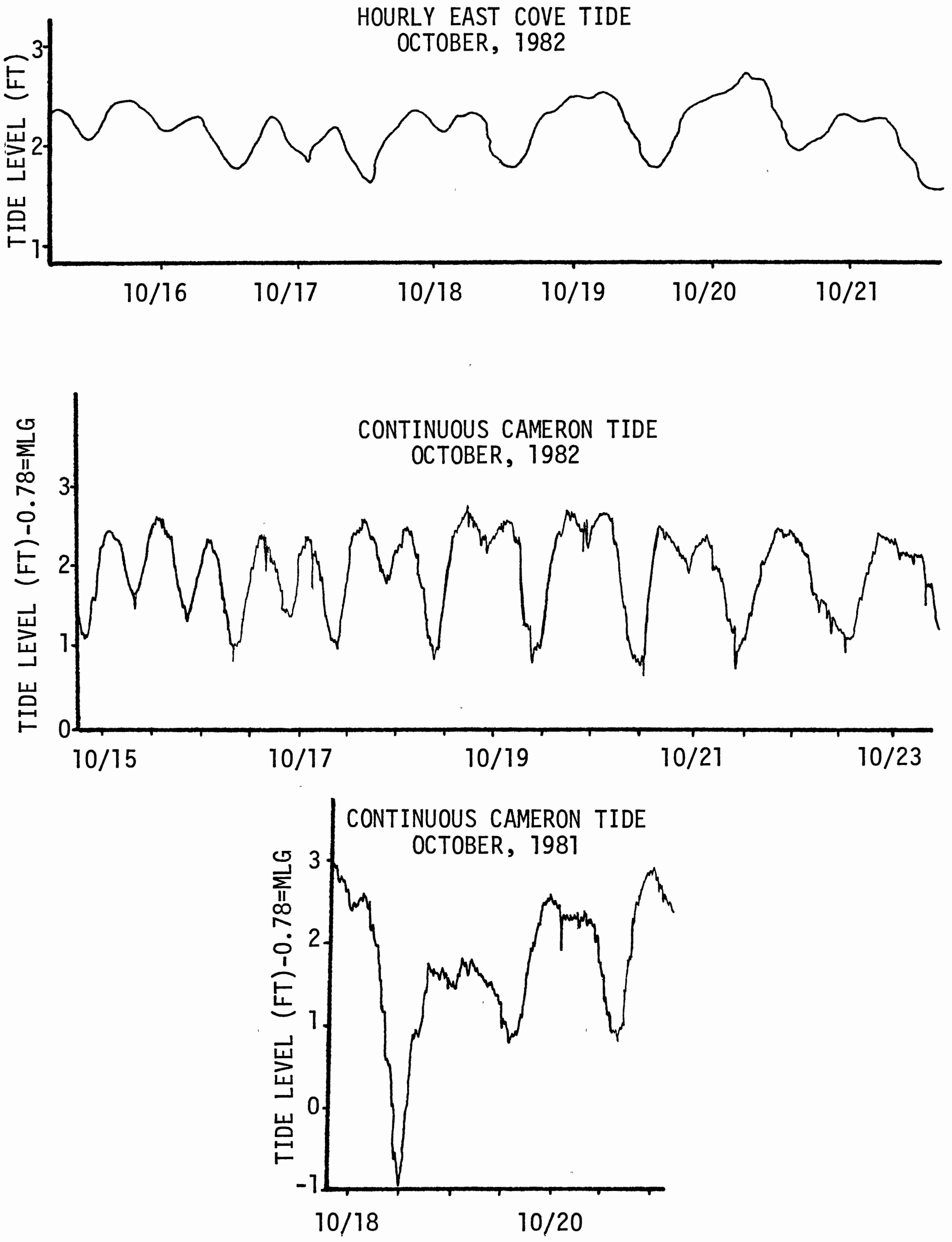


Figure 14. Tide Level Data Used for Water Model

Vegetative Salinity Zones

Landsat classified data sets were further analyzed by plotting the vegetative salinity zone polygons on the images by using the COMTAL image display device. Each vegetative zone map was analyzed as to detail, date, and method of information compilation. None of the maps were coincidental with the dates that Landsat data were collected. The map chosen for use in this study, was produced by Gosselink et al., in 1979 (Figure 7). This map had the most detail of the vegetative-type maps previously mentioned as it was a product of a Chenier Plain regional study, as opposed to the entire Louisiana Coast. Information was collected during the winter 1976-77 season, approximately midway between the Landsat dates. Aerial photography was used to aid in locating areas of differing vegetative types.

The type of change in each zone (DBAS second run), the amount of shoreline change (SLIN), the shoreline density change (SLID), and the type of change related to the distance to water (DIST) was calculated and presented in a change matrix. The procedures used to arrive at marsh zone areal measurements were the same as those used in calculating change for the entire study area, by using the PLYA overlay. The amount of shoreline in each data set should not vary on account of the water level, as shown by the tidal water model results.

CHAPTER IV

RESULTS AND DISCUSSION

Analyses of the Landsat data sets yielded a classification which showed the nature and location of changes between 1972 and 1981 in the East Cove Marsh. The data suggest that the marsh is deteriorating, and becoming more saline. The spatial location of change was non-uniform, and varied for each marsh zone, through it exhibited a pattern which indicated a relationship to water. Ancillary data were used to help explain the patterns of change and the processes involved which produced the change.

Change Detection Results and Discussion

Several digital data sets derived from classified Landsat data were produced to aid in the evaluation of spatial change patterns. The initial, cover-type classification, was utilized as input to determine changes, from 1972 to 1981, regarding change in cover-type, shoreline length, shoreline density and distance-to-water, for both, the entire study area and individual vegetative zones. Tide level data were analyzed to determine if water level in the study area affected the amount of water acreages calculated.

Cover-Type Classification and Change in the East Cove Study Site

The Landsat cover-type classifications for the East Cove Study Area produced 32 spectral classes for 1972, and 24 for 1981. The number of spectral classes differ because their generation, in any classification, is data dependent. All classes were combined into land, water, transitional, or unclassified. The classes were checked for accuracy against field data, photography and personal observations in the area. The two classifications were compared for any change (Table IV). Table IV shows that the majority of change happened in the land and water classes. The amount of land area decrease was nearly proportional to the amount of water area increase. The percentage of transitional and unclassified area did not change appreciably, however, their locations did change. Figure 15 shows the spatial location of the change, and a delineation of the vegetative zones. The marsh zones were derived from a vegetative study done by Gosselink et al., (1979). Changes occurred next to water bodies and within impounded areas; large changes were located along the east side of the marsh and on the south side of Calcasieu Lake. A maximum less than or equal to 7.9 percent of the changes occurred next to water because of misregistration or misclassification errors. Changes which took place within impounded areas were not included because the water was not controlled by the same variables which affected the remainder of the marsh.

The specific identity of each type of change is presented in Table V. The sixteen change classes resulted from the combination of four, 1972 and four, 1981 classes. The total change of all types for the

TABLE IV

PERCENT AREA AND NET CHANGE BETWEEN 1972 AND 1981 CLASSES

	Percent of Area		
Class	1972	1981	Change
Land	78.36	70.13	-8.23
Transitional	9.52	10.02	.50
Water	10.37	17.26	6.89
Unclassified	1.75	2.59	.84

Note: The maximum misregistration error is $\leq$ 7.9 percent.

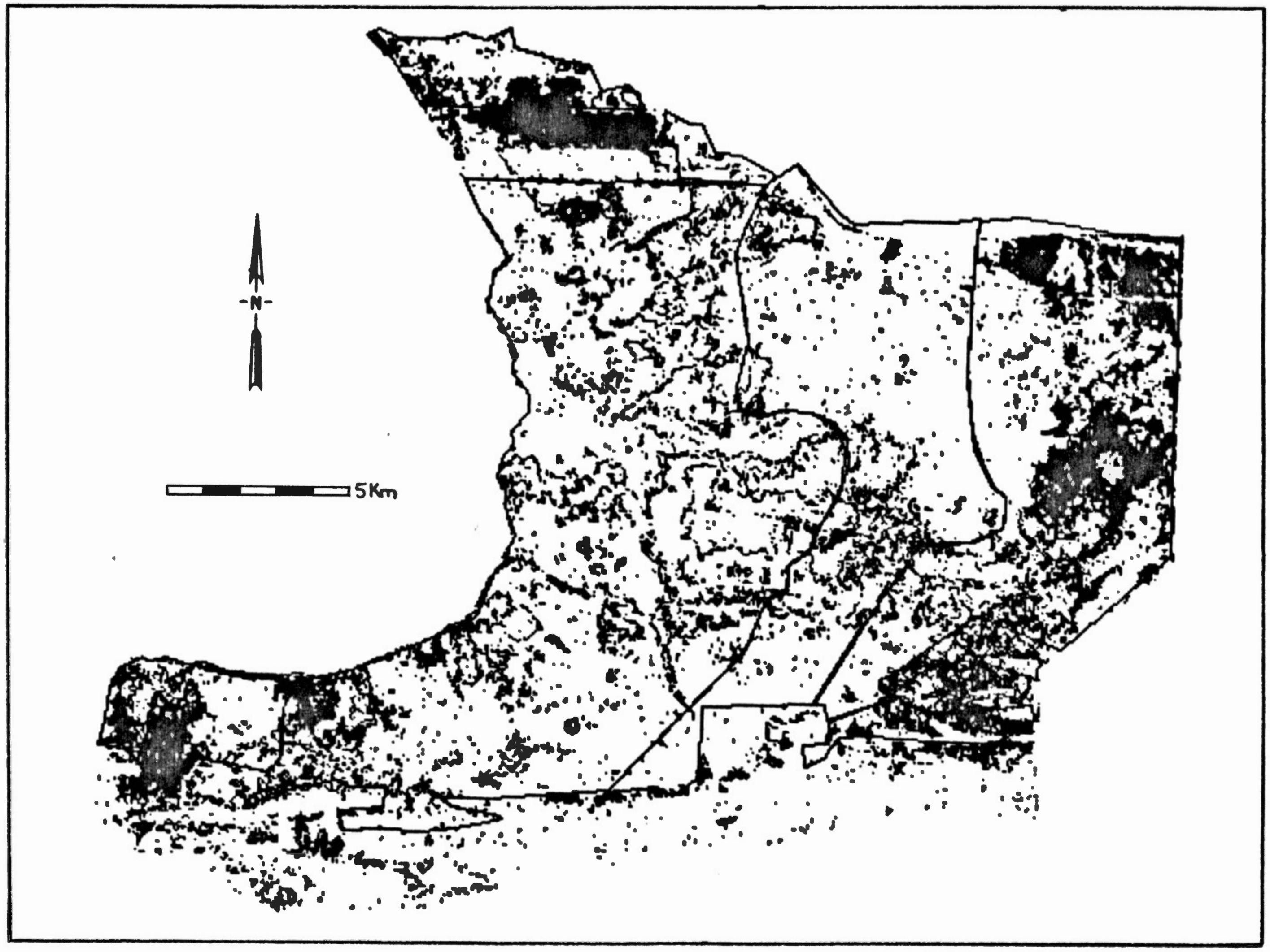


Figure 15. Cover-Type Change Between 1972 and 1981

TABLE V

CHANGE MATRIX INDICATES CLASS OVERLAP BETWEEN 1972 AND 1981, AS A PERCENT OF TOTAL AREA

	1972 Classes			
1981 Classes	L	T	W	U
Land	64.36	4.24	0.59	0.93
Transitional	6.82	2.15	0.80	0.26
Water	5.28	2.81	8.73	0.44
Unclassified	1.91	0.32	0.25	0.11

Note: The maximum misregistration error is $\leq$ 7.9 percent.

study area was 7,025 ha (24.65%). The results for each type of change indicated that most of the change was:

1) from land-to-transitional;
2) from land-to-water;
3) from transitional-to-land, and;
4) from transitional-to-water.

Figure 16 indicates the location of each type of change. Figures 17-32 show each of the sixteen possible change classes. Clusters of change identified locations of significant change and showed that not all change took place along land/water interfaces, nor was it due to misregistration. Most of the change from land-to-transitional occurred on the south end of Calcasieu Lake, between the lake and the chenier ridges. A smaller amount of this type of change appeared on the east side of the study area, along Creole Canal.

The change from land-to-water took place predominantly: 1) in the area along Creole Canal; 2) on the boundaries of large water bodies and bayous; 3) in the area near Calcasieu Pass; and 4) in an abandoned rice field (impounded) on the north side of the study area.

The transitional-to-land changes took place in three major areas: 1) on the north side of the site, in an area burned during 1972; 2) between chenier remnants, near Creole; and 3) along the eastern side of the site in breaking-up areas. This type of change seemed to be a reversal of changes leading to deterioration. The burn was low and wet, and had sparse vegetation and dark soil until revegetated, and classed as land. The area between the chenier remnants is poorly drained. The precipitation for ten days prior to the 1972 Landsat pass was 10.7 cm, as opposed to 4.4 cm in 1981. Low areas between the impedient cheniers may hold water for some time before it infiltrates,

Figure 16. Nature of Cover-Type Change Between 1972 and 1981, Shown in Sixteen Classes

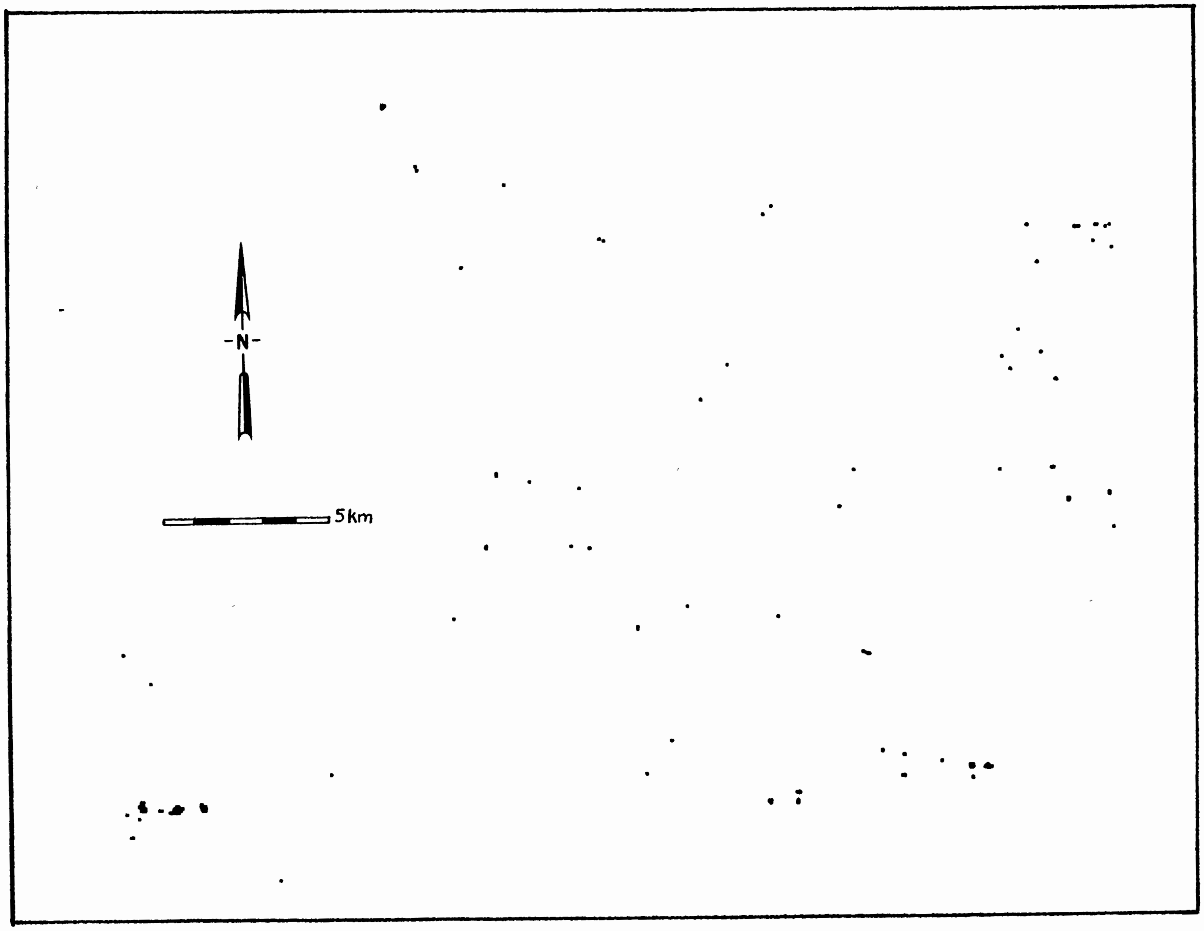


Figure 17. Cover-Type that Remained Unclassified

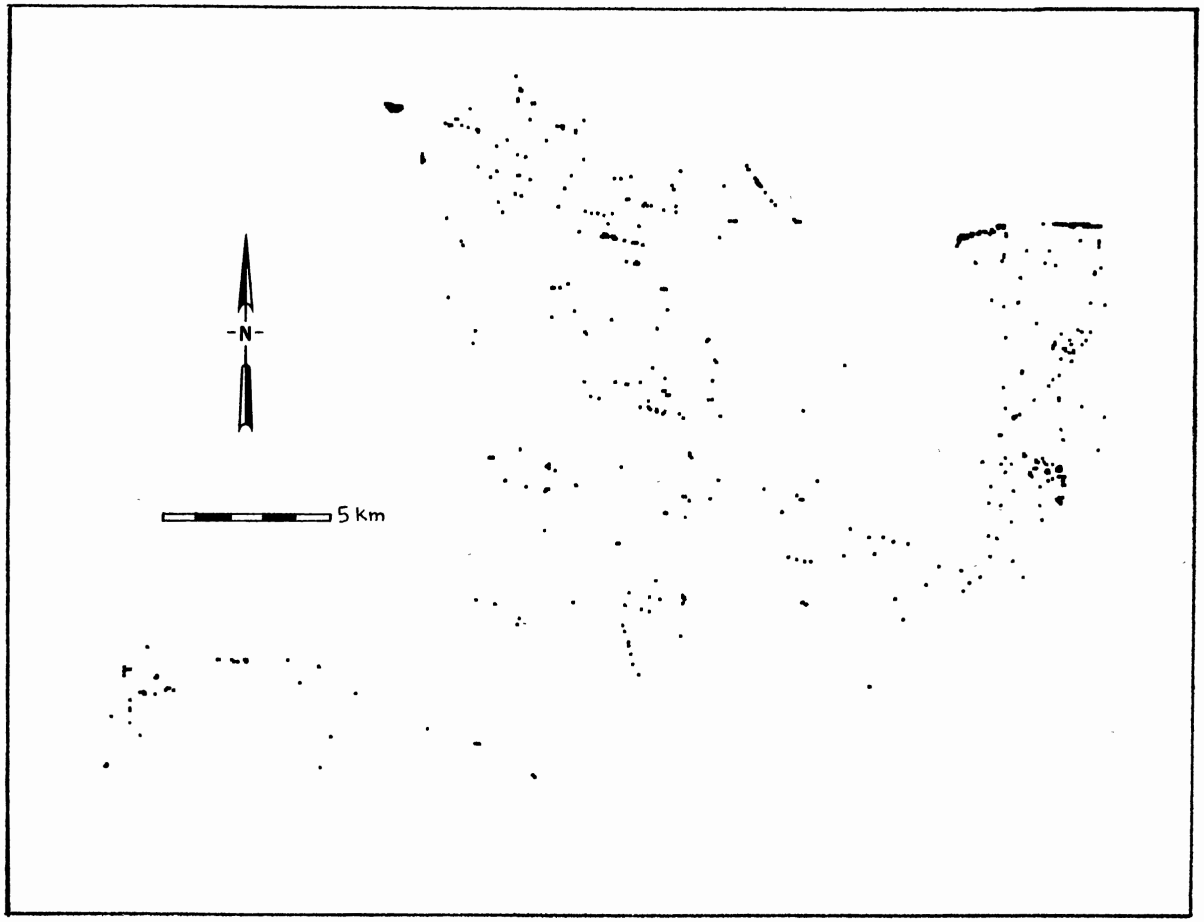


Figure 18. Cover-Type Change from Unclassified to Water

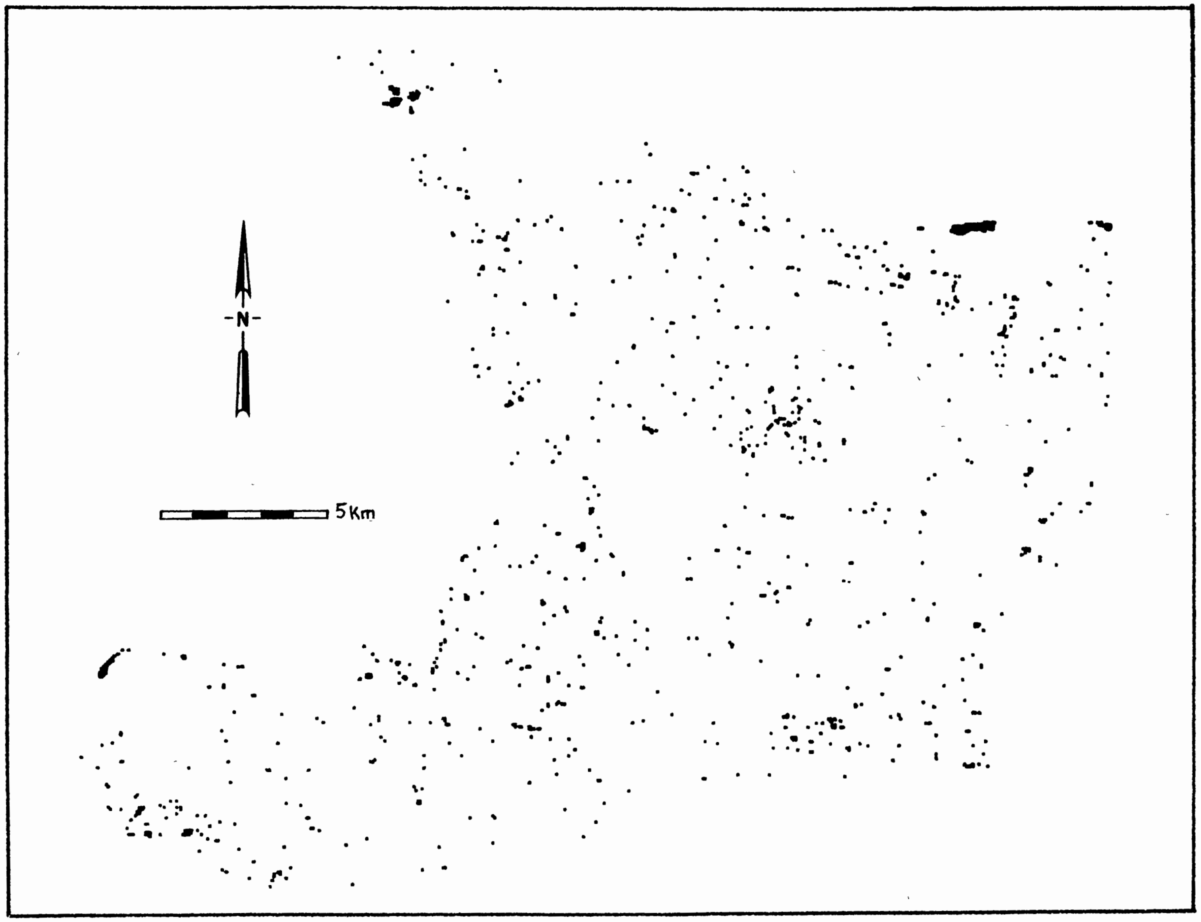


Figure 19. Cover-Type Change from Unclassified to Land

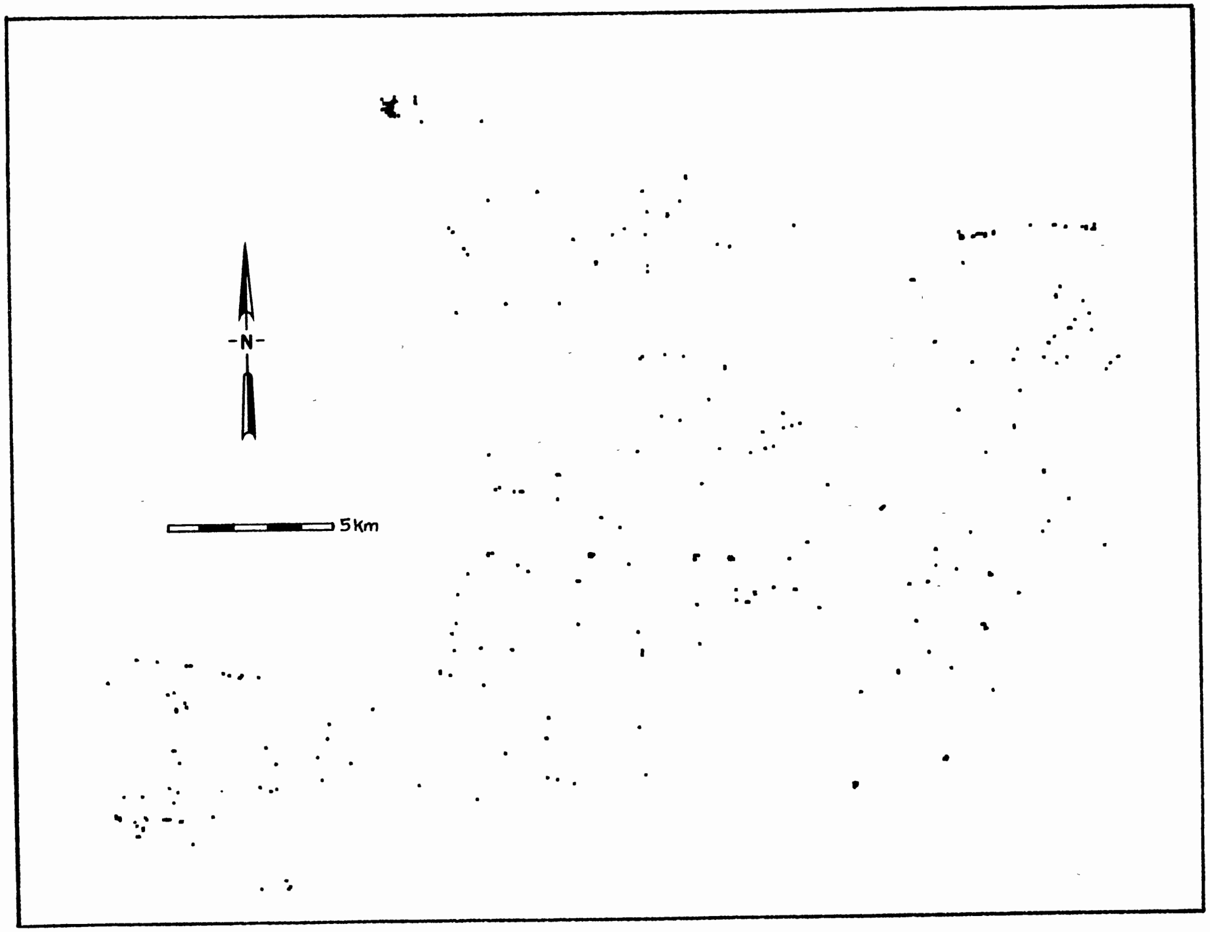


Figure 20. Cover-Type Change from Unclassified to Transitional

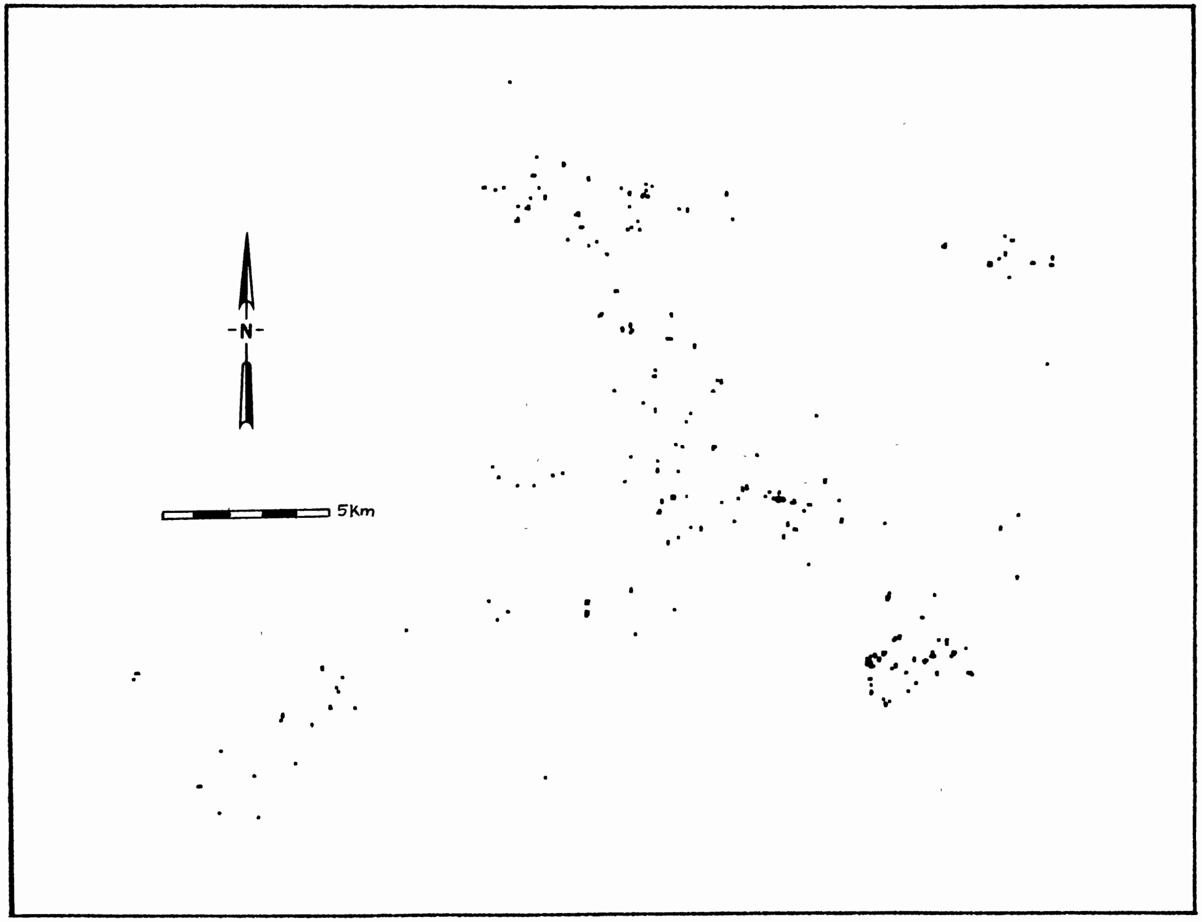


Figure 21. Cover-Type Change from Water to Unclassified

Figure 22. Cover-Type that Remained Water

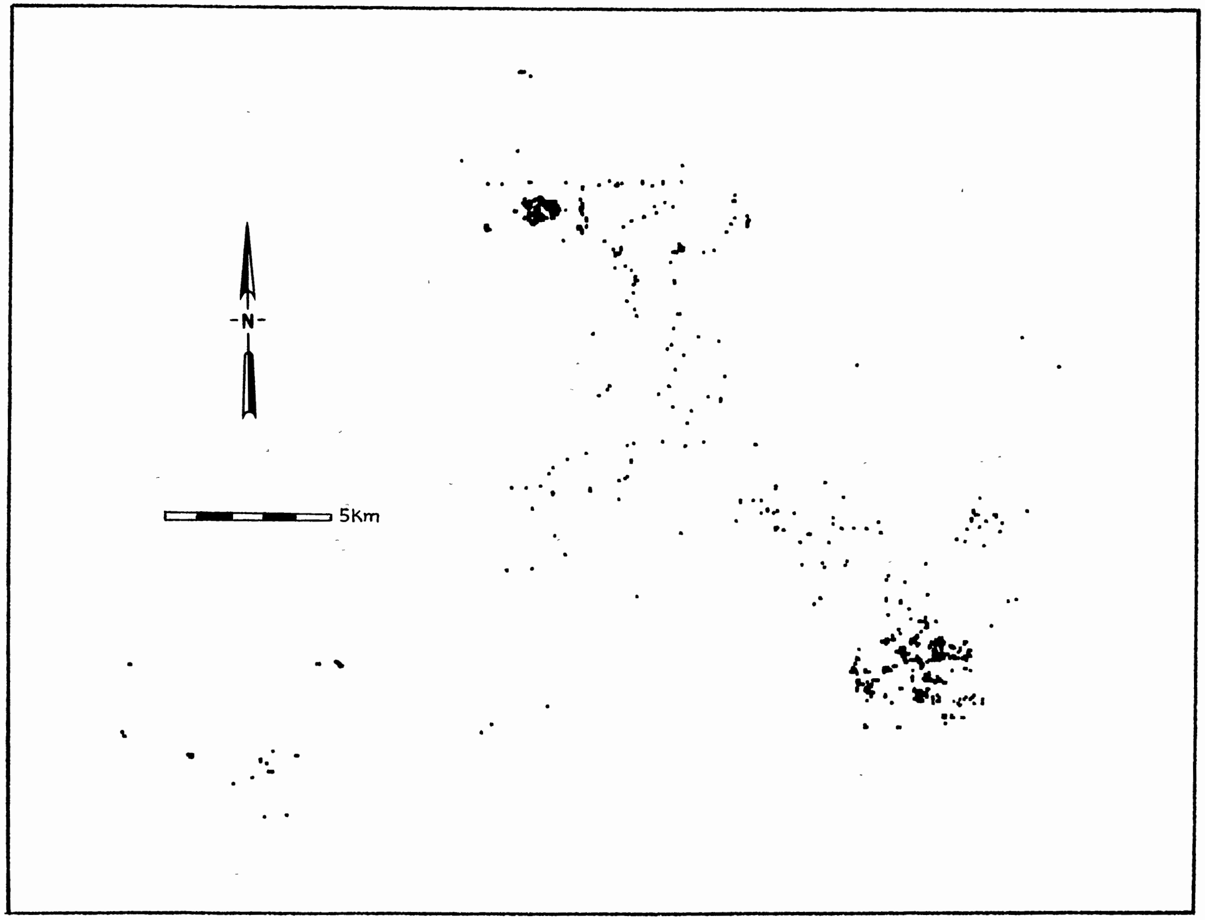


Figure 23. Cover-Type Change from Water to Land

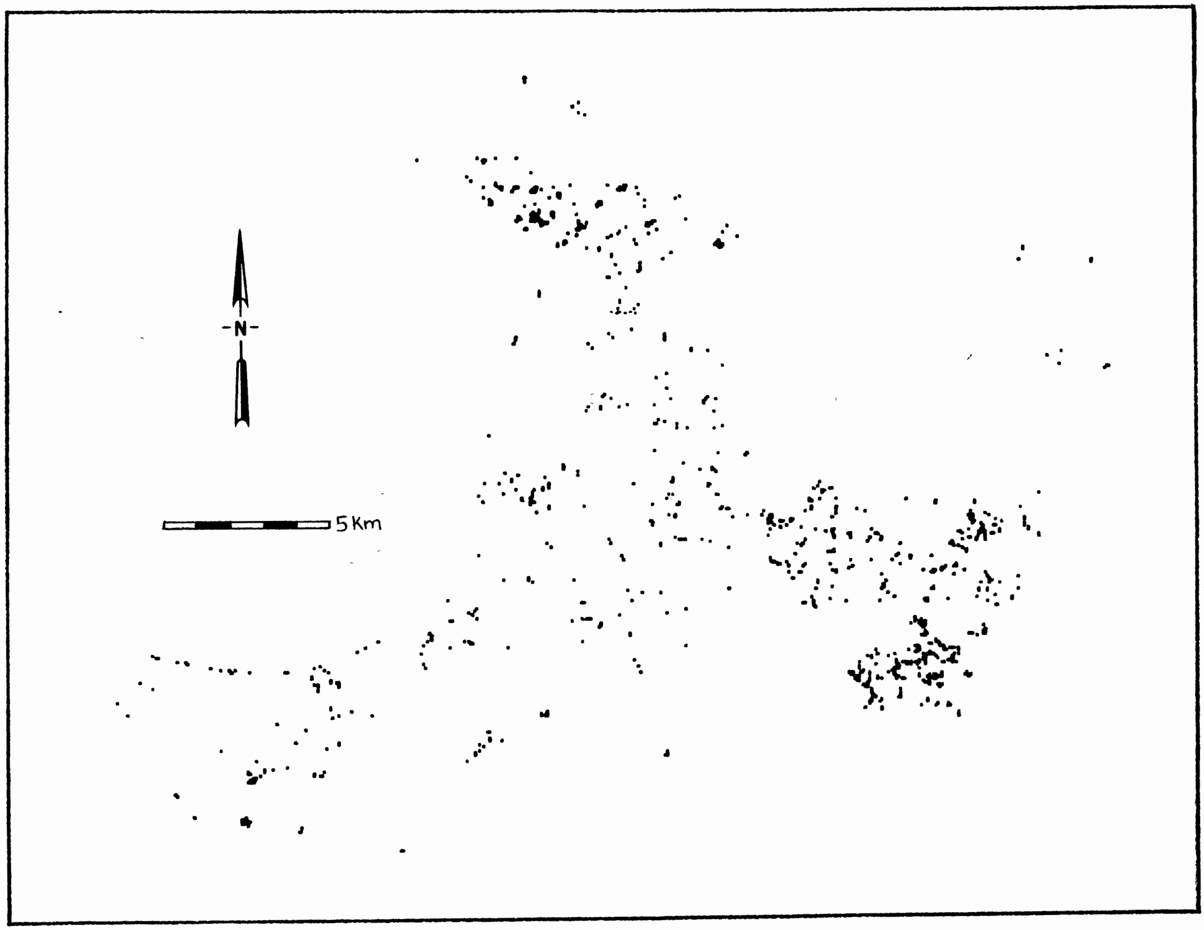


Figure 24. Cover-Type Change from Water to Transitional

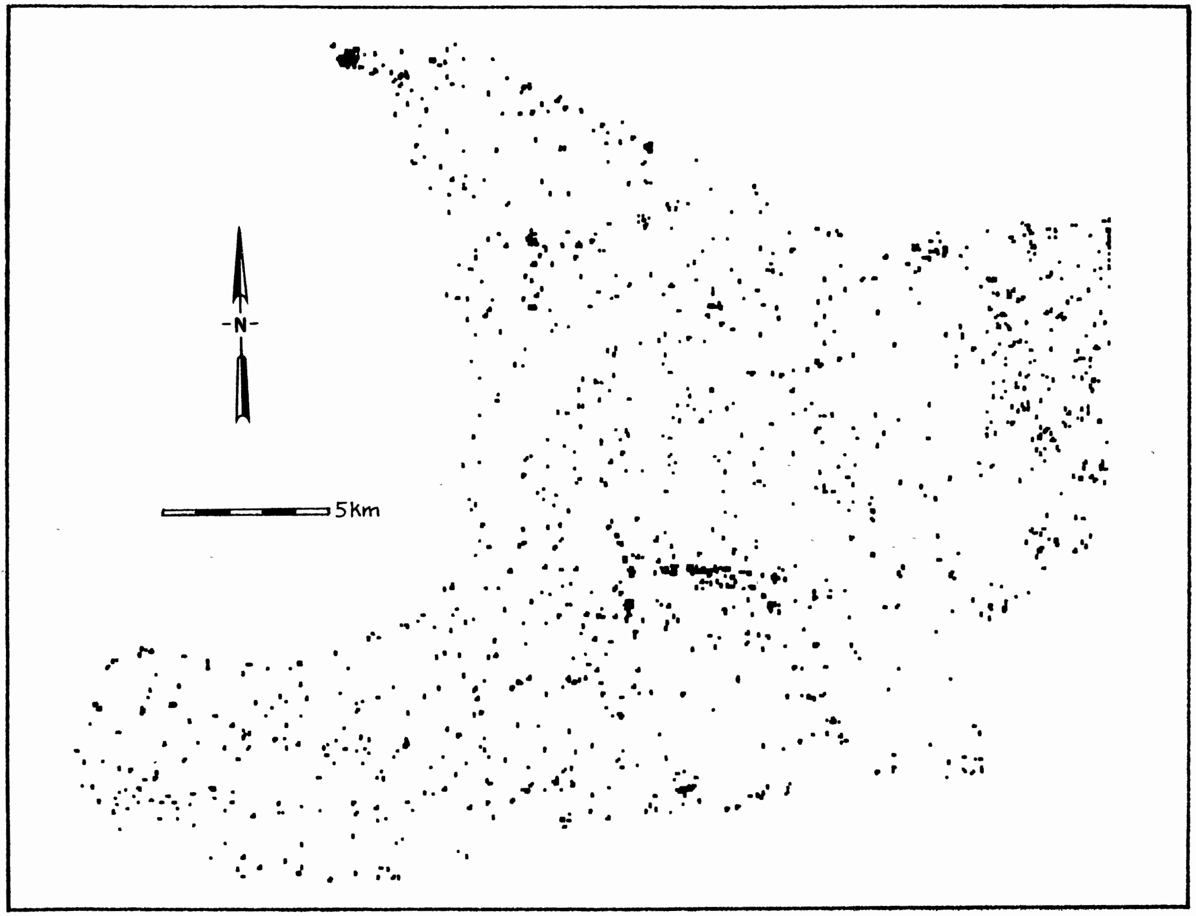


Figure 25. Cover-Type Change from Land to Unclassified

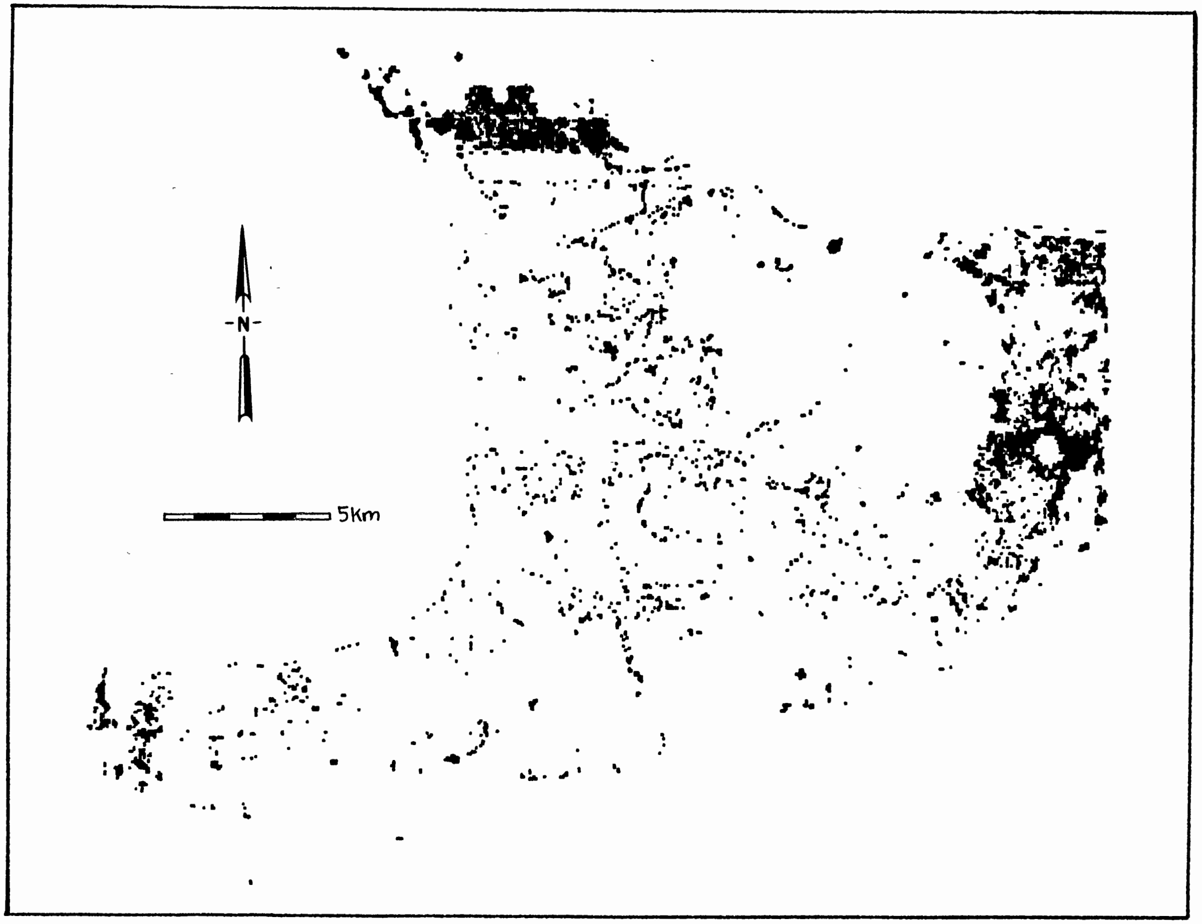


Figure 26. Cover-Type Change from Land to Water

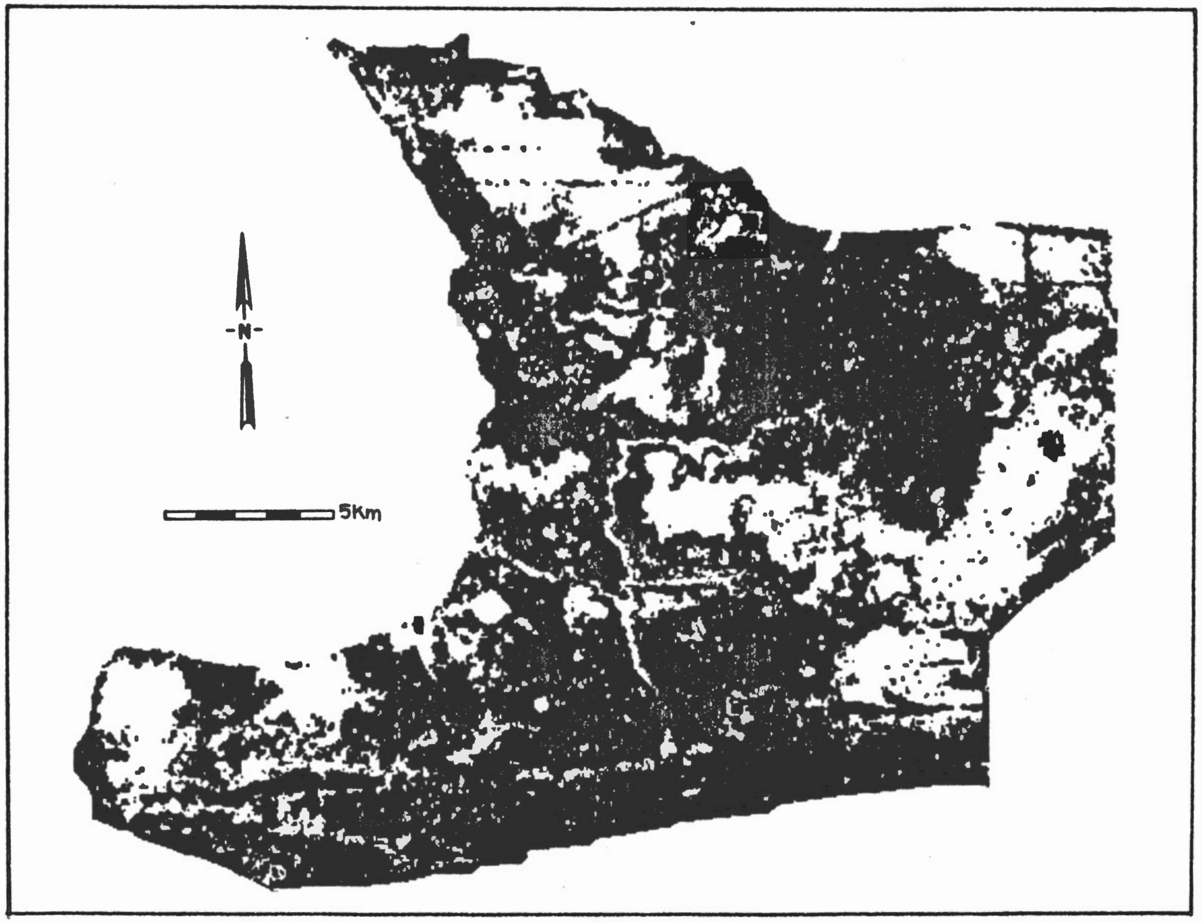


Figure 27. Cover-Type that Remained Land

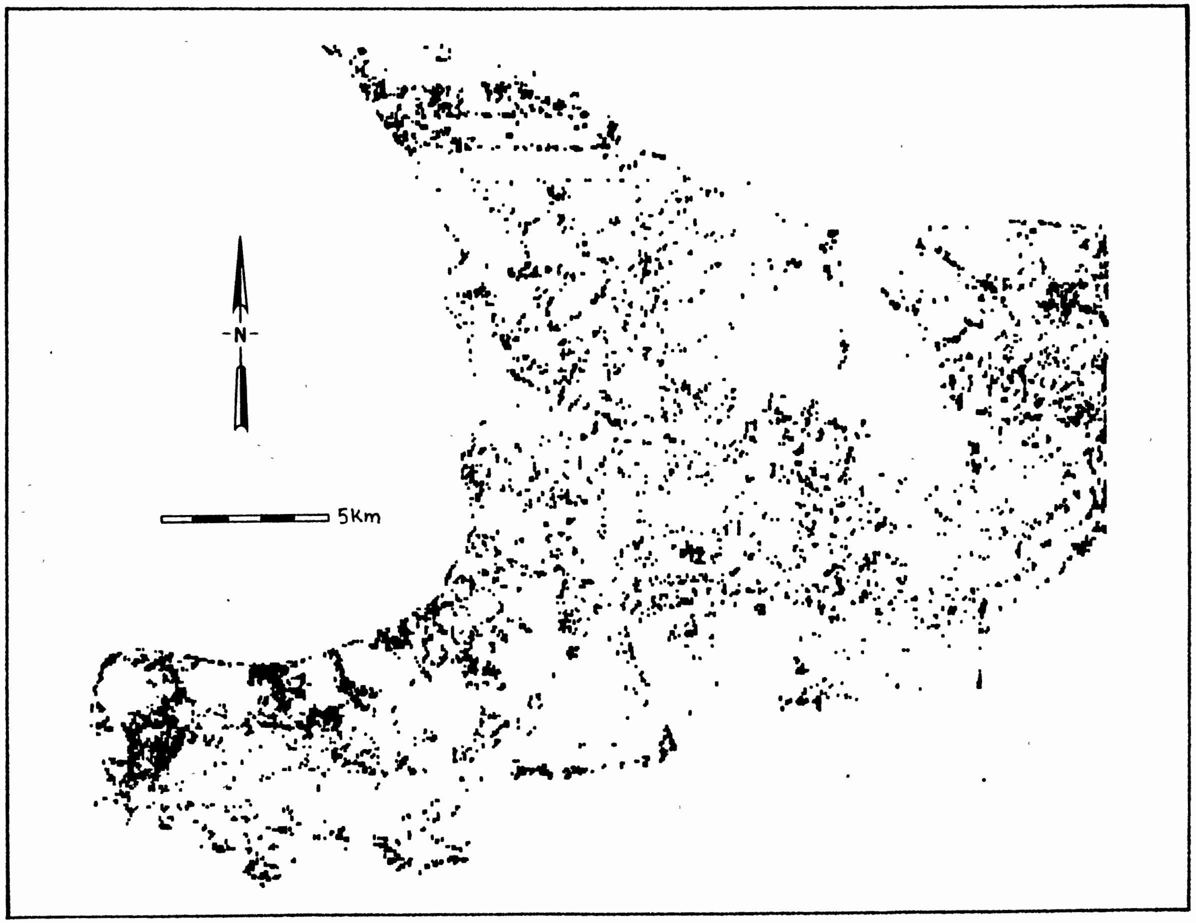


Figure 28. Cover-Type Change from Land to Transitional

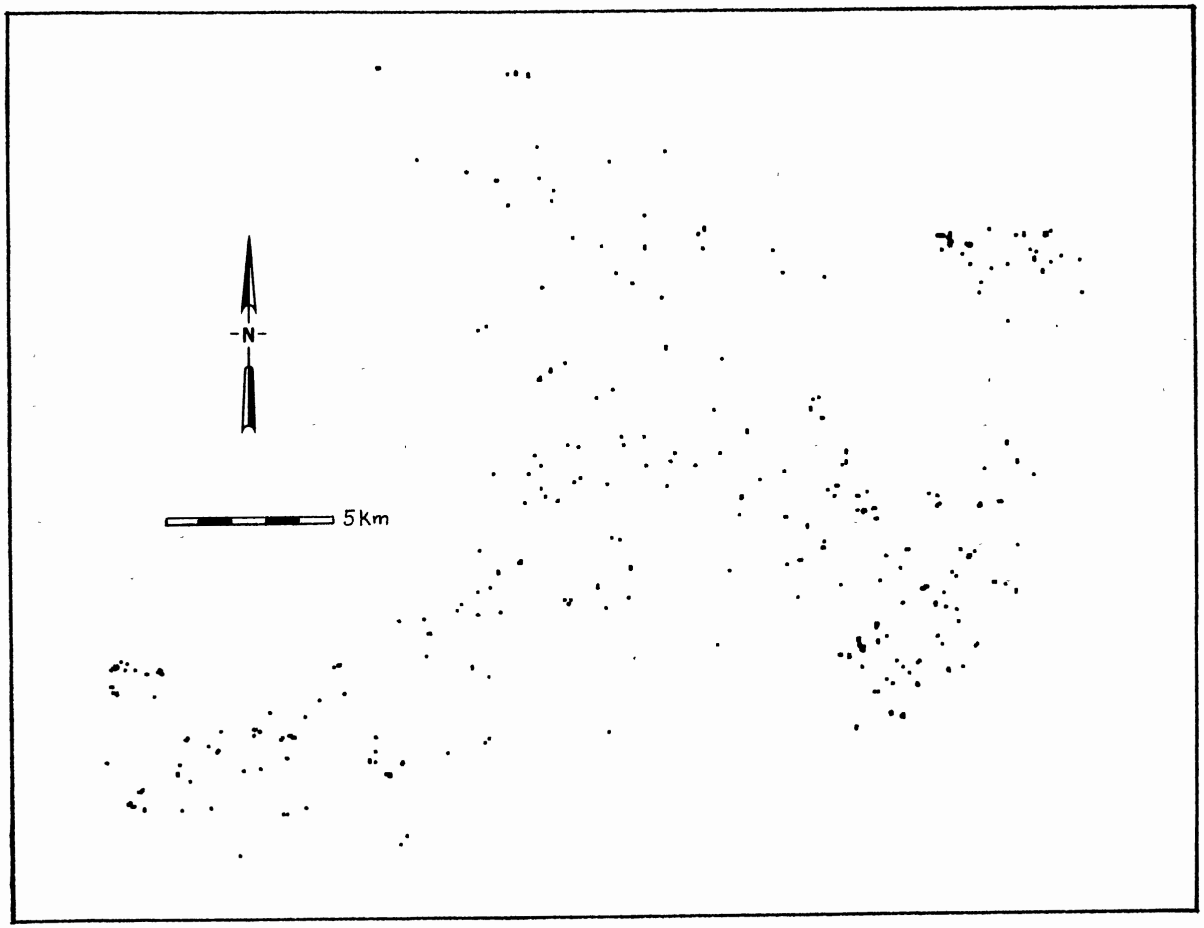


Figure 29. Cover-Type Change from Transitional to Unclassified

Figure 30. Cover-Type Change from Transitional to Water

Figure 31. Cover-Type Change from Transitional to Land

Figure 32. Cover-Type that Remained Transitional

therefore, the different amount of precipitation received prior to each Landsat date may have differentially reduced the soil reflectance in this area. A portion of these areas were utilized for grazing pastures with controlled water levels. The change in the heavily dissected areas could partially be attributed to misregistration/ misclassification errors, or varying water levels over mudflats, which have nearly the same elevation as the water. Registration error was slightly more than one pixel.

The change from transitional-to-water occurred: 1) along the east side of the site; 2) in the non-functional rice impoundments; and 3) on the edges of water bodies to the south of Calcasieu Lake. The change on the east side and on the south side of Calcasieu Lake could be attributed to salinity changes or other factors causing present water bodies to open up. The change in the impoundment may occur because of water level control structures around the area.

The areas of greatest change were concentrated in the eastern and southwestern portions of the study area, although changes occurred throughout the study site. Unexplained changes may have been caused by something in the water or related to the water. Possible factors included: 1) chemical composition; 2) erosion from wave action; 3) different rates of vegetative break up; 4) differing substrate composition; 5) lack of sediments for rebuilding and refilling; 6) entrapment of saline waters; or 7) a combination of all of the above. Some factors affected the entire land/water marsh interface, while others may have been more site-specific. The sources of sediment were outside the marsh, and were introduced through Grand Bayou. Much of the sediment may have settled out before reaching the eastern portions of the marsh. Therefore, when areas in the east subsided or deteriorated, they were not rebuilt and could not revegetate.

Vegetative Zones. The vegetative zones depicted on the map produced from the Chenier Plain Study (Gosselink et al., 1979), were delineated on the 1972 and 1981 classified products. The zones did not comprise the entire study area. Cheniers and impoundments were not considered marsh areas, and therefore, were not included in the marsh zones. The zones, depicted in Figure 15, totalled 21,852.5 ha, intermediate = 928.25 ha, brackish = 10,851.75 ha, intermediate = 5,255.5 ha, and fresh = 4,817 ha. The amount of change for each cover-type in each zone is presented in Table VI. The change in each zone was much greater than the change for the entire study area. Most of the change occurred in the fresh and saline zones. When the percent of area changed was calculated for the total of the zone areas, the fresh and brackish zones incurred the highest percentages, and saline land areas changed moderately. The size of the brackish zone was more than double the fresh zone, however, the changes in the fresh zone were proportionately greater than any other zone in the marsh. The class overlap for each zone between 1972 and 1981 is presented in Table VII. In comparing the nature of changes in each zone, the dominant changes were similar to those for the entire study area, except different proportions occurred. In the fresh zone, most of the changes which took place were from land-to-water. This was the only zone in which this type of change dominated, and may indicate an accelerated rate of deterioration. The other changes, land-to-transitional, and transitional-to-water, were intermediate stages, indicative of deterioration.

TABLE VI

PERCENT AREA AND NET CHANGE BETWEEN 1972 AND 1981 CLASSES FOR EACH ZONE

		Percent of Area			
	Class	1972	1981	Zone Change	Of Total
Fresh (4,817 ha)	Land	73.68	54.68	-19.00	4.19
	Transitional	12.22	11.25	- 0.97	0.002
	Water	11.31	31.10	19.79	4.36
	Unclassified	2.79	2.97	0.18	0.001
Intermediate (5,255.5 ha)	Land	83.30	84.13	0.83	0.002
	Transitional	8.40	5.48	- 2.92	0.01
	Water	6.45	8.25	1.80	0.004
	Unclassified	1.85	2.14	0.29	0.001
Brackish (10,852 ha)	Land	77.11	68.32	- 8.79	4.37
	Transitional	7.15	11.16	4.01	1.99
	Water	14.06	17.74	3.68	1.83
	Unclassified	1.68	2.78	1.1	0.05
Saline (928 ha)	Land	72.93	44.95	-27.98	1.19
	Transitional	17.18	28.84	11.66	0.005
	Water	7.33	23.27	15.94	0.01
	Unclassified	2.56	2.94	0.38	0.001

Note: The maximum misregistration error is $\leq$ 7.9 percent.

TABLE VII

CHANGE MATRICES INDICATE CLASS OVERLAP BETWEEN 1972 AND 1981 AS A PERCENT OF EACH ZONE

		1972 Classes			
	1981 Classes	L	T	W	U
Fresh	Land	50.6	2.7	0.2	1.3
	Transitional	8.0	2.2	0.7	0.3
	Water	12.7	7.0	10.2	1.1
	Unclassified	2.4	0.4	0.1	0.1
Intermediate	Land	76.7	5.9	0.6	0.9
	Transitional	3.2	1.3	0.7	0.2
	Water	1.7	0.9	5.0	0.7
	Unclassified	1.6	0.3	0.2	0.1
Brackish	Land	64.0	2.8	0.6	0.9
	Transitional	7.6	2.4	0.9	0.3
	Water	3.4	1.7	12.2	0.4
	Unclassified	2.1	0.3	0.3	0.1
Saline	Land	42.0	1.7	0.1	1.2
	Transitional	22.0	5.6	0.5	0.5
	Water	6.7	9.1	6.6	0.9
	Unclassified	2.0	0.8	0.1	0.1

Note: The maximum misregistration error is $\leq$ 7.9 percent.

The largest change in the intermediate area was from transitional-to-land. As mentioned before, this was a reversal of the other deterioration trends, and was a function of precipitation and water level control. The aforementioned burn site, that returned to vegetated marsh was located in this zone. Some deterioration was apparent, as land had changed to transitional cover in small areas.

In the brackish zone, the greatest acreage alteration which occurred was from land to transitional. This may indicate that this area was not in the advanced deterioration stages of the fresh zone, or that the rate of change did not match that of the fresh. Land-to-water and transitional-to-land changes were lower, but still important. Most of the modification to transitional and to water classes occurred on the south end of Calcasieu Lake next to water bodies. The changes from transitional-to-land were adjacent to unaltered transitional areas. This result may indicate a misclassification error. The percent overlap from land to unclassified supported this idea. This change occurred, for the most part, in what was intrinsically believed to be transitional areas.

The changes which took place in the saline zone were the most dramatic. Nearly one-third of this area changed from land-to-transitional and transitional-to-water. Even misregistration errors or misclassification errors would not have been this large. Land-to-water was also a major change. With all phases of deterioration taking place, and a sizeable percentage in the first phase (land-to-transitional), this zone may be next in line to become open water. This zone is directly adjacent to both Calcasieu Lake and Calcasieu

Pass, and is more directly influenced by these water bodies than any others.

Shoreline Length/Density Classification

East Cove Study Site. The relationship of change in the proximity of water was examined to help identify possible causes. The shoreline length (SLIN) was calculated for 1972 and 1981. The interface between water and the other cover types was designated as shoreline. The results of the classification of the entire study area is presented in Table VIII. The increase in shoreline length, from 350,229m to 582,490m, as shoreline becomes heavily dissected, indicates a trend toward deterioration.

Shoreline density (SLID) is another measure of change related to water variables (Table IX). The calculation of shoreline density included the area near the interface, therefore, the figure for shoreline density was larger than shoreline length. The average density value increased between 1972 and 1981 from 1,202,225m, to 1,995,914m over the entire study site. If the total of shoreline density had increased, and the average decreased, one would expect that new areas of water had opened up, with less dense shoreline. Because the average class density value increased, from 70, to 79, a more dissected shoreline dominated the other classes of shoreline density.

Vegetative Zones. SLIN and SLID overlays were also run on each of the vegetative zones to determine if they exhibited inter-zone differences (Table X). Again, all of the zones displayed an increase in shoreline length with the fresh zone having the greatest change. The

TABLE VIII

PERCENT AREA AND NET CHANGE IN SHORELINE LENGTH BETWEEN 1972 AND 1981

	Percent of Area		
Class	1972	1981	Change
Land Transitional and Unclassified	81.71	70.31	-11.40
Water	10.37	17.26	6.89
SLIN	7.92	12.43	4.51

Note: The maximum misregistration error is $\leq$ 7.9 percent.

TABLE IX

PERCENT AREA AND NET CHANGE IN SHORELINE DENSITY BETWEEN 1972 AND 1981

	Percent of Area		
Class	1972	1981	Change
Land, Transitional, and Unclassified	74.51	60.37	-14.14
Water	10.37	17.26	6.89
SLID	15.12	22.37	7.25

Note: The maximum misregistration error is $\leq$ 7.9 percent.

TABLE X

PERCENT AREA AND NET CHANGE IN SHORELINE LENGTH BETWEEN 1972 AND 1981, FOR EACH ZONE

		Percent of Area			
		1972	1981	Zone Change	Of Total
Fresh:	Land	79.67	51.16	-28.51	6.28
	Water	11.31	31.11	19.80	4.36
	SLIN	9.02	17.73	8.71	1.92
SLIN Length (m)		68339.25	150,925.53	82,586.28	
Intermediate:	Land	86.88	83.20	- 3.68	0.01
	Water	6.46	8.25	1.79	0.004
	SLIN	6.66	8.55	1.89	0.005
SLIN Length (m)		51,560.55	69,687.72	18,127.17	
Brackish:	Land	76.25	67.86	- 8.39	4.17
	Water	14.06	17.74	3.68	1.83
	SLIN	9.69	14.40	4.71	2.34
SLIN Length (m)		162,116.43	249,782.22	87,655.79	
Saline:	Land	83.44	58.61	-24.83	1.05
	Water	7.33	23.27	15.94	0.01
	SLIN	9.23	18.12	8.89	0.004
SLIN Length (m)		14,138.12	28,361.06	14,222.94	

Note: The maximum misregistration error is $\leq$ 7.9 percent.

intermediate zone had the least percentage of water, and shoreline length, and the least percent of change.

The results for shoreline density in the zones were also similar to those of the entire study area (Table XI). The highest average density occurred in the saline zone, although the average for the brackish zone changed the most, which indicates a wide range of processes contributing to change between 1972 and 1981. This zone had many types of water bodies, including bayous, large lakes, small ponds, and areas beginning to break-up with a 'clumpy' appearance. In the intermediate zone, a decrease in shoreline density was detected in response to the cover change from transitional-to-land.

Distance-to-Water Classification

East Cove Study Site. It was hypothesized that changes which took place in the marsh between 1972 and 1981 were related to water. To accept this hypothesis, a correlation should exist between distance-to-water and the change of land cover. The co-occurrence of the type of change and specific distances-to-water was calculated. A total of 25.7 per cent of all vegetative zones changed. Of this, 27 percent occurred in the first 50 m from water (Table XII). The per cent of change (independent variable) was regressed against the distance-to-water (dependent variable) in which the change took place. A second-order regression analysis produced a high correlation with the r^2 value equal to 0.935 at a significance level of 0.0005. The possibility of rejecting the null hypothesis in error was extremely low. An exponentially, inverse relationship existed between the two variables. As the distance-to-water increased, the percent change de-

TABLE XI

PERCENT AREA, NET CHANGE, SHORELINE DENSITY TOTAL AND AVERAGE DENSITY FOR EACH ZONE

			Percent of Area		
	Class	1972	1981	Zone Change	Of Total
Fresh:	Land	72.82	40.41	-32.41	7.14
	Water	11.31	31.11	19.80	4.36
	SLID	15.87	28.48	12.61	2.78
SLID Total (m/4817 ha)		234,753	511,023	276,270	
SLID Average (m)		71.65	76.85	5.20	
Intermediate:	Land	80.87	75.55	- 5.32	1.28
	Water	6.46	8.25	1.79	0.004
	SLID	12.67	16.20	3.53	0.01
SLID Total (M/5255.5 ha)		179,120	241,451	62,331	
SLID Average (m)		66.83	64.23	-2.60	
Brackish:	Land	66.72	57.76	- 8.96	4.45
	Water	14.06	17.74	3.68	1.83
	SLID	19.22	24.50	5.28	2.62
SLID Total (m/10852 ha)		559,637	861,370	301,733	
SLID Average (m)		55.75	73.15	17.40	
Saline:	Land	75.51	44.61	-30.90	1.31
	Water	7.33	23.27	15.94	0.01
	SLID	17.16	32.12	14.96	0.01
SLID Total (m/928 ha)		48,147	96,906	48,759	
SLID Average (m)		75.80	82.10	6.30	

Note: The maximum misregistration error is $\leq$ 7.9 percent.

TABLE XII

PERCENT CHANGE AT DISTANCE-TO-WATER INTERVALS

Distance-to-Water(m)	% of Change	% of Total
50	27.1	7.0
100	13.5	3.5
150	7.4	1.9
200	5.8	1.5
250	6.8	1.8
300-500	3.5*	0.9*
550-750	2.1*	0.5*
800-1000	1.2*	0.3*
1050-1250	0.7*	0.2*
1300-1500	0.3*	0.1*
1500	0.1*	0.03*

*Average percent of change which occurred every fifty meters within the specified distance range.

Note: The maximum misregistration error is $\leq$ 7.9 percent.

creased at an exponential rate. A noteable exception developed 250 m from water. Slightly more change occurred at this distance, than at 200 m, although it was less than took place at 150 m. One explanation of this phenomenon is that intertidal lakes were beginning to form.

Vegetative Zones. The analysis of distance-to-water in the individual zones supported findings for the entire zone (Table XIII). The most change took place in the first 50 m, and decreased as the distance-to-water increased. The increase in change at 250 m was not exhibited in the intermediate zone.

Most of the change in the first 50 m, was from transitional-to-water, in the fresh and saline zones. These were typical deterioration responses as an area changes toward more open water. The intermediate zone exhibited a change atypical of deterioration responses, from transitional-to-land, in the first distance class. As noted before, water levels were controlled in this area. The dominant change within the first 50 m of the brackish zone was from land-to-water. The latter result was not as expected. A change directly from land-to-water would indicate a higher rate of deterioration, by skipping intermediate stages. This could result from variations in soils and rates of erosion, characteristics of vegetation, or the broader vertical tidal fluctuation in this zone.

Tide Level

A water model was developed to determine tide level in the marsh at the time of Landsat data collection, given the level at Cameron. Hourly data for October 14 - 25, 1982 was plotted for both Cameron and East Cove (EC2). It was noted that the readings at EC2 lagged behind

TABLE XIII

PERCENT CHANGE AT DISTANCE-TO-WATER INTERVALS, FOR EACH VEGETATIVE ZONE

	Fresh Zone		Intermediate Zone		Brackish Zone		Saline Zone	
DIST-to-water (m)	% Change	% Change of Total	% Change	% Change of Total	% Change	% Change of Total	% Change	% Change of Total
50	20.87	1.84	31.14	1.19	32.62	3.56	17.06	0.004
100	12.17	1.07	16.97	0.01	14.05	1.54	10.11	0.002
150	6.46	0.01	7.97	0.003	8.11	0.01	7.24	0.002
200	4.96	0.004	5.38	0.002	6.26	0.01	7.24	0.002
250	5.77	0.01	4.84	0.002	8.11	0.01	8.26	0.002
300-500	3.39*	0.003*	3.83*	0.001*	3.43*	0.004*	5.49*	0.001*
550-750	2.46*	0.002*	1.74*	0.001*	1.52*	0.002*	3.65*	0.001*
800-1000	2.13*	0.002*	0.01*		0.01*	0.001*	0.01*	
1050-1250	1.46*	0.001*	0.01*		0.003*			
1300-1500	0.003*		0.003*		0.002*			
>1500	0.002*		0.002*		0.003*			

*Average percent of change which occurred every fifty meters within the specified distance range.

Note: The maximum misregistration error is $\leq$ 7.9 percent.

Cameron data. A two, three, four, five and six-hour lag was applied to EC2 data. The data from a four-hour lag produced the best results. The correlation coefficient was 0.854. A linear regression analysis of EC2 (dependent variable) versus Cameron (independent variable) resulted in a r^2 value equal to 0.729 at a significance level <0.001. The regression weight (0.428) and the y-intercept (81.235) were used to determine the tide levels on the 1972 (5.45 ft) and 1981 (5.00 ft) collection dates. Both were below MML (5.68 ft), therefore, water acreages for either set should not have been signigicantly influenced by tide level. Considering that tidal fluctuation is attenuated as the distance to the Gulf increases, the effect of tide is greatly reduced with increased distance within the marsh.

Results From Analysis of Change Factors and Discussion

Salinity and precipitation data were analyzed to determine trends over time, and seasonal and site variations. Results showed that salinity did increase, although not for the entire nine-year period. Variation in salinity responds to the amount of precipitation. Water level data were analyzed to discover trends over a time period including the nine years being studied. Tide level data were analyzed to determine if the water level was above mean marsh level during the Landsat overpasses.

Salinity

Monthly Sabine salinity data were plotted for the study period (1972-1981), and revealed no definite trends. The entire length of record, a sixteen-year period from 1967 through 1982, was analyzed to better understand the variability. Data from the four stations were averaged to derive a salinity measurement for the study site (ECAVG). The numerical distributions of the monthly data appear in Table XIV. Five-year running averages of ECAVG, from 1967 - 1982 were plotted against time. Analysis of the data curve showed a dramatic increase occurred in late 1968 - 1969, then steadily decreased until 1974. The completion date for the last major dredging of the ship channel was October 1968. The peak indicated that the salt water wedge during this period had reached the study site. The highest salinities, during those early years, for individual months, were recorded (in ppt) at EC1, EC2, EC3 and EC6 as 32.07, 31.61, 21.68 and 29.81 respectively. This unusually high salinity level could have influenced fresher areas for a long time.

The five-year running average from 1974 - 1982 had a positive correlation with time (r=0.859). A linear regression analysis of salinity (dependent variable) and time (independent variable) produced an r^2 value equal to 0.738 at a significance level of 0.003, demonstrating that the salinity had increased during the latter portion of the study period.

Data for each salinity station were analyzed and compared by station and on a seasonal basis. EC1, EC2 and EC6 all exhibited the highest salinities in the fall, then summer and spring and freshest in the winter. EC3 varied the most but winter was always freshest. Generally, the seasonal salinity at each station, varied the most in 1967 and became less variable over the seasons until 1982.

TABLE XIV

NUMERICAL DISTRIBUTIONS OF 1967 - 1982 MONTHLY SALINITY DATA (PPT), N=144

Station	Mean	Standard Deviation	Coefficient of Variation
EC1	16.16	9.56	0.59
EC2	14.16	9.83	0.69
EC3	7.47	8.33	1.12
EC6	11.75	9.63	0.82
ECAVG	14.12	8.97	0.64

Comparison of seasonal salinities between stations always showed EC1 the most saline and EC3 the freshest, with the exception of spring, when EC6 was sometimes freshest. EC6 and EC2 showed a reverse in position of salinity levels. EC6 was most saline of the two in the winter and most summers. EC2 was most saline in the spring and fall. The variations could be due to precipitation, winds, and distance to the Gulf's saline waters. It was observed that precipitation and winds were highly variable, leading to variability in salinity. It was apparent that the waters closer to the Gulf were more saline than those furthest from the Gulf.

The salinity data collected by Materne (1982) and the Sabine National Wildlife Refuge, were compiled to produce an isohaline map of the water salinities in a portion of East Cove for the summer of 1982. The salinity zone ranges, established by Gosselink et al., (1979) were located on the isohaline map to produce the map for figure 18. Since the zone salinity ranges overlapped, there were no distinctive boundaries. Comparison of this map with the vegetative map by Gosselink et al. (1979), (see Figure 7), revealed that the water salinities were nearly one zone advanced over vegetative-type salinities. Although this observation is qualitative, it suggests that the marsh vegetation has been modified or has deteriorated because of the salinity levels.

Precipitation

Judging by the variability of salinity data, it was hypothesized that an analysis of the relationship between salinity and precipitation might reveal an inverse relationship. The average monthly precipitation from 1967 - 1982 was 12.50 cm, the standard deviation

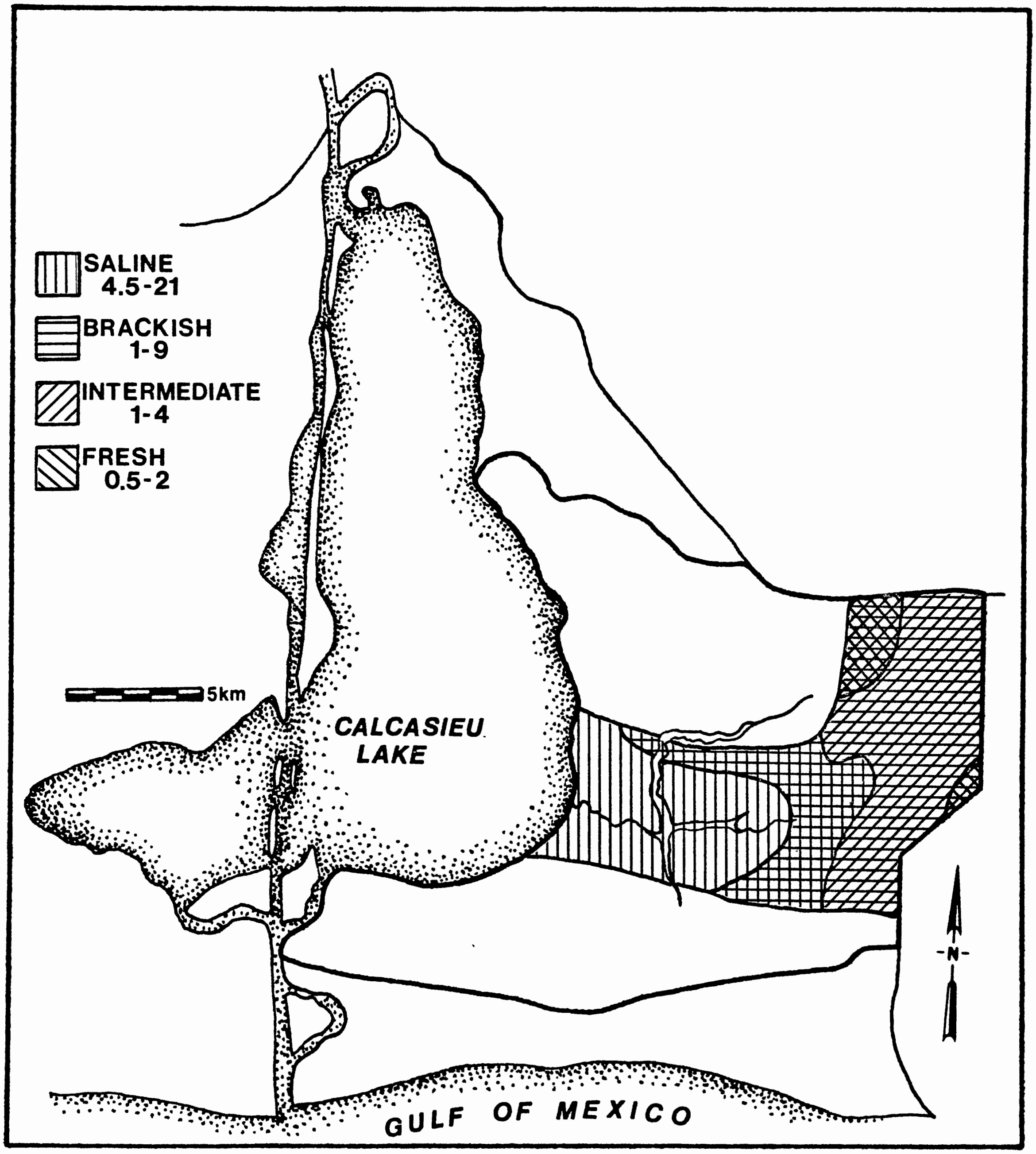


Figure 33. Water Salinities (ppt) for March-August, 1982 Based on Salinities for Vegetative Zones (Gosselink et al., 1979)

Sources: Sabine Wildlife Refuge and M. Materne was 8.46 cm and the coefficient of variation (COV) was 0.64. A five-year running average of the annual average precipitation was used in a linear regression. The ECAVG salinity (dependent variable) and precipitation (independent variables) were poorly correlated (r^2=0.46) from 1967 - 1981. The temporal aspect of the two sets of data was analyzed to determine trends by including time as an independent variable in a multiple linear regression. The data exhibited a high correlation (r=-0.92) between 1974 and 1982. The r^2 value equalled 0.853, and was significant at the 0.003 level. Precipitation in combination with time explains up to 92 percent of the variability in salinity levels between 1974 and 1982. Seasonal precipitation showed that summers were wettest, followed by fall and spring, while winter months had the least precipitation. On the whole, summer rainfall amounts increased from 1972 to 1981, and fall, spring and winter amounts decreased. Although, spring rainfall increased moderately from 1977 to 1981. The amount of precipitation received throughout the year varied the least in 1972, and then seasonal amounts became more variable up to 1977 and leveled out through 1981 (Figure 34).

Water Level

Trend analysis of water level (from 8 a.m. readings) at Cameron over a 16-year period, indicated that a parabolic relationship existed between water level and time, with a peak in 1975. The average water levels, in meters above sea level, for 1967 - 1971, 1972 - 1980, and 1981 - 1982 were 0.27, 0.40, and 0.31, respectively. Comparison of their graphs showed that precipitation data did not correlate well with water level, and salinity levels seemed to be the lowest during

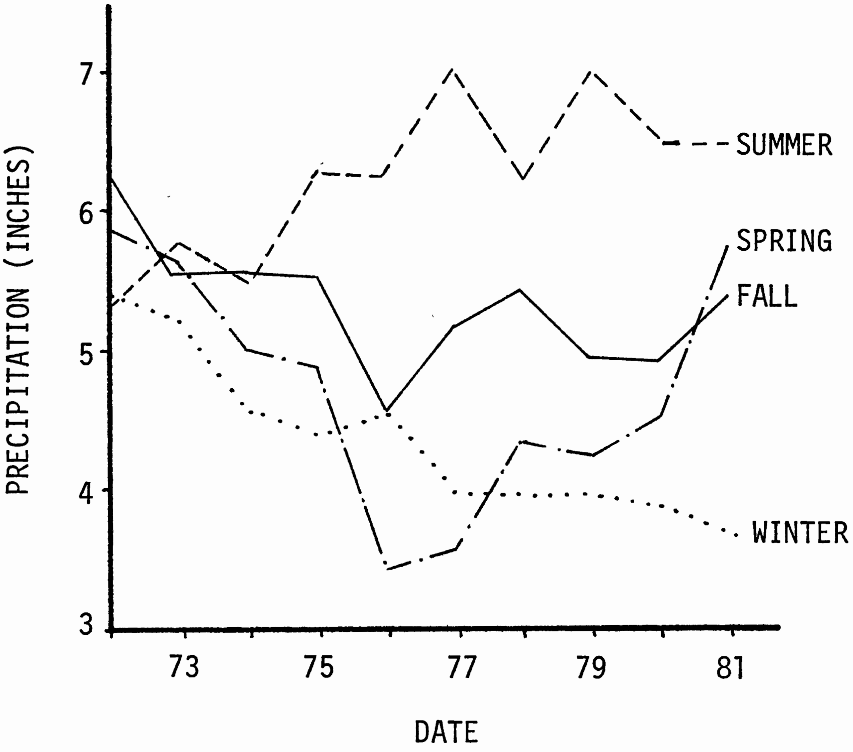


Figure 34. Monthly Seasonal Precipitation Averages, 1972-1981

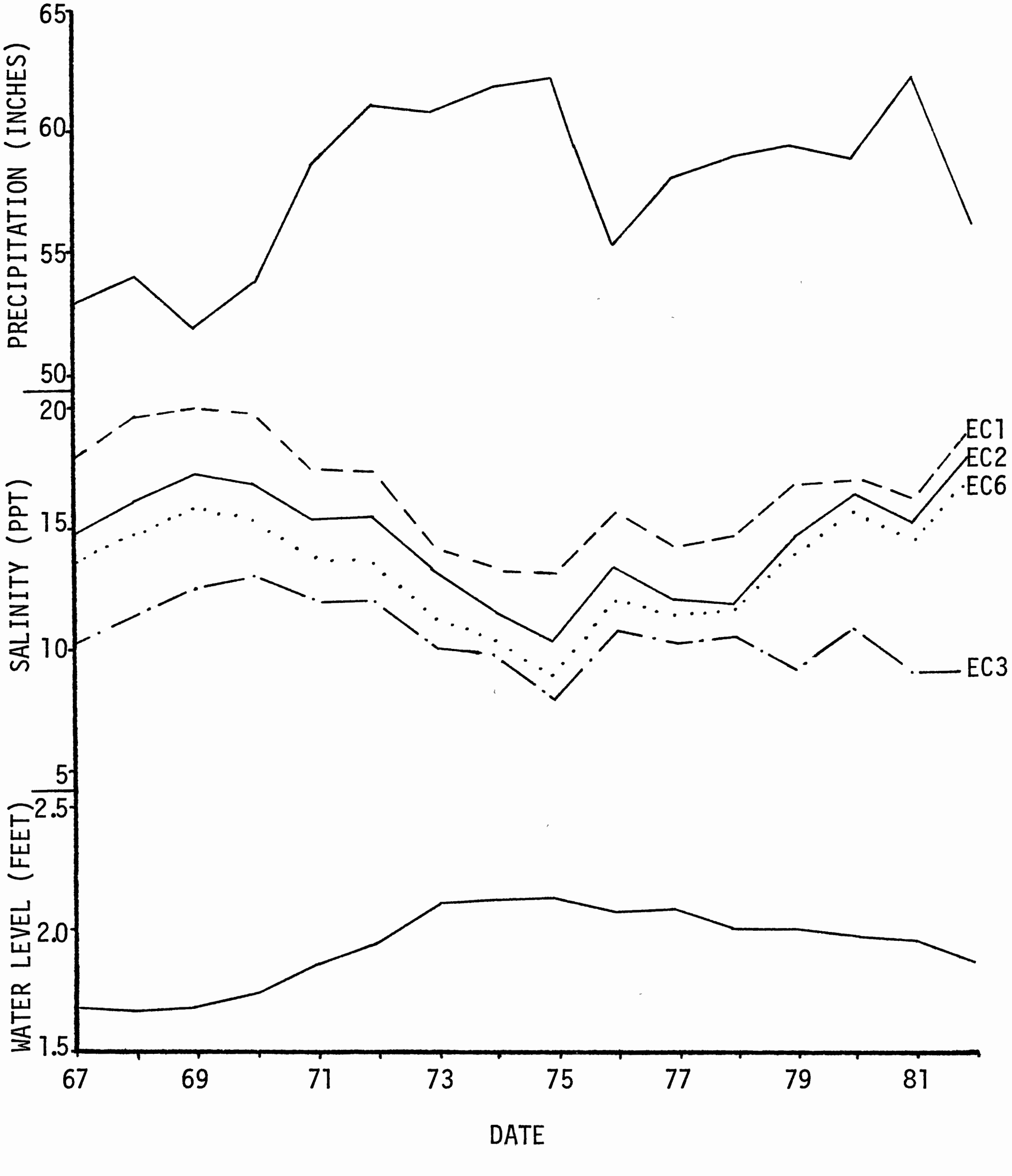


Figure 35. Five-Year Running Annual Averages for Precipitation, Salinity, and Water Level, 1967-1982

the years with the highest water levels (Figure 35). Analysis of seasonal data revealed that average summer water levels were highest, followed by spring, fall and winter (Figure 36). Fall levels were the most variable.

Summary and Conclusions

In summary, the analyses of Landsat data produced the following results:

1. The marsh was deteriorating and becoming more of an open water ecosystem.
2. The rates of change were different for each zone; the freshwater zone had the highest rates of deterioration.
3. The intermediate zone trended toward more land area because of water level control.
4. Shoreline length increased in all zones, although not always in proportion to the amount of water.
5. Total shoreline density increased in all but the intermediate zone where transitional areas returned to land cover-classes.
6. Average shoreline density increased, indicating that more complex shorelines dominated shoreline type.
7. Most of the change developed within the first 50m from water, and exponentially decreased as the distance-to-water increased.
8. An increase occurred in the amount of change at 250m, possibly indicative of enlarging intertidal lakes.

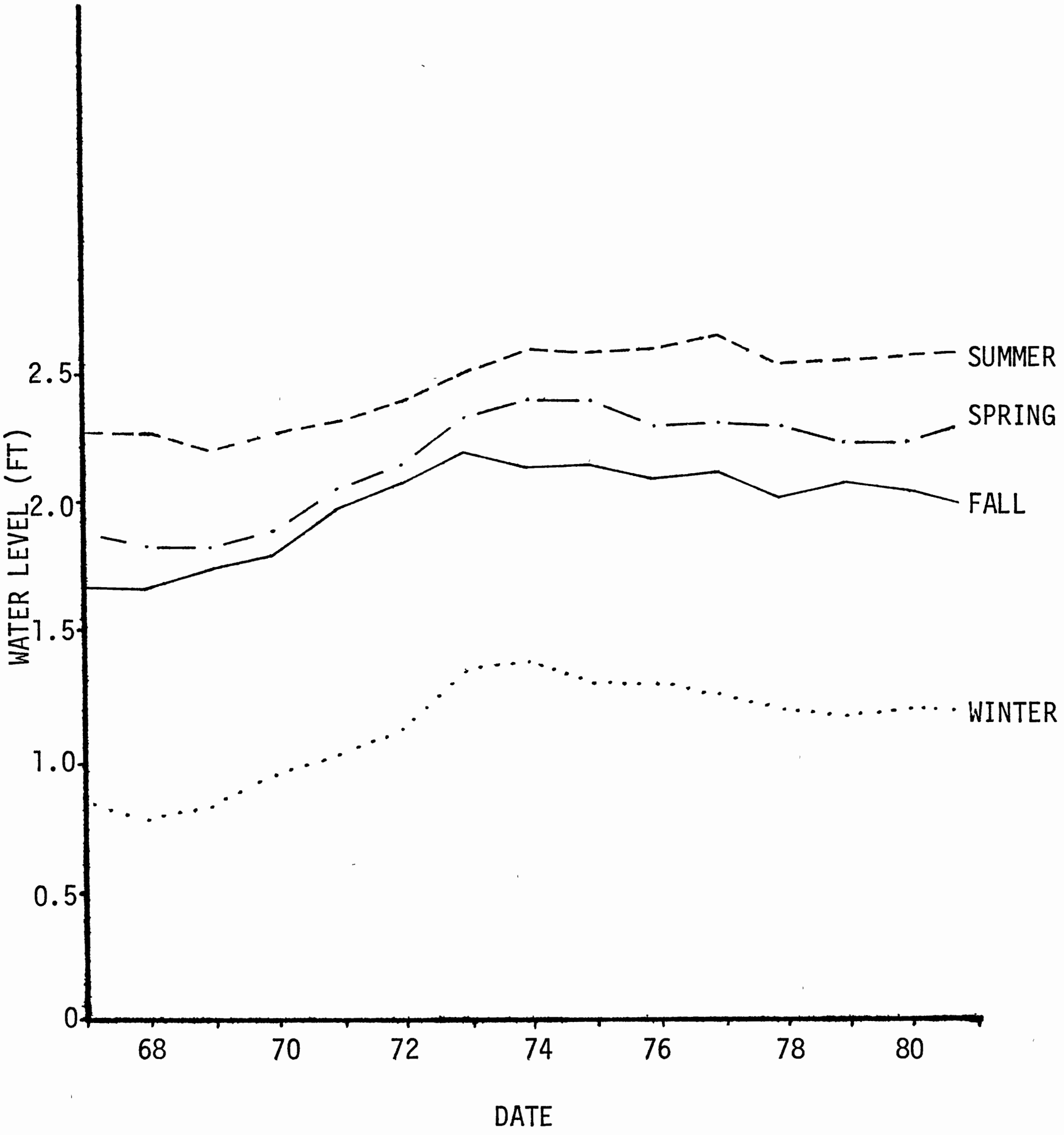


Figure 36. Five-Year Running Seasonal Averages for Water Level, 1967-1981

A summary of the ancillary data indicated that:

1. Water salinity levels in the marsh peaked immediately following the ship channel dredging (1968-1969) and then gradually increased from 1974 to 1982.
2. Water salinity levels, determined for the summer of 1982, increased across the marsh and advanced one zone over vegetative zones.
3. Precipitation in combination with time explains 92 percent of the variability in salinity levels between 1974 and 1982.
4. Although water level did not appear to correlate with salinity or precipitation upon viewing their graphs, the extremes exhibit a nearly inverse relationship between salinity and water level.
5. Seasonally, salinity does not have an inverse relationship with precipitation or water level, though they show some annual correlation.
6. Analysis efforts indicated that the tide level in the marsh during Landsat acquisituion was below MML, and there fore, did not appreciably affect the amount of water acreages calculated.

Many researchers have noted that Louisiana marshes are becoming more open water ecosystems (O'Neil, 1949, Fogarty, 1965 and Morgan, 1972). When the results of Landsat and ancillary data were compared, some indication of the causes of change in the East Cove Marsh were detected. The change to a more open water environment shown by satellite data could have been caused by the increased salinity levels from 1974 - 1981. Another set of Landsat data for the period between 1972 and 1981 may have helped to more accurately define when the change occurred and to establish a rate of change. The increase in salinity immediately following the dredging of the ship channel could have caused change to take place years later. As Brupbacher (1973), McMillan (1974), and Mudie (1974) suggested, plants adjust slowly to changing salinities. The 1982 water salinity map, which included some of the water areas in East Cove, showed that the water salinities had advanced approximately one zone over the vegetative salinities. This indicated that increasing salinities in each zone has and will continue to change the marsh. The freshwater zone incurred the most change because: (1) salt tolerance was lower; (2) cell structure in fresh species was more fragile and broke down more rapidly; and (3) less sediments existed to fill-in eroded or subsiding areas.

More important than gradual change in level of salinity in the water was the process of deterioration. The fresh zone is in advanced stages of deterioration, as shown by the presence of ponds and lakes. The brackish, intermediate and saline zones had intertidal lakes forming, and _Spartina patens_ in clumpy vegetative growth forms, shown by analysis of aerial photography and ground truth data. As suggested by Baumann (1983), once marshes reach this stage in deterioration, revegetation rarely occurs, unless water and salinity levels are lowered. Again, the intertidal lakes were a direct result of salinity levels for some period of time (O'Neil, 1949 and Fogarty, 1965). The heavily dissected and 'clumpy' areas were increasing in size. The increase in shoreline length and average shoreline density also revealed that marsh was deteriorating during the study period. If these conditions continue, average shoreline density would decrease as clumpy areas would deteriorate and become open water.

The water level for each Landsat data was determined to be below MML. The water level, however, varied at the time of Landsat data collection, hense, the area inundated may have been slightly affected. Graff (1976) noted that water level could cause problems because of Landsat's resolution. Although the water was not above MML, water saturation of the soil would vary. The soil would absorb energy differently, thereby creating mixed signals and misclassification. Part of the change which took place in the first 50 m could have been from misclassification because of the effect of water level, althought the water level was below MML.

Salinities were highly variable, so the exact impact on the marsh was not certain. Water level and, to a larger extent precipitation, did have an effect on this variability. The salt wedge could successively intrude deeper into the marsh. An unusually wet year, however, could bring the salinities lower than normal, instead of increasing. Other variables may have played a role in altering the marsh, although only the variables used in this study were documented well enough and contained a sufficient number of replicates for statistical analysis.

Baumann and others (1983) suggested that marsh salinity levels had not increased appreciably in the last 30 years. They determined that aggradation had not kept pace with submergence in a portion of East Cove. This factor may have contributed to change in the entire East Cove Marsh, although it did not seem likely that the vast changes were due solely to an imbalance in those processes over the nine-year period studied. Others (Adams et al., 1976) have had difficulty in short term change detection in a marsh. Erosion, geologic factors, and sea level fluctuation (increase) would all play some part in any change. The portion of East Cove investigated in the Baumann study was located in the saline zone, which as mentioned earlier, exhibited changes far different from the remainder of the marsh. These differences occurred because of: soil characteristics; water salinities; and hydrology. The saline area, the nearest zone to the ship channel, is more directly influenced by the Gulf salinities and tidal fluctuations. One variable that could have been a key factor of the apparent change across the entire marsh was sediment fluctuation because of the lack of sediment sources, and reduced water velocities. The slow bayou waters decrease in velocity and may have dropped their sediment load before reaching the fresh zone. Thus, subsidence and die-backs may have continually lowered the surface with no revegetation. This variable was not measured for the entire marsh, and therefore cannot be accepted as the causal factor.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The idea of a simple comparison of multitemporal Landsat images of the same area can become a difficult task, considering the characteristics of the satellite data and the complexities of the environment being studied. By manipulating the digital reflectance values collected at two moments in time, change was detected in the East Cove Marsh. The water area increased across the entire marsh, with the largest portion of this change taking place in the fresh zone. The cause of increased water acreages could have been initiated by increased salinities or an increase in water level, due to lowering of the marsh substrate.

The water salinities advanced spatially by the summer of 1982 by approximately one vegetative salinity zone. The water salinities increased after the ship channel dredging, and from 1974 to 1982. Ground water withdrawal could have had a tremendous impact in lowering the marsh and aiding in salt water intrusion. Lower precipitation levels could also have increased salinity concentrations. The water interface is dynamic, therefore, a large amount of change at 50 m from water was expected, then decreasing change as the distance-towater increased. The increase in change at 250 m from water, however, was not expected, but can be explained by the formation of intertidal lakes. Although many of the variables studied could have been a major factor causing the marsh to change, the data were not sufficient to prove that a causal relationsip existed.

Limitations of the Study

The major problem encountered during the study was meshing ancillary data collected for other purposes. The ancillary data were utilized in an attempt to assess and evaluate temporal change. The Sabine salinity data were collected only once a month, on an unknown day, at locations which did not cover the entire marsh; but the length of record was impressive. Salinity data collected by Materne (1982) were not replicated enough to statistically determine a spatial relationship between salinity and change. The samples, however, covered the majority of the marsh water areas, and were useful in a qualitative analysis of the 1982 salinity map.

The water level data used for the long term analysis were collected at 8 a.m. during various tidal stages. The location of data collection, however, was outside of the marsh and, therefore, was difficult to correlate over a long time period.

The precipitation stations were not located within the marsh boundaries. The basin precipitation was determined from three outlying stations, but may have been independent of measured values. Daily precipitation records for an extensive time period outweighed the locational difficulties.

The vegetation maps were noncoincidental with Landsat data. It was believed that the zones had not changed appreciably, by comparing small scale 1949-1978 maps of Louisiana. If they had changed, errors might be introduced in locating zone boundaries.

Processing Landsat data involved many prolems before analyses of the results could take place. Picking points for the georeferencing procedure was difficult in the uninhabited marsh. The rms error was magnified for the 1972 data set because error occurred in the scene-to-scene registration. A slight misalignment between the two images could have greatly affected small or linear features such as, ponds, islands, transitional areas and shoreline.

Some misclassification error was inevitable, considering Landsat's acre cell size and the complexity of the marsh environment. The photography used to judge the computer classification, was non-coincidental with Landsat data, so it is difficult to answer the questions relating to cover-type of the 1972 or 1981 data.

Recommendations

Many researchers are involved in studing the dynamics in the East Cove Marsh and other Louisiana marshes. Many variables must be considered in detecting change. The analysis of change for the period of time between 1972 and 1981 would have been more conclusive, if more salinity data were available for the study period, and if the data format was more compatible with the other data formats.

Future studies should be based on data collected across the entire marsh on a time frame suitable to study spatial and temporal variations and extremes in salinity concentration. Precipitation, water level, current velocity, soil samples, and vegetative species should also be obtained coincidentally. Landsat data should be obtained for two or more dates at the same tidal stages, and coincidentally with photography.

Further research conducted in more contolled environments might lead to a better understanding of plant - salinity associations. Wide salinity fluctuations and the matrix of complicating factors in natural settings would deter the direct applicability of lab results to actual field observations.

Data from this study could be used and compared to Landsat data during an interim period between 1972 and 1981 to determine the rates of change. Marsh burns were readilly apparent upon visual analysis of Landsat data. Landsat could be used to locate and map exact burn boundaries before they recover.

A levee was installed along the entire interface of Calcasieu Lake and the East Cove Marsh, during 1982 and 1983, and the levee along Creole Canal was reconstructed for the purpose of returning the marsh to a fresh water ecosystem. The only opening for water exchange is the mouth of Grand Bayou. Soon, a low level weir will be place at the mouth and used to control the water level within the marsh. Even before this installation, samples taken during the spring of 1983 showed that the hydraulic pressure had built up in the marsh, because the incoming tidal velocity and periodicity had been greatly reduced. What effect will the weir have on the marsh? Will it initiate a return to a fresh-type marsh? Will it become open water? Will the present open water revegetate? This investigation forms a base to use for future change detection studies to measure the effect of the weir.

Concluding Statement

The East Cove Marsh a dynamic environment, has more open water in 1981 than in 1972. Many of Louisiana's wetlands are undergoing similar changes. Human impact on the marshes is becoming increasingly important. The effect of salinity on aquatic vegetation is not completly understood, and the intraction with other environmental variables may complicate the problem. Although salinity has played an important role in influencing deterioration in the East Cove Marsh, this conclusion was equivocal. Causal factors must be quantified in change detection studies in order to improve management decisions concerning coastal wetlands.

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APPENDIXES

APPENDIX A

ORIGINAL AND TRANSFORMED REFLECTANCE VALUE STATISTICS FOR 1972 AND 1981 LANDSAT DATA

TABLE XV

		Original		Rescaled As	Transformed	
Date	Channel	Mean	Standard Deviation		Mean	Standard Deviation
1972	1	26.75	2.83	9.81* old-176.5	75.99	27.79
	2	18.53	4.01	9.44* old- 94.4	71.10	37.91
	3	27.49	10.27	5.31* old- 31.8	108.87	54.57
	4	13.43	6.45	879* old +0	109.30	56.69
1981	1	14.44	2.77	12.14* old-85.0	78.24	33.59
	2	15.24	4.15	8.50* old-42.5	78.55	35.31
	3	31.53	13.41	4.25* old-4.25	125.50	57.01
	4	31.87	15.98	4.05* old +0	125.11	64.38

APPENDIX B

SEARCH PARAMETERS

Number of Channels: 4
Channels: 1, 2, 3, 4
Standard Deviation Lower Bound: 0.0001 (0.1)
Standard Deviation Upper Bound: 10 (1.0)
Coefficient of Variation: 10 (5)
Maximum to Delete: 4
Maximum Classes: 60
Scaled Distance: 4 (3)
Number of Bins: 60

Note: The standard default parameters which were not employed, appear in parenthesis.

APPENDIX C

TWO-SPACE PLOTS OF CHANNEL TWO VS. CHANNEL FOUR, FOR 1972 AND 1981

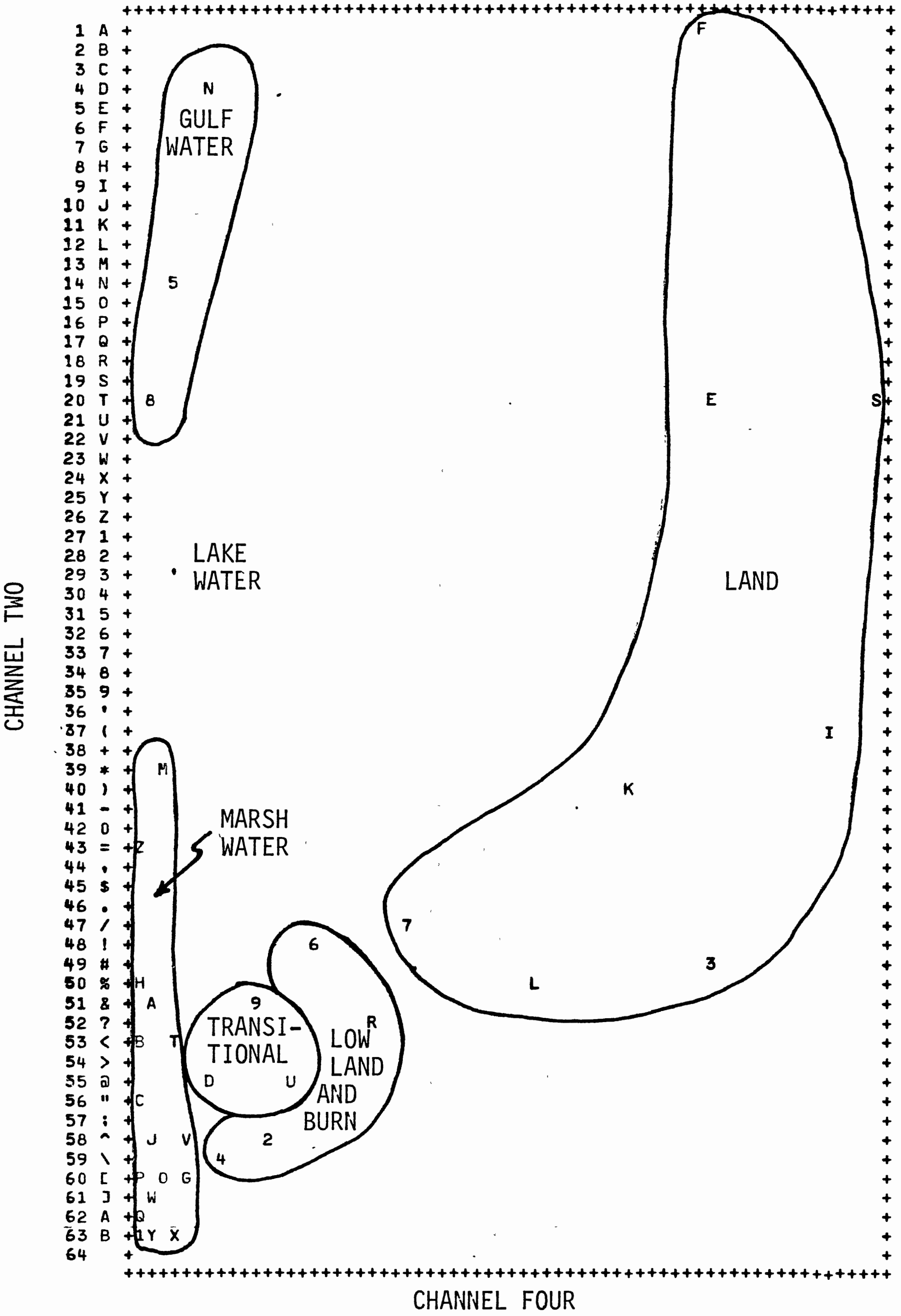

Figure 37. Two-Space Plot of Channel Two Vs. Channel Four, 1972 Landsat Data

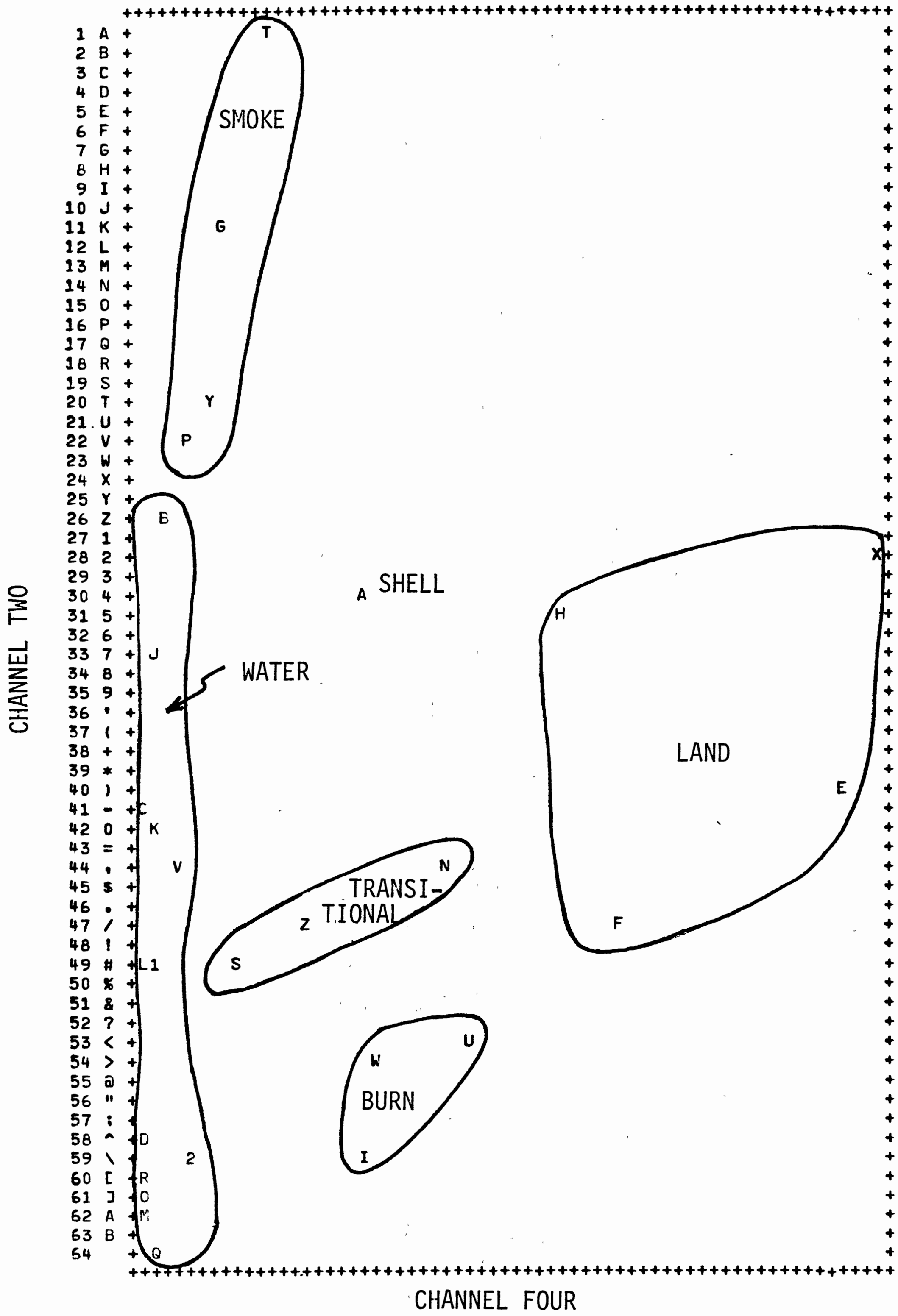

Figure 38. Two-Space Plot of Channel Two Vs. Channel Four, 1981 Landsat Data

APPENDIX D

BASIC RUN-STREAMS, INDEX TABLES AND POSSIBLE OUTPUT FOR CHANGE DETECTION

TABLE XVI

RUN-STREAM USED TO DETERMINE ANY CHANGE

```
10  IF(CH2 - CH1) 20(neg.), 40(zero), 20(pos.)
20  CHO = 1
30  RETURN
40  CHO = 0
50  RETURN
60  END
```

Index Table

	1981 (CH1)	1972 (CH2)
Unclassified	0	0
Water	1	1
Land	2	2
Transitional	3	3

Possible Output:

CHO = 0 = no change
CHO = pos. or neg. = change

TABLE XVII

RUN-STREAM USED TO DETERMINE NATURE OF CHANGE

```
10  CHO = CH1 + CH2
20  RETURN
30  END
```

Index Table:

	1981 (CH1)	1972 (CH2)
Unclassified (U)	1	3
Water (W)	2	9
Land (L)	4	27
Transitional (T)	6	81

Possible Output:

1972	to	1981		1972	to	1981	
U		U	= 4	L		U	= 28
U		W	= 5	L		W	= 29
U		L	= 7	L		L	= 31
U		T	= 9	L		T	= 33
W		U	= 10	T		U	= 82
W		W	= 11	T		W	= 83
W		L	= 13	T		L	= 85
W		T	= 15	T		T	= 87

APPENDIX E

SHORELINE CLASS COEFFICIENTS

TABLE XVIII

Class					
1-5		0	0.227924	0.455848	0.455848
6-10	0.683772	0.683772	0.683772	0.719674	0.719674
11-15	0.911696	0.911696	0.911696	0.947598	0.947598
16-20	0.947598	0.947598	0.983500	1.139620	1.139620
21-25	1.175522	1.175522	1.175522	1.175522	1.211424
26-30	1.211424	1.367544	1.367544	1.403446	1.403446
31-35	1.403446	1.403446	1.439348	1.439348	1.439348
36-40	1.439348	1.439348	1.631370	1.631370	1.631370
41-45	1.631370	1.667272	1.667272	1.703174	1.703174
46-50	1.823392	1.823392	1.823392	1.823392	1.895196
51-55	1.895196	1.967000	2.087218	2.087218	2.087218
55-60	2.087218	2.087218	2.087218	2.087218	2.087218
61-65	2.351044	2.351044	2.351044	2.351044	2.735088
66-70	2.735088	2.735088	2.735088	2.735088	2.735088

VITA

2

Amanda Lu Frick

Candidate for the Degree of

Master of Science

Thesis: DETECTING CHANGE IN A LOUISIANA GULF COAST MARSH USING REMOTE SENSING

Major Field: Geography

Biographical:

Personal Data: Born in Clare, Michigan, March 2, 1957, the daughter of Mr. and Mrs. D. L. Frick.

Education: Graduated from Davison High School, Davison, Michigan, in June, 1975; received Bachelor of Science degree in Physical Geography from the University of Michigan - Flint in 1980; completed requirements for the Master of Science degree at Oklahoma State University in May, 1984.

Professional Experience: Federal and State Grants Clerk, C.S. Mott Community College 1976-80; Geologic Seismic Clerk, Shell Oil Company, 1980-81; graduate teaching and research assistant, Oklahoma State University, 1981-82; Co-op student trainee and temporary geography appointment, National Aeronautics and Space Administration/Earth Resources Laboratory, 1982-84.