OCS Study
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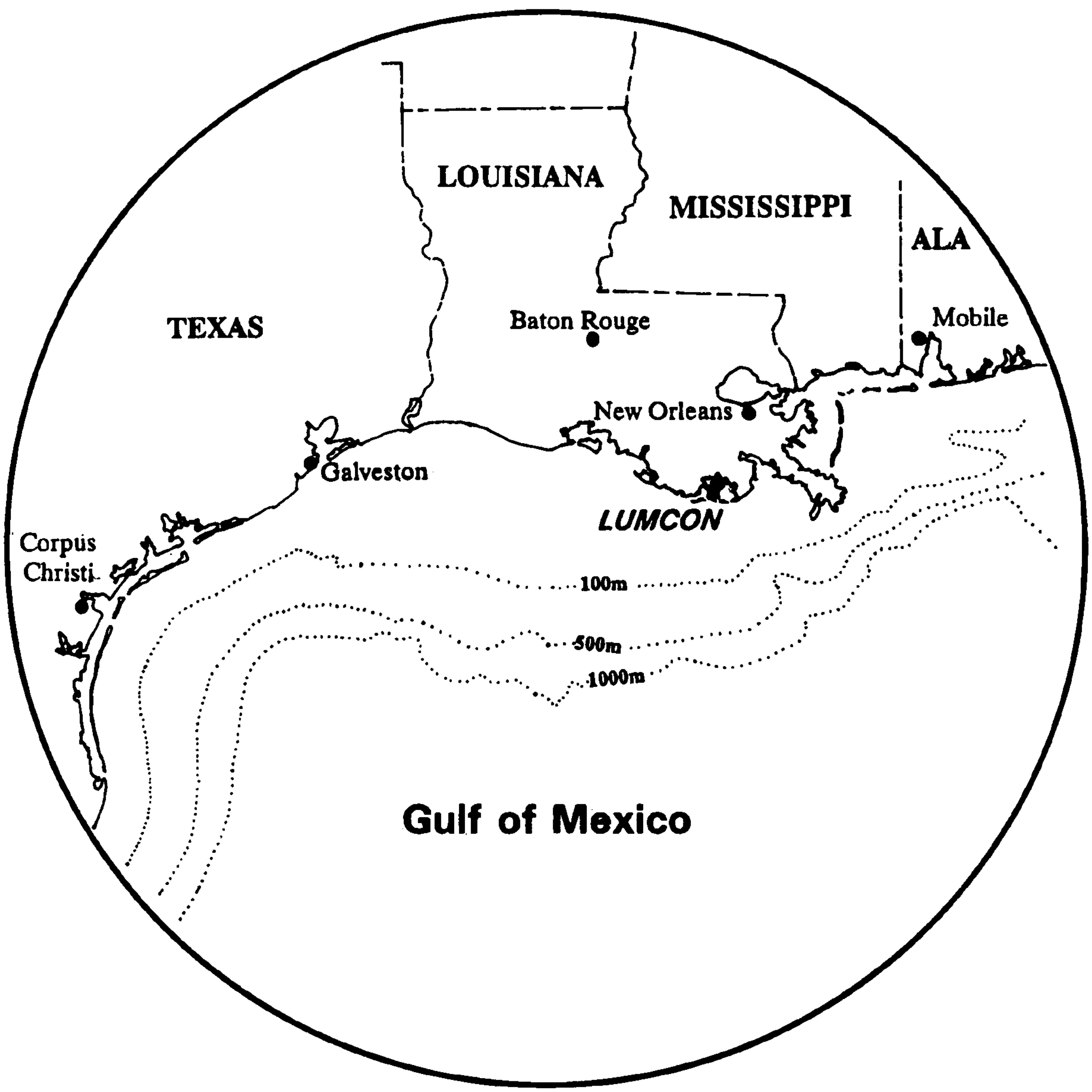
Recovery of a Deltaic Barrier Island to Hurricane and Oil Spill Impacts in Coastal Louisiana



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Cooperative Agreement
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Recovery of a Deltaic Barrier Island to Hurricane and Oil Spill Impacts in Coastal Louisiana

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ABSTRACT

Oil spills can have significant acute and long-term impacst on coastal marshes. Longer term effects and eventual recovery are not well documented. In addition, natural disturbances such as strong winds from storms and hurricanes may have a confounding effect on the recovery of coastal salt marshes from oil spill impacts. The overall goal of this project was to evaluate the effects of the 1992 Greenhill Petroleum Corporation oil spill and Hurricane Andrew on salt marsh recovery on East Timbalier Island, a deltaic barrier island in coastal Louisiana and the extent to which this recovery was influenced by the hurricane that occurred one month prior to the oil spill.

The project objectives were accomplished through a combination of landscape scale and community scale analyses. The landscape scale analysis relied on remote sensing/image analysis procedures and field surveys. Large-scale changes in island geomorphology, marsh habitat, and oiling were documented with pre- and post-disturbance imagery (1990, 1992, and 1993) in conjunction with field surveys (1992 and 1993). The community scale analysis required quantitative field sampling to evaluate responses in live aboveground biomass, dead aboveground biomass, total aboveground biomass, live to dead aboveground biomass, height of plants, live vegetative cover, dead vegetative cover, total vegetative cover, and soil hydrocarbon content.

Generally, the landscape analysis indicated that Hurricane Andrew had a profound effect on island land cover and morphology. East Timbalier Island's land mass decreased by 25% between 1990 and 1992 and its previously continuous shoreline changed to a fragmented one after the hurricane. Most of this land loss occurred on the extreme east and west end of the island and in the mid section of the island between the seawalls. One year after hurricane impact, the island's morphology had continued to change due to the reworking of sediment by storm surges and local changes in the hydrodynamics where the hurricane had previously breached the island.

Both the landscape and community scale analyses showed that the post-hurrican oil spill had minimal effect on island vegetation. The 1993 landscape scale analysis detected some changes in vegetative cover in areas where oiling occurred in 1992. In addition, the field surveys identified several additional small areas where oil had a negative effect on land cover. The community scale analysis detected fine-scale vegetative responses to the oil spill. However, this investigation indicated that the post-hurricane coastal processes controlling island morphology did not appear to have an effect on salt marsh recovery to the Greenhill Petroleum Corporation oil spill.

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INTRODUCTION

Although oil spills often have significant acute impacts on coastal marshes (Cowell 1969; Stebbings 1970; Baker 1973; Lytle 1975; Bender et al. 1977; Hershner and Moore 1977; Hampson and Moul 1978; Holt et al. 1978; Hershner and Lake 1980; de la Cruz et al. 1981; Webb et al. 1981; Webb et al. 1985; Mendelssohn et al. 1990), longer term impacts and eventual recovery are not well documented. Furthermore, the confounding effects of natural disturbances, such as strong winter storms and hurricanes (both frequent phenomena in the Gulf of Mexico), on the recovery of coastal salt marshes from oil spill impacts are unknown.

Because oil spill impacts do not occur in isolation, a thorough understanding of oil spill effects and habitat recovery cannot be attained without considering these accompanying disturbances. Impacts from such disturbances can be acute and long term as well and could include stressed or destroyed vegetation and habitat loss or alteration. Thus, the occurrence of an imposing Category 3 hurricane on 26 August 1992 (Hurricane Andrew) and a 96,000-gallon crude oil spill on 29 September 1992 (SL PP 192 well no. 250 oil spill–Timbalier Bay field), both impacting the salt marshes of East Timbalier Island, Louisiana, provides an excellent opportunity to evaluate the interacting effects of these two major disturbances on salt marsh impact and recovery (Figure 1). This investigation has value from an applied research standpoint, e.g., oil impacts and factors controlling recovery, as well as from a basic science standpoint, e.g., the effect of natural and human-induced disturbances on ecosystem stability and resiliency (rate of recovery).

Greenhill Petroleum Corporation Oil Spill

At 4:30 p.m., on 29 September 1992, loss of well control during workover operations at well no. 250, in Timbalier Bay, Louisiana, resulted in the discharge of crude oil into bay waters. The wellhead, owned and operated by Greenhill Petroleum Corporation (GPC), is located about one mile north of East Timbalier Island. On 1 October 1992, the well ignited as crews were preparing to cap the well. An intense fire engulfed the drilling rig and workover barge preventing crews from reaching the wellhead to control the blowout. The well was capped at 4:20 p.m. on 9 October 1992.

Estimates from GPC and the U.S. Coast Guard (USCG) indicate the well lost about 600,000 gallons over 11 days. Although the majority of the oil flowing from the well was consumed by the fire, approximately 96,000 gallons of oil were discharged into Timbalier Bay. GPC immediately attempted to contain and recover the spilled oil that threatened sensitive wetlands and fish and shellfish habitat in the bay as well as birds that rest and feed on the barrier islands. Because of brisk 20–25 knot northeast winds during the first days of the spill, oil escaped from the containment booms and spread southwest toward the west end of East Timbalier Island and into the Gulf of Mexico through Little Pass Timbalier. Shifts in wind and tidal current directions during subsequent days resulted in the continued oiling of East Timbalier Island and the barrier islands to the west of East Timbalier Island. The USCG estimated that about 4,000 gallons of crude oil washed ashore on East Timbalier Island. Minor amounts of oil were reported at the islands to the west: Timbalier, Caillou, Brush, Casse Tete, and Calumet islands (Figure 1).

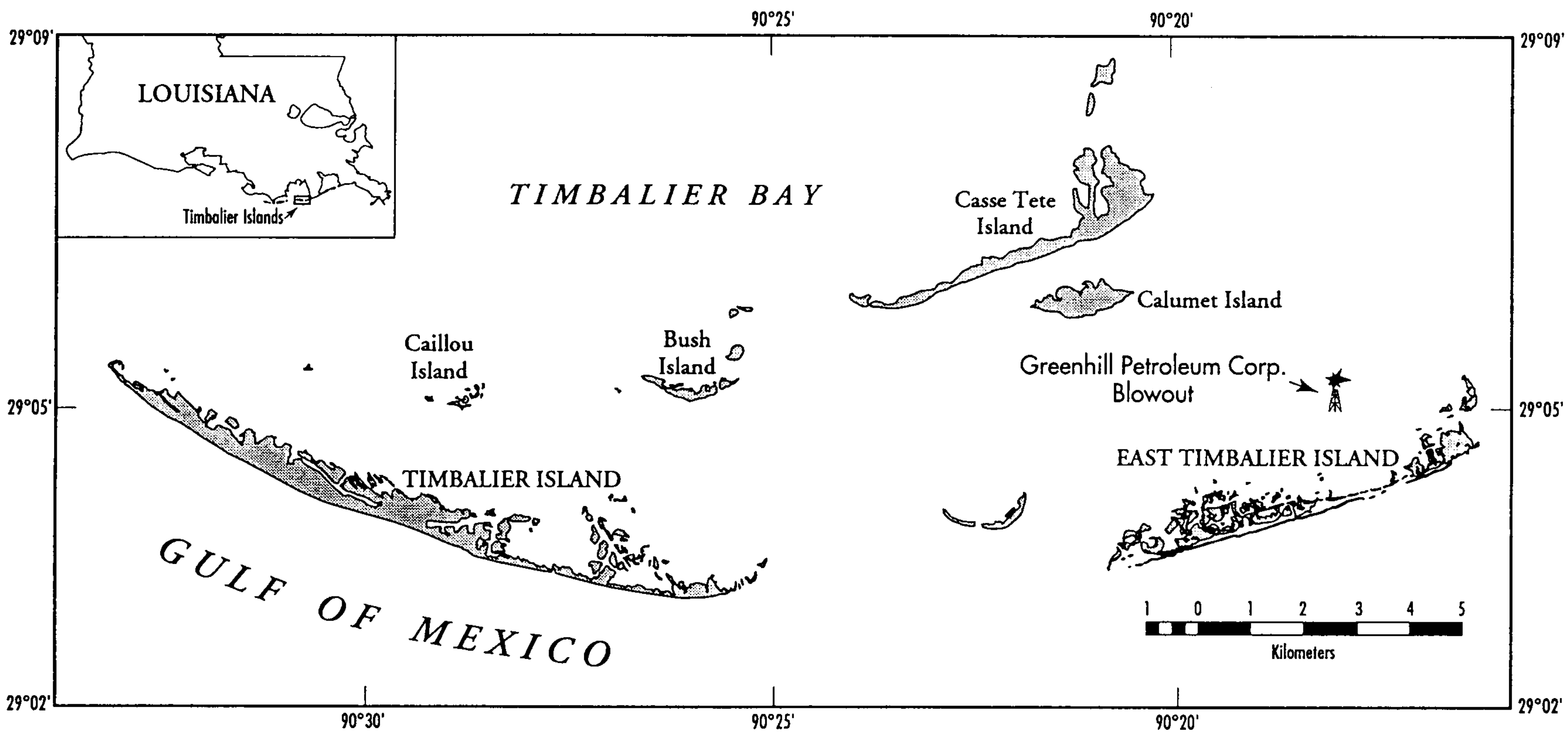

Figure 1. Location map of study area.

The distribution of oil on East Timbalier Island was a function of the area's coastal geomorphology and ecology as well as local weather conditions and oceanographic processes over the 11-day period (Debusschere et al. in preparation). During the initial oiling of the west end of East Timbalier Island, the water levels were high, and as the oil moved throughout the island only the upper half of the marsh plants were oiled. After the high water levels subsided, the marshes typically developed a "bathtub ring" that coated the lower half of the marsh vegetation. Under normal tidal conditions, oil became pooled within the salt marshes, on the beaches, and on coastal structures. Oiling on the other islands in the area was relatively light, consisting mainly of oil sheen in salt marsh areas, a "bathtub ring" that coated parts of the marsh plants, and occasional patches of black oil.

Cleanup efforts concentrated on skimming in Timbalier Bay and shoreline cleanup on East Timbalier Island by using sorbents that collected oil as it flushed out of the salt marshes. By 12 October 1992, only small patches of retrievable oil remained on East Timbalier Island, and there was no recoverable oil in the bay. During the final phases of the cleanup, crews used sorbent boom and viscous sorbent sweep along parts of East Timbalier Island to collect any residual oil that washed out of the marshes. The cleanup was completed by 20 October 1992.

Hurricane Andrew

Andrew entered the Gulf of Mexico as a Category 3 strength hurricane (Saffir/Simpson scale) on 24 August 1992 and was upgraded to a Category 4 hurricane while moving westward into the gulf. The storm approached the Louisiana coastline with sustained winds of 63 meters per second (m/s). Andrew was downgraded to Category 3 status as it entered the Atchafalaya–Vermilion Bay Complex, prior to landfall along the Louisiana coast. Andrew made landfall at approximately 3 a.m. on 26 August 1992 approximately 40 kilometers west-southwest of Morgan City (Grymes 1992); sustained winds were estimated at 54 m/s at that time. After landfall, Andrew's trajectory shifted to a more northerly direction, moving inland and weakening in strength to a Category 1 status and finally a tropical depression within 24 hours after landfall.

Stone et al. (1993) conducted a chronological overview of the climatological and hydrological aspects of Hurricane Andrew based on a review of offshore wave, wind, and sea level pressure data (National Data Buoy Center [NDBC] deepwater buoys), water level data (Louisiana Department of Natural Resources and the U.S. Geological Survey, Water Resources Division gaging stations [LDNR/USGS]), and wind speed and sea level pressure data (Coastal Marine Automated Network [C-MAN]) recorded at stations along the Louisiana coast. According to their study, East Timbalier Island, located approximately 90 km to the north and east of Andrew's storm track, was subjected to drawdowns and surges in water levels as the storm passed through the area.

Waves as high as 6 m with 17 second swells were recorded at offshore buoys during Andrew's passage in the Gulf of Mexico. Although these peak wave heights and periods decreased rapidly, wave conditions did not reach pre-storm conditions until approximately 72 hours later. In the vicinity of East Timbalier Island, water level changes are estimated to have been at least 1 m from initial levels to peak surge condition. Sustained abovenormal water levels were recorded for approximately 40 hours. Winds speeds recorded at Grand Isle, approximately 30 km to the northeast of East

Timbalier Island, indicated maximum sustained winds in excess of 20 m/s and wind speeds remaining above 13 m/s for at least twelve hours.

OBJECTIVES

The overall goal of this project was to evaluate the effects of the GPC oil spill on East Timbalier Island with regard to salt marsh recovery and the extent to which this recovery was influenced by hurricane disturbance. Specific objectives were to

1) determine the impact and recovery of salt marshes on East Timbalier Island to the oil spill as a function of degree of initial oiling and residual surface and oil-penetrated sediment;

2) document the impact of Hurricane Andrew on East Timbalier Island and its effect on salt marsh recovery to the oil spill.

MATERIALS AND METHODS

The project objectives were accomplished through a combination of remote sensing/image analysis procedures, replicated field surveys, and quantitative field sampling. Large-scale changes in island geomorphology, marsh habitat, and oiling were documented with pre- and post-disturbance aerial imagery (1990, 1992, and 1993) in conjunction with field surveys (1992 and 1993). The data were mapped, analyzed, and processed for spatial and temporal variations in oiling and hurricane impacts.

Field surveys provided researchers with the opportunity to ground truth for the photointerpretation and mapping of the area from the aerial imagery and to make qualitative assessments of oiling and Hurricane Andrew's impact on East Timbalier Island. In addition, results of the surveys were used to select potential sites for the plots used to evaluate the community scale response from which statistical assessments of oil impact on the marsh vegetation were made.

Landscape Scale Response

Field Surveys

Field surveys were conducted on East Timbalier Island to collect geomorphological, ecological, and surface oiling and oil penetration impact data immediately after the spill (1992) and one year after oil impact (1993). The surveys consisted of a combination of field investigations (foot, airboat, and boats) and low-altitude helicopter overflights. The data collected during this phase of the project were then used to create landscape scale oiling maps and to ground truth for land cover mapping and Hurricane Andrew impacts. The following sections discuss the methodology used during the field data collection phase of the project.

1992 Survey

The first field survey was conducted between 11 and 15 October 1992 as part of an interagency shoreline cleanup assessment team (SCAT) survey. The intent of the SCAT process is to support the State and Federal On-Scene Coordinators by providing information on the oiling conditions and potential ecological constraints for cleanup operations in oil- impacted areas (Debusschere et al. 1993). The SCAT surveys are designed to be an interagency effort where state, federal, and local agencies work with the responsible party to determine the oiling conditions of the site and coordinate response efforts. Because the agencies and the responsible party visit each site together, this process facilitates a consensus of the field conditions at each site.

The SCAT survey was initiated by GPC (the responsible party) during the early stages of the spill for the purpose of assisting them in developing cleanup priorities (Debusschere et al. in preparation). On 11 October 1992, an interagency reconnaissance helicopter overflight was conducted to obtain a general overview of the oiling conditions on East Timbalier Island. Based on this preliminary oiling information, the island was divided into segments and a "hot spot" map was developed to prioritize the activities for the survey teams. While delineation of segments was based on geomorphological features, selection of "hot spots" was based on the relative greater amounts of oil present in those areas. The field survey consisted of a mapping effort where the area of spill impact was assessed, and data on oiling, ecology, and geomorphology were collected. Two teams, consisting of a geomorphologist, ecologist, and government representatives were deployed on 12 October 1992.

Each segment was surveyed for geomorphological and ecological characteristics pertinent to cleanup operations such as general morphology, sediment characteristics, bearing capacity, access restrictions, wave exposure, shore slope, habitat, dominant vegetation, and sensitive species. In addition, the teams documented surface and oil pentration conditions, extent of oiled area, depth of oil penetration, percent oil coverage, oil thickness, oil character, sediment type, amount and type of oiled debris, oiled plant and animal species, and location of oil on plants. Subdivisions of these segments were created where the geomorphological, ecological, or oiling characteristics were inconsistent throughout a segment.

The data collected for each segment and/or subdivision was subsequently recorded on a series of forms. The forms ensure consistency during the data collection process between the different teams by using predefined standardized terminology and definitions. The segment/subdivision reports include sketch maps reflecting the oiling conditions and geomorphological and ecological characteristics; photographic documentation; and an interagency comment sheet providing cleanup recommendations and concerns by the federal and state agencies' representatives on the teams. A more detailed explanation of the procedures followed during SCAT field surveys during the GPC spill can be found in Debusschere et al. (in preparation).

The forms with their respective terminology, definitions, codes, and explanations used in these surveys were developed by Woodward-Clyde Consultants under contract to Louisiana State University (LSU). The GPC oil spill in Timbalier Bay was the first time the forms were used during an oil spill response in Louisiana. Although the forms were not always suitable to describe the local environment, no changes were made to the forms during the GPC spill response to ensure consistency in the data collected and allow for comparative analysis at a later time.

1993 Survey

The second field survey was conducted in two phases, approximately one year after the spill. The purpose of this survey was to evaluate the oiling conditions and assess potential geomorphological and vegetative changes that may have occurred because of oil and/or hurricane impact. The first phase of the survey consisted of field investigations over a three-day period between 8 and 10 November 1993. Although some of the segments/subdivisions were inaccessible during the field investigations, all segments/subdivisions where oiling had been observed during 1992 were surveyed in this first phase. To survey the segments/subdivisions inaccessible during the first phase of this survey, a helicopter overflight was conducted on 16 December 1993. In addition, this overflight provided a better overview of the geomorphological characteristics and vegetative cover on East Timbalier Island one year after the spill and Hurricane Andrew.

The survey was conducted by a geomorphologist and an ecologist, both of whom had worked as a team on the field survey in 1992. Segment and or subdivision boundaries, survey procedures, and type of data collected during this survey were consistent with the first survey. The data collected during this survey was compiled on the same forms, using the same terminology and definitions, to allow for temporal analysis.

Mapping

Evaluation of the oil spill and/or Hurricane Andrew impacts on East Timbalier Island, required mapping of pre- and post-hurricane disturbance, the land/water interface and land cover, and the areal extent and degree of oiling. Mapping was done from vertical color infrared aerial photography flown in December 1990 (1:62,500), 12 October 1992 (1:12,000), and 21 November 1993 (1:12,000). The 1990 photography was the most recent pre-spill and hurricane photography available for East Timbalier Island. The 1992 photography, flown for the U.S. Fish and Wildlife Service, reflected changes to the island immediately after Hurricane Andrew and the 1993 photography, flown specifically for this project, provided information on island changes one year after hurricane and spill impacts.

The 1992 and 1993 field surveys, conducted during the 1992 aerial photography overflight and within 12 days of the 1993 overflight, respectively, provided a unique opportunity for ground truthing the aerial photography for both years. The extensive collection of photo documentation obtained with 35-mm cameras during the field surveys also was used during the vertical photography interpretation and mapping process.

The following sections outline the methodologies used for the map compilation phase of the project. The methodologies are discussed according to the three types of maps produced.

Base Maps

A land/water interface base map was created for the three years of data used in this study. Vertical aerial photography for 1990, 1992, and 1993 was photointerpreted at a scale of 1:12,000 using a Cambridge Instruments stereo zoom transfer scope. The reference base map used for this interpretation consisted of a 1992 digital map produced by Aerodata Corporation, Baton Rouge, Louisiana (Aerodata). This reference map was created from 1992 black-and-white vertical aerial photography flown by Aerodata during the spill at a scale of 1:12,000. The map was created for GPC because the field survey and subsequent mapping efforts and spatial analysis of oiling impact required an up-to-date location of the shoreline.

Selection of this reference map was based on a review of existing maps. Although reference maps for aerial photointerpretation commonly consist of U.S. Geological Survey (USGS) topographic maps, the most recent map available for East Timbalier Island dates back to 1978. Another potential reference map was the 1988 land/water interface map produced by the Louisiana Geological Survey. Both maps were considered inappropriate because of the major changes to the landscape of and bathymetry around East Timbalier Island that had occurred since 1988, especially due to Hurricane Andrew. In addition, the 1988 digital map did not have any structures, rigs, platforms, etc. that could be used as reference points.

Based on this initial evaluation of available maps, the 1992 map, produced by Aerodata, was selected as a reference map because it provided the most recent land/water interface map for East Timbalier Island and had been mapped at a scale suitable for the purpose of this project. In addition, this reference map enabled us to maintain consistency with the oiling maps produced for GPC in 1992. Subsequent comparison of this map relative to the 1992 color infrared photography and the original 1992 black-and-white photography indicated the need for some corrections. The revised 1992 map was ultimately used as the reference map for all mapping efforts for this project and provided the land/water interface map for 1992.

Land/water interface base maps for 1990 and 1993 were subsequently created at a scale of 1:12,000 from color infrared photography flown in December 1990 (scale 1:62,500) and November 1993 (scale 1:12,000). Although delineation of the shoreline or land/water interface was based on color reflectance of the vertical aerial photography, availability of low-altitude oblique color photography and personal knowledge of the area from numerous overflights and field surveys since 1992 provided additional information for determining the location of the shoreline.

The land/water interface maps produced in this phase of the project provided the base maps for the land cover and oiling maps and were used to evaluate shoreline changes between 1990 and 1993.

Land Cover Maps

Land cover maps for East Timbalier Island were created from the color infrared aerial photography for the three years of record. Photointerpretation of land cover was based on color reflectance and texture of the aerial imagery, field notes, and low-altitude color photography. Land cover was broken down into 3 broad categories and 10 subcategories: *Land* (vegetated marsh, vegetated shrubs, no vegetation, and marsh platform), *Water* (intertidal, submerged washover, and ponds), and *Human-made* or inert features (seawall, other solid structures, and liquid). The 10 land cover subcategories are a modification of habitat categories used in Mossa et al. (1990) and are described in Table 1. Primary plant species found on the island for each of those subcategories are listed when applicable.

Although most of the land cover subcategories could be clearly defined on the photography, delineation of the vegetated marsh and shrub subcategories requires some further explanation. The extent of vegetation varied widely on the island. Some areas contained thick, healthy stands of plants (marsh or shrub) that could easily be seen on the photography as a combination of red, pink, and reddish brown colors. Other areas were sparsely covered by less vigorous plants which appeared grayish or light pink with some texture changes in the image. Although land cover in the sparsely vegetated areas did not solely consist of vegetation, these areas were mapped as vegetated where the resolution of the mapping scale did not allow for making that degree of detail for distinguishing between vegetated or not vegetated areas.

The resulting land cover maps provided a record of land cover changes between 1990 and 1993. The maps with polygons representing the respective land cover categories could then be input into a geographic information system (GIS) for data processing and area calculations.

Oiling Maps

The oiling data collected during the field surveys allow for analysis and synthesis regarding the extent and degree of oiling. Each segment/subdivision report provides information on the location, areal extent (width and length) of the oiled areas, oil character, and thickness within each area, percent oil coverage for each segment/subdivision, and percent coverage for each oil character.

The oiling results of the 1992 and 1993 field surveys were analyzed to compile oiling maps of East Timbalier Island. Both surface and oil-penetrated sediment conditions were processed and classified according to a four-fold rating system, developed for describing the general surface and oil penetration conditions on the island (Debusschere et al. in preparation). These conditions are very light, light, moderate, and heavy. The intent of this classification is to provide decision makers with a cleanup prioritization tool by producing a quick reference of the general oiling conditions in each segment.

Table 1. Land cover habitat assigned for mapping of East Timbalier Island.

Vegetated Marsh	includes salt marshes with predominant vegetation including; *Spartina alterniflora, S. patens, Salicornia virginica, Batis maritima*, and *Distichlis spicata*. Other species recorded during field surveys include; *Avicennia germinans, Solidago sp., Limonium carolinianum*, and *Sesbania sp.*—delineated as land.
Vegetated Shrubs	includes shrubby vegetation that often occurs on higher ground, along the seawall, and on spoil deposits and include *Baccharis halimifolia, Borrichia frutescens, Iva frutescens*, and *I. imbricata*—delineated as land.
No Vegetation	includes sand or spoil areas that have no vegetation such as sand or spoil—delineated as land.
Submerged Washover	includes areas where sand deposits form washover fans on the flood side of the barrier island. Most of these features are clearly visible in the photography immediately after Hurricane Andrew—delineated as water.
Water	includes ponds and canals—delineated as water.
Seawall	includes linear human-made rock structures—delineated as human made or inert.
Marsh Platform	includes remnant marsh peat along the shoreline—delineated as land.
Intertidal	includes areas where land is exposed during low tide and/or a north wind and areas submerged during high tide and/or a south wind—delineated as land.
Inert (solid)	includes human-made rock structures, usually for pits—delineated as human made or inert.
Inert (liquid)	includes liquid in human-made pits—delineated as human made or inert.

Two steps were involved in the ground survey assessment of surface oiling to describe the surface oiling category. The first step requires determination of the width of the oil band and distribution of oil. Oil width represents the average width of the oiled area or band in the segment or subdivision. If multiple bands or areas occur, width represents the sum of their widths (Table 2). Oil distribution represents the percent of the surface within a band or area covered by oil. In the event of multiple bands, distribution refers to the term that best represents the oil conditions for the segment or subdivision (Table 2). Oil width and oil distribution are combined in the initial surface oil cover matrix to determine the initial surface oil cover category (degree of oiling) (Figure 2).

The second step in the process requires oil thickness data recorded during the field surveys. Oil thickness refers to the average or dominant oil thickness within a band or area (Table 2). Oil thickness is then combined with results of step one (from the initial surface oil cover matrix) in the surface oil categorization matrix to determine the surface oil category for each oiled polygon within a segment or subdivision (Figure 3). For example, a 4-m-wide area with 75% surface oil cover is classified as moderate in the initial surface oil cover matrix. If the oil in this area was more than 1 cm thick (pooled), the area was reclassified as heavy in the surface oil categorization matrix; if the oil was between 0.01 and 0.1 cm (coat) thick, the area was classified as moderate.

A similar rating system was used to describe the oil penetration conditions. Oil penetration is classified according to the oil character or relative oil concentration and the depth of oil penetration into the sediment or thickness of the buried oil lens (Figure 4).

Oiling maps with polygons representing the respective oiling categories and categories of no oil, water, and not-surveyed areas can thus be produced and the resulting maps input into a GIS for data processing and area calculations.

Although this data reduction process was conducted for the 1992 oiling data by LSU as part of the technical support contract with GPC, the field survey reports and data reduction were re-evaluated as part of this project to provide for additional quality control. This evaluation established some discrepancies in data reduction and oiling maps produced. Furthermore, the 1992 land/water interface was re-interpreted for this project. The resulting base map was slightly different than the one used in the original study, which produced additional changes in total areas calculated. The oiling maps and data presented in this report consist of the revised version.

Geographic Information System

Temporal and spatial analysis of the oil spill and/or hurricane impacts on East Timbalier Island was achieved by using a GIS approach. The primary variables (data) for impact analysis for East Timbalier Island consisted of the land/water interface, land cover type, and degree of oiling. The mapped variables were digitized as polygons in different layers into an Intergraph system and attributed according to land cover and oiling classifications. The data were subsequently processed to produce basic land cover and oiling maps and calculation of each of the

		Width of Oiled Area			
		Wide >6m	**Medium** 3–6m	**Narrow** 0.5–3m	**Very Narrow** <0.5m
Oil Distribution	**Continuous** 91–100%	Heavy	Heavy	Moderate	Light
	Broken 51–90%	Heavy	Moderate	Light	Light
	Patchy 11–50%	Moderate	Moderate	Light	Very Light
	Sporadic 1–10%	Light	Light	Very Light	Very Light
	Trace <1%	Very Light	Very Light	Very Light	Very Light

Figure 2. Initial surface oil cover matrix.

		Initial Surface Oil Cover Category (from Initial Surface Oil Cover Matrix)			
		Heavy	**Moderate**	**Light**	**Very Light**
Average Thickness	**Thick or Pooled > 1 cm**	Heavy	Heavy	Moderate	Light
	Cover 0.1–1.0 cm	Heavy	Moderate	Moderate	Very Light
	Coat 0.01–0.1 cm	Moderate	Moderate	Light	Very Light
	Stain/Film <0.01 cm	Light	Light	Light	Very Light

Figure 3. Surface oil categorization matrix.

Oil Penetrating the Sediment					
		> 30 cm	21-30 cm	11-20 cm	0-10 cm
*Relative Oil Concentratio n	OP	Heavy	Heavy	Heavy	Moderate
	PP	Heavy	Moderate	Moderate	Light
	OR	Moderate	Moderate	Light	Light
	TR	Light	Very Light	Very Light	Very Light

*OP Oil-Filled Pores: pore spaces in the sediment matrix are completely filled with oil. Often characterized by oil flowing out of the sediment when disturbed.

PP Partially Filled Pores: pore spaces are filled with oil, but oil generally does not flow out when exposed or disturbed.

OR Cover, coat, stain, or film of oil residue on the sediment surface and/or some pore spaces filled with oil.

TR Discontinuous film or spots of oil on sediment, or an odor or tackiness with no visible evidence of oil.

Figure 4. Categorization matrix for oil penetrating the sediment.

Table 2. Definition of surface oiling characteristics.

Surface Oil Variable	Parameter	Definition
Oil Width	Wide	> 6 m
	Medium	> 3 m and ≤ 6 m
	Narrow	> 0.5 m and ≤ 3 m
	Very narrow	≤ 0.5 m
Oil Distribution	Trace	< 1%
	Sporadic	1 - 10%
	Patchy	11 - 50%
	Broken	51 - 90%
	Continuous	91 - 100%
Oil Thickness	Pooled	> 1.0 cm
	Cover	≤ 1.0 cm and > 0.1 cm
	Coat	≤0.1 cm and > 0.01 cm
	Stain	≤ 0.01 cm
	Film	transparent or translucent film or sheen

attributes for the study period. The results of this analysis provided an overview of the spatial distribution of land cover (1990, 1992, and 1993) and oiling (1992 and 1993).

Oil spill and/or hurricane impacts were analyzed by superimposing different data layers of the same data (e.g., 1990 land cover over 1992 land cover) and/or correlation of different data types (e.g., oiling data over land cover data). Four map types were created through superimposition: shoreline change, land cover change, oiling over land cover, and oiling over land cover change. Shoreline change maps were based on the land/water interface maps. Land cover change maps were created from the land cover maps by grouping the land cover categories into three broad classes: vegetated, not vegetated, and water. Land cover change analysis and area calculations were based on a 3X3 matrix (vegetated, not vegetated, and water X vegetated, not vegetated, and water).

Oiling over land cover maps were created by using a 3X1 matrix (vegetated, not vegetated, and water X oiling) where the oiling data had been synthesized to one broad category of oil. The oiling over land cover change required a 9X1 matrix (vegetated to vegetated, vegetated to not vegetated, vegetated to water, not vegetated to vegetated, not vegetated to not vegetated, not vegetated to water, water to vegetated, water to not vegetated, water to water X oiling).

Once these maps were finalized, the data were processed to calculate the area for each of the combinations. The results of this analysis provided an overview of the spatial distribution of Hurricane Andrew and/or oil spill impact.

Calculation of Actual Oiling

Area calculations for the extent of oiling based on the oiling maps are somewhat limited in the information they provide. The area calculations obtained through the data reduction process to create the oiling maps reflect overall areas that were observed to contain oil with various percentages of surface cover rather than a measurement of actual area oiled. During the field surveys oiled areas were mapped according to the general perimeter of oil impact in a polygon; the areal extent of *actual oiling* is represented by an estimate of percentage surface oil cover. For example, a 200 m^2 area has sporadic patches of oil uniformly distributed throughout its entire extent covering approximately half of the total surface area. A field survey would record this as a 200 m^2 area with 50% surface oil coverage.

During this data reduction process, the 200 m^2 area would be classified as oiled because measuring and mapping each oiled patch as a distinct polygon is too time consuming and irrelevant for cleanup operations. The 200 m^2 area would subsequently be digitized as one polygon on the oiling map and attributed as a surface oil category based on the dominant oiling condition.

This limitation for area calculations results from the type of data collected and methodology used in the data reduction process; both were designed to answer questions related to prioritization of cleanup operations. While, as mentioned previously, these limitations were noted during the 1992 surveys, no adjustments were made to ensure consistency in the data collected and to allow for temporal analysis of the oiling distribution. However, a more detailed analysis of the survey reports and revision of the data reduction process used in the compilation of the oiling maps provided sufficient oiling information to obtain a more realistic assessment of the actual acreage oiled and a more site-specific oiling classification.

Each segment and subdivision surveyed during the field survey is potentially divided into a series of "locations," each with their site-specific oiling data. Some of these "locations" were clustered together in the initial data reduction process because they fell in the same general oiling category. During the more site-specific data reduction process, the oiling information for each "location" was extrapolated and evaluated individually. The following steps were performed during this process:

Step 1. The oiling information for each "location" of a field survey report was identified relative to the polygon on the oiling maps.

Step 2. A "location" was treated as an individual polygon and acreage, as estimated from the field surveys for each "location" identified, was calculated.

Step 3. Each "location polygon" was classified according to oil distribution and width of oiled area (Initial Surface Oil Cover Matrix).

Step 4. If one or more "locations" were part of a larger polygon, the "location's" area was subtracted from the total polygon acreage.

Step 5. Oiled area was calculated for each "location polygon" according to percent surface oil cover as estimated in the field survey reports (i.e., if percent oil cover is 50%, acreage oiled is only half of total acreage calculated in step 2).

Step 6. The area observed to be oiled was classified according to the results of the Initial Surface Oil Cover Matrix and the average oil thickness (Surface Oil Categorization Matrix).

Step 7. Whenever two or more oil thicknesses occurred in the same area, the "location polygon" was attributed a classification according to the thickest oil cover.

Area calculations obtained through this process combined with the oiling maps and field survey reports provided for an overall overview of amount and distribution of oil observed on East Timbalier Island.

Community Scale Response

The community scale assessment of recovery was based on a statistical evaluation of the degree to which the oil-affected areas had recovered (in terms of plant species composition, biomass, and percent cover), compared to adjacent reference marshes (hereafter referred to as unoiled marshes). This technique provided a quantitative and statistical assessment of residual oil effects on the vegetation and a measure of residual oil in the soil.

Based on the original information derived from the post-spill SCAT survey, approximately 18 oiled backbarrier marsh sites on East Timbalier Island were identified as possible sampling sites. From this population, nine marsh sites (Figure 5), each composed of an oiled and adjacent unoiled location, were chosen for sampling. The selection of these sites was based on (1) the ability to identify the oiled area because this sampling occurred 14 months after the spill, and (2) the presence of an unoiled or lightly oiled reference marsh immediately adjacent to the oiled marsh. Five 1-m^2 plots were randomly selected within each oiled and adjacent unoiled marsh at each of the 9 marsh sites for a total of 90 plots. All oiled marshes were originally classified from the 1992 post-spill survey as moderately oiled. All reference marshes were originally classified as unoiled except those located at marsh sites 6 and 9 (Figure 5). These marshes were originally classified as lightly oiled, but were used as reference marshes because of the absence of unoiled marshes immediately adjacent to these sites.

On 22 and 23 November 1993, the following data were collected at each plot within a 0.5-m^2 quadrat: (1) live plus dead percent vegetative cover, henceforth referred to as total percent vegetative cover; (2) percent vegetative cover of the live vegetation by species; (3) percent vegetative cover of the dead vegetation; and (4) average height of the vegetation by species. Percent vegetative cover (the percent of the area of ground covered by vegetation) was determined visually by the Braun-Blanquet method (Braun-Blanquet 1932) with 5% cover intervals.

Live and dead standing crop of the vegetation by species was determined by clipping 0.25-m^2 quadrats within the section of the permanent plot not used for vegetative cover estimates. In addition, oil presence in the soil as determined by total hydrocarbon analysis of the top 15 cm of marsh sediment was determined for each marsh site, oiled and unoiled (18 hydrocarbon samples). Total soil hydrocarbons were determined by the gravimetric method: ca. 3 g of soil from the top 5 cm of the soil core was extracted with 20 ml of hexane in a vial for 24 hours. The soil sample and hexane were thoroughly mixed with a stainless steel spatulas. During the 24-hr extraction, the vial was shaken with a vortox at high speed 3 times for 2-minute periods. After the extraction, 5 ml of clear extract were transferred to an evaporation dish placed in a vent hood at room temperature for hexane evaporation for two hours. The unevaporated oil remaining in the dish was weighed, and total hydrocarbons in the soil were calculated.

The community scale data were analyzed in two different ways. Statistical comparisons (unpaired t-tests) were made between each oiled and adjacent unoiled marsh for each of the nine pairs of marshes. In addition, all pairs of oiled and unoiled marshes were analyzed with a paired t-test to provide an estimate for the average oil effect integrated over all the backbarrier marshes sampled. The first approach provides site-specific differences, while the second approach averages the impacts over all the sampled backbarrier marshes. All statistical differences were significant at the 0.05 probability level unless otherwise noted.

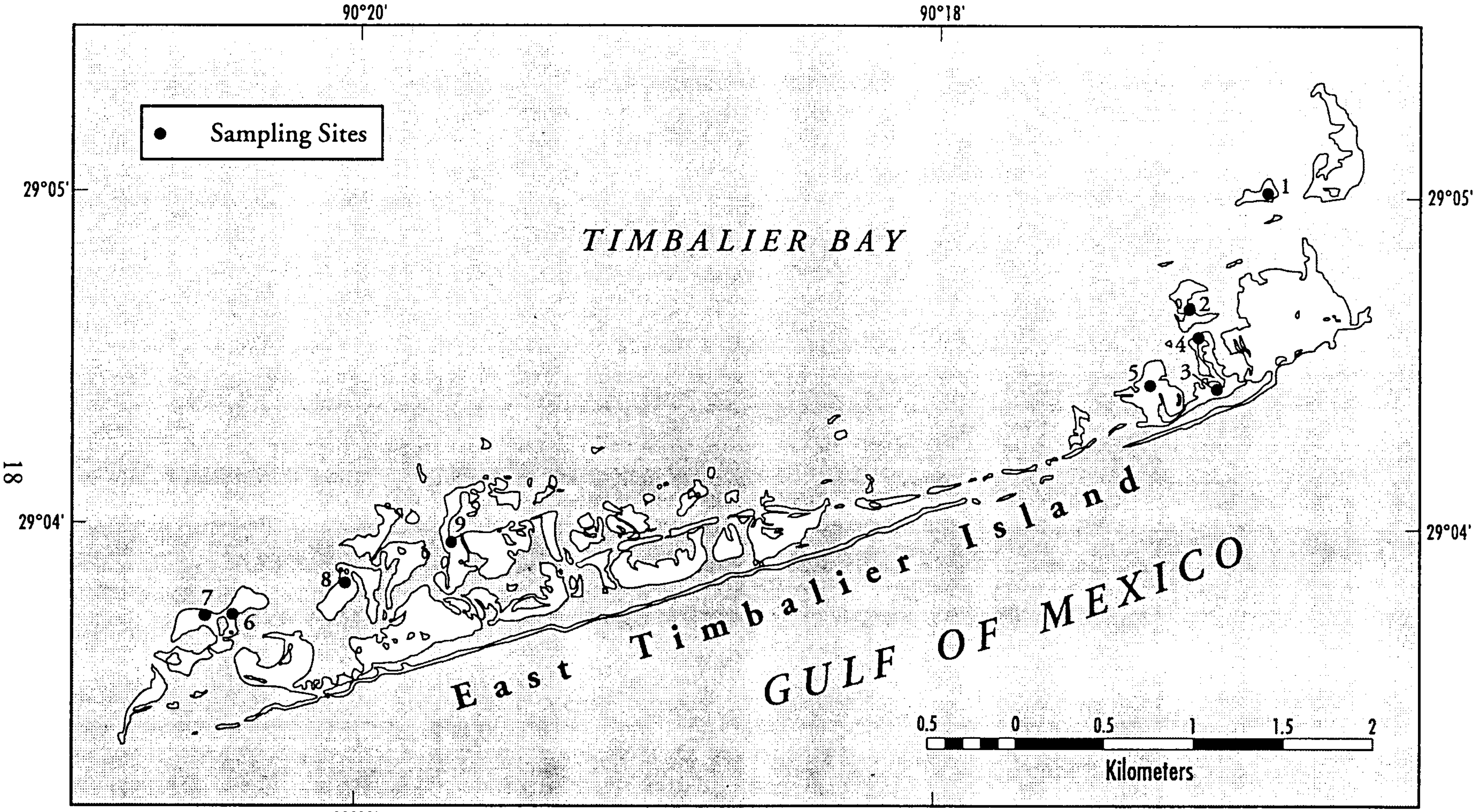

Figure 5. Sampling sites for community-scale analyses. Each marsh site, denoted by a number on the map, consists of two sampling locations, an oiled and adjacent unoiled marsh.

RESULTS AND DISCUSSION

Hurricane Andrew Impact

The impacts of Andrew on East Timbalier Island were evaluated through a combination of field surveys and remote sensing/image analysis procedures. Field surveys allowed for ground truthing the aerial photointerpretation for land cover and provided qualitative information on the sediment dynamics and island morphology. The remote sensing/image analysis component of this phase of the project consisted of photointerpretation of vertical color-infrared photography (1990, 1992, 1993) and data analyses through a GIS system. Unfortunately, the most recent pre-storm aerial photography available for East Timbalier Island was for 1990. Because the pre-storm conditions in this analysis were represented by data interpreted from this 1990 photography, the analysis is based on the assumption that the majority of the changes between 1990 and 1992 for the location of the shoreline and land cover are the result of the hurricane. Based on a review of the average land loss rates for this area and our knowledge of the geomorphology and morphodynamic changes commonly associated with hurricane impacts, the researchers involved in this project considered this a reasonable assumption.

Shoreline Change

The 1990, 1992, and 1993 land/water interface base maps provided the basis for the shoreline change analysis. Figures 6 and 7 and table 3 present the shoreline change for the period immediately after Hurricane Andrew (1990–1992) and one year later (1992–1993) respectively. During the three-year period, 29% (670,672 m^2) of East Timbalier Island's land area was lost. Much of this loss was concentrated in the mid section of the island between the bayward and seaward seawalls and on the extreme eastern and western ends of the island. The most dramatic change in the island's morphology was that the island's shoreline changed from a continuous shoreline in 1990 to a fragmented one with numerous breaches in the land and seawall by 1993.

1990–1992

East Timbalier Island's land mass was reduced by 25% between 1990 and 1992. The area changed from 2,300,888 m^2 in 1990 to 1,730,394 m^2 in 1992, with a total loss of 570,494 m^2 of land area (Table 3). Land loss in this two-year period was more than seven times the land loss between 1988 and 1990 which was only 76,648 m^2 (1988 land area was obtained from Williams et al. 1992). The most apparent change in the island's geomorphology occurred in the narrow mid section of the island where unvegetated sand flats were washed away by storm surges topping the seawalls (Figure 6). Elevated water levels and high-velocity flows resulting from Hurricane Andrew surged across the island and breached both seawalls over a distance of approximately 1,500 m (van Beek 1993). The sediment was subsequently deposited as washover fans in the shallow waters bayward of the inner seawall.

Land loss also was apparent at the western and eastern tips of the island where the high velocity flows surged around the island. On the eastern end of the island this flow resulted in a shallow breach, approximately 300 m wide, that severed the eastern tip of the island from the main land mass (van Beek 1993). This area lost 53% (149,678 m^2) of its total land mass which consisted of unvegetated sands, marsh platform, and vegetated marsh. Although the land mass at the western end of the island was reduced greatly, no breaching had occurred in that area by October 1992.

1992–1993

During the year following the hurricane, East Timbalier Island lost 6% or 100,178 m^2 of its total land mass. The total land area decreased from 1,730,394 m^2 in 1992 to 1,630,216 m^2 in 1993 (Figure 7 and Table 3). This annual rate is approximately three times the rate calculated for the 1988–1990 period. The majority of the land loss occurred in the same areas as in the period between 1990 and 1992. Tidal currents through the breaches in the mid section of the island further eroded and reworked the remaining unvegetated sand flats. Based on field observations during the 1993 field surveys, some of these sediment were deposited on the small islands behind the inner seawall at the western side of the breached area. The breach at the eastern tip of the island widened even more, and tidal currents eroded another 26,378 m^2 of the remaining land mass on both sides of the breach. At the western end of the island the narrow stretch of land that remained in 1992 breached. Unvegetated and vegetated areas were eroded significantly, and a new sand bar developed as a result of local reworking of sediment (Figure 7).

Land Cover and Land Cover Change

The 1990, 1992, and 1993 land cover maps (Figures 8–10) and area calculations (Tables 3 and 4) present the land cover for pre-hurricane and spill, immediately post-hurricane and spill, and one year after disturbance. The maps illustrate the distribution of marshes, shrubs, unvegetated land, marsh platform, intertidal areas, submerged washover, water, seawall, and other inert features for each year. Total land cover ranged from 2,300,888 m^2 in 1990 to 1,630,216 m^2 in 1993. The most predominant land features in all three years were marsh and unvegetated land (Table 3). Although the total area for these land cover subcategories decreased between 1990 and 1993, the relative percentages of vegetated and not vegetated land remained constant, around 50% and 30% of the total land mass respectively.

In addition to the 29% decrease in overall land area and fragmentation of the island as a whole, several changes in land cover occurred on East Timbalier Island during the three-year period. Figures 11–12 and Table 5 represent the land cover changes that occurred between 1990–1992 and 1992–1993. The most dramatic changes occurred in the mid section of the island, where large marsh areas were either eliminated or only fragmented sections remained by 1993, and at the extreme western and eastern ends of the island.

1990–1992

In 1990, marsh and not vegetated land appear in relatively large, continuous stretches throughout the island, covering 1,284,815 m^2 (56%) and 713,202 m^2 (31%) of the total land area respectively (Table 3). No submerged washovers were visible (Figure 8). Ponds, classified as water, composed a large area (334,018 m^2), particularly in the mid section of the island, between the two seawalls. By 1992, marsh (932,474 m^2 or 54%) and not vegetated land (596,289 m^2 or

34%) had decreased in total area, 27% and 20% respectively, but remained the most predominant land features in 1992 (Table 5). Shrubs, the third land mass subcategory also decreased 20% between 1990 and 1992. Vegetated and not vegetated areas no longer form large continuous blocks but appear patchy in the mid section of the island where geomorphological changes have been most prevalent (Figure 9).

This decrease in total marsh area between 1990 and 1992 can be attributed to two distinct processes: land loss and land cover changes. Some of the marsh lost through a decrease in total land area can be seen on the eastern end of the island where intertidal flats form the remnants of the land mass that was present in 1990. Most of the land cover changes occurred in the western part of the mid section of the island, between the seawalls. Some of the areas mapped as marsh in 1990 had changed to unvegetated land in 1992, presumably as a result of washover deposits during Hurricane Andrew storm surges. Land cover change from marsh to marsh platform is evident from the 71% increase of this subcategory in areas where marshes had been eroded.

In addition, the post-hurricane photography clearly showed a series of large washover deposits in the mid section of the island and some smaller ones at the ends of the island, totaling 748,085 m^2. The increase in this subcategory from 0 to 748,085 m^2 between 1990 and 1992 provides some indication of the amount of sediment moved during Hurricane Andrew. When compared to the total emergent land mass for 1992 (1,730,394 m^2), these washovers added a large area of shallow submerged deposits equal to approximately 40% of the total land area.

One major change in land cover that occurred between 1990 and 1992 was an 82% decrease of the water subcategory. Taken out of context, these numbers could potentially be explained by the filling in of ponds and channels with sediment transported during Hurricane Andrew's passage. However, a review of the land cover patterns on figures 8, 9, and 11 provide a different explanation. In 1990, the seawalls were relatively continuous and enclosed distinct waterbodies classified as water within the total land area. By 1992, Hurricane Andrew had breached both seawalls in numerous places. Some of the areas classified as waterbodies in 1990 were no longer individual features in 1992; those waterbodies were connected with the water in the Gulf of Mexico and were no longer classified as inland water.

Figure 11, which is derived by superimposing the 1990 and 1992 broad land cover categories, illustrates specifically where and what type of changes in land cover occurred between 1990 and 1992. Analysis of the map and area calculations of the land cover changes further support the trends of land loss and sediment dynamics noted on the land cover maps for 1990 and 1992. Between 1990 and 1992, more than half (56%) of the island's land cover changed (Table 5). This high number is an an indication of how rapidly changes occurred on this island during this two-year period. Most of these changes are presumably attributed to Hurricane Andrew. The greatest change constituted actual land loss consisting of 809,092 m^2 of vegetated and not vegetated land that was converted to water. More vegetated land was converted to not vegetated (232,155 m^2) than not vegetated to vegetated (126,062 m^2). The change from water to not vegetated land (177,470 m^2) is represented mostly in the mid section of the island where sand was moved into interior waterbodies between the seawalls during Hurricane Andrew storm surges.

1992-1993

By 1993, the total land area was reduced to 1,630,216 m^2 and marsh (896,012 m^2 or 55%) and not vegetated land (486,150 m^2 or 28%) were still the most predominant land features on the island (Figure 10). During this time period marsh decreased by 4%, a much slower rate than the previous two years, not vegetated areas decreased by 15%, and submerged washover decreased by 38% (Table 4). While many land cover subcategories decreased in area during this one-year period, vegetated shrubs increased by 4%, marsh platform increased by 65%, and intertidal increased by 17% (Table 4).

These land cover changes clearly depict the continued erosion of the island, some of which result from the physical processes initiated by Hurricane Andrew. The most significant land changes occurred in the mid section and the eastern and western ends of the island. Marsh platform increased mainly on the eastern end of the island where the shoreline has continued to be eroded dramatically between 1992 and 1993. The increase in shrubs is small (4%) and may be due to colonization of low spoil deposits and expanded shrub areas along the interior seawall.

The decrease of not vegetated areas and submerged washovers can be attributed to the fact that those sand bodies are more susceptible to erosion then vegetated areas; in the one year after Hurricane Andrew, most of the large and shallow washover deposits in the mid section of the island were no longer visible. Although approximately 462,035 m^2 were still classified as submerged washover, this high number is partially the result of new washovers that developed during subsequent storms through the breaches at the eastern end of the island (Figure 10).

Most washover sediment present in 1992 in the mid section of the island were probably removed by the increased tidal flows through the breaches in the island created by Hurricane Andrew and subsequent storm events. However, some of those sediment were reworked into intertidal flats that had increased in 1993. In addition, field investigations noted newly deposited clean sands on vegetated islands landward from the inner seawall and to the west of the breached mid section of the island.

One land cover change between 1992 and 1993 was the increase of the seawall subcategory by 7%. Because no repairs were done on the seawall after it was breached in 1992 by Hurricane Andrew (36% of the seawall was lost between 1990 and 1992), this increase is most likely a function of visibility of the seawall in the photography. Although the outer seawall is clearly more visible in the photography for the three years of record and changes such as breaches and length of the sections area more easily discernible, this is not the case for the inner seawall. The 1990 photography clearly shows the interior seawall for much of the length of the island. However, since 1990 vegetation covers much of this inner seawall in many areas, so the seawall cannot be easily delineated from the photography. In addition, the quality of the 1992 imagery made photointerpretation more difficult along some of the island sections.

Although the decrease in unvegetated areas is mostly due to erosion of those areas, the land cover change maps and area calculations indicate that part of this decrease is also the result of colonization of unvegetated sandbodies by marsh plants (Figure 12 and Table 5).

Figure 12, which is derived by superimposing the 1992 and 1993 broad land cover categories, illustrates specifically where and what type of changes in land cover occurred between 1992 and 1993. Analysis of the map and area calculations of the land cover changes further support the trends of land loss and sediment dynamics noted on the land cover maps for 1992 and 1993. Between 1992 and 1993, 46% of the island's land cover changed (Table 5), about 10% less than for the 1990–1992 period. The greatest changes occurred from not vegetated to water, as between 1990–1992, and from water to not vegetated where sediment has been reworked to form emergent sand bars. The changes from land, either vegetated or not vegetated, to water decreased during this period and occurred in the same areas as it did between 1990 and 1992. Stable areas where vegetated land cover remained also are represented in protected areas on the island between the two seawalls.

The high number of the water to water category (Table 5) appears to be an anomaly in the data. These numbers are accounted for in the large submerged washovers that were present after Hurricane Andrew and were classified as water for the land cover change analysis.

SHORELINE CHANGE OF EAST TIMBALIER ISLAND
(1990 -- 1992)

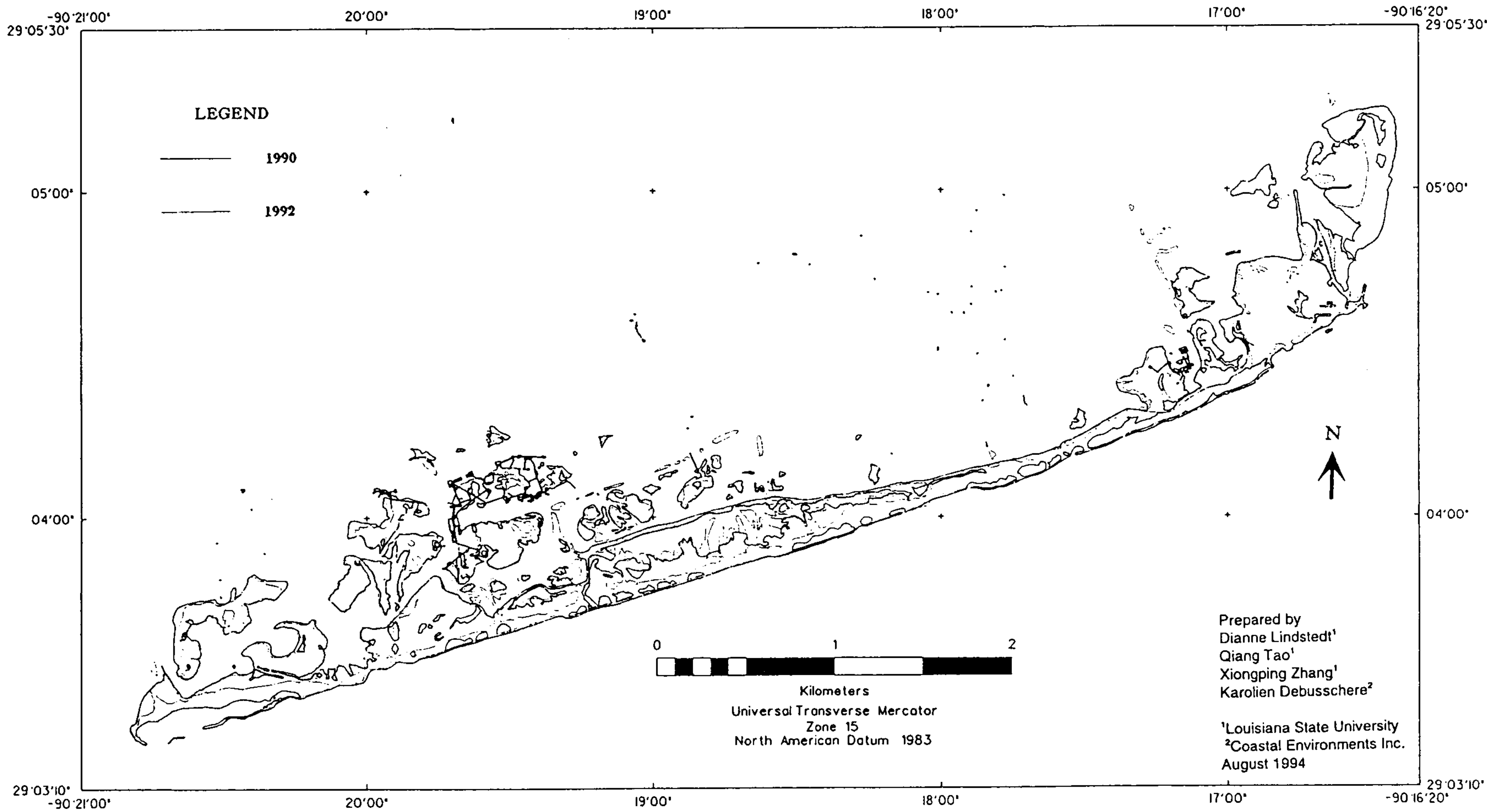

Figure 6: Shoreline change map of East Timbalier Island 1990-1992.

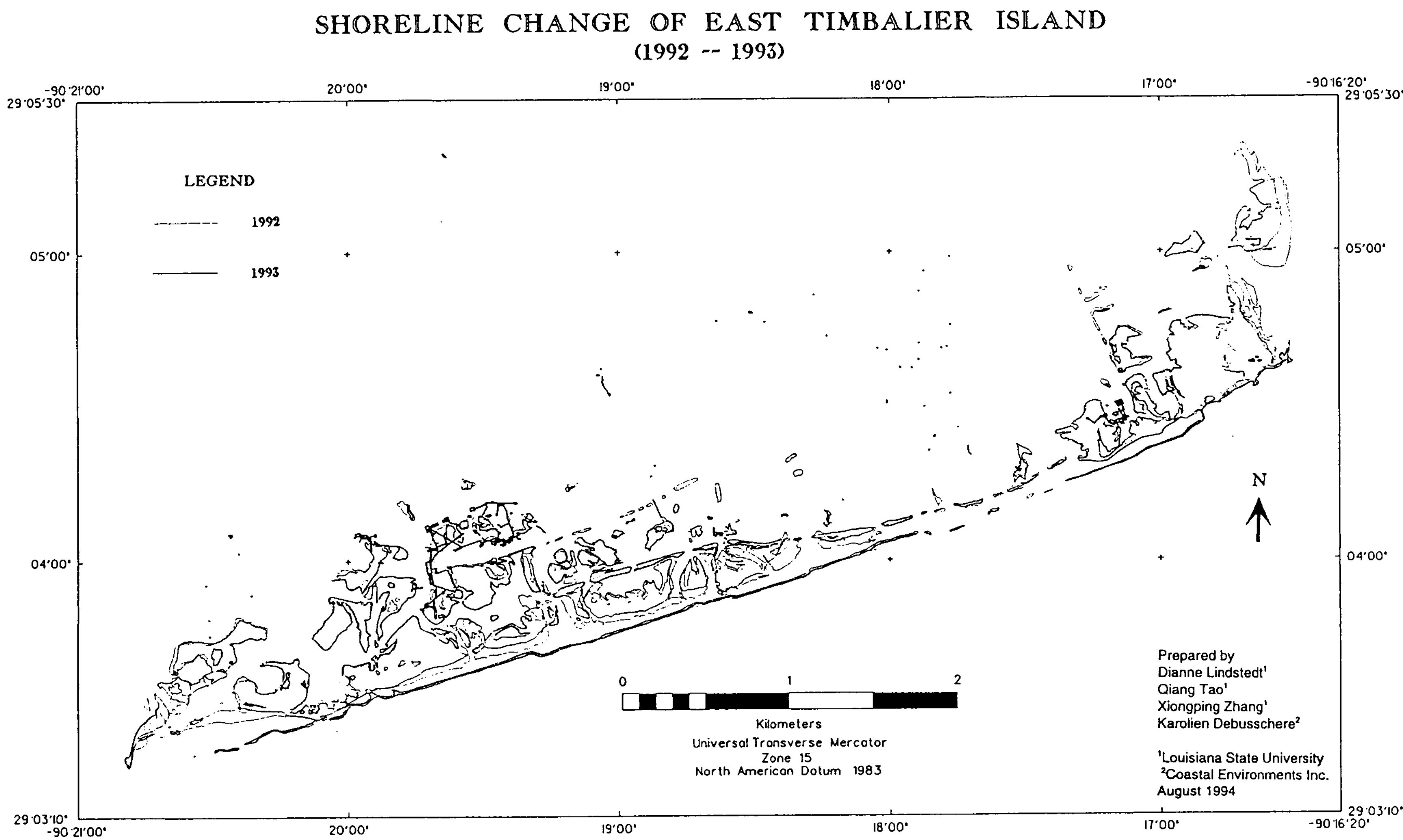

Figure 7: Shoreline change map of East Timbalier Island 1992-1993.

Table 3. Summary of land cover area in square meters by land cover type for the study period.

Land Cover	1990	1992	1993
Vegetated Marsh	1,284,815	932,474	896,012
Vegetated Shrubs	121,007	96,946	101,159
No Vegetation	713,202	569,289	486,150
Submerged Washover	0	748,085	462,035
Water	334,018	61,217	54,233
Seawall	154,451	118,809	126,539
Marsh Platform	16,012	4,577	12,143
Intertidal	22,152	49,209	57,375
Inert Solid	6,335	4,053	4,212
Inert Liquid	5,065	4,246	4,001
Total Land Area	**2,300,888**	**1,730,394**	**1,630,216**

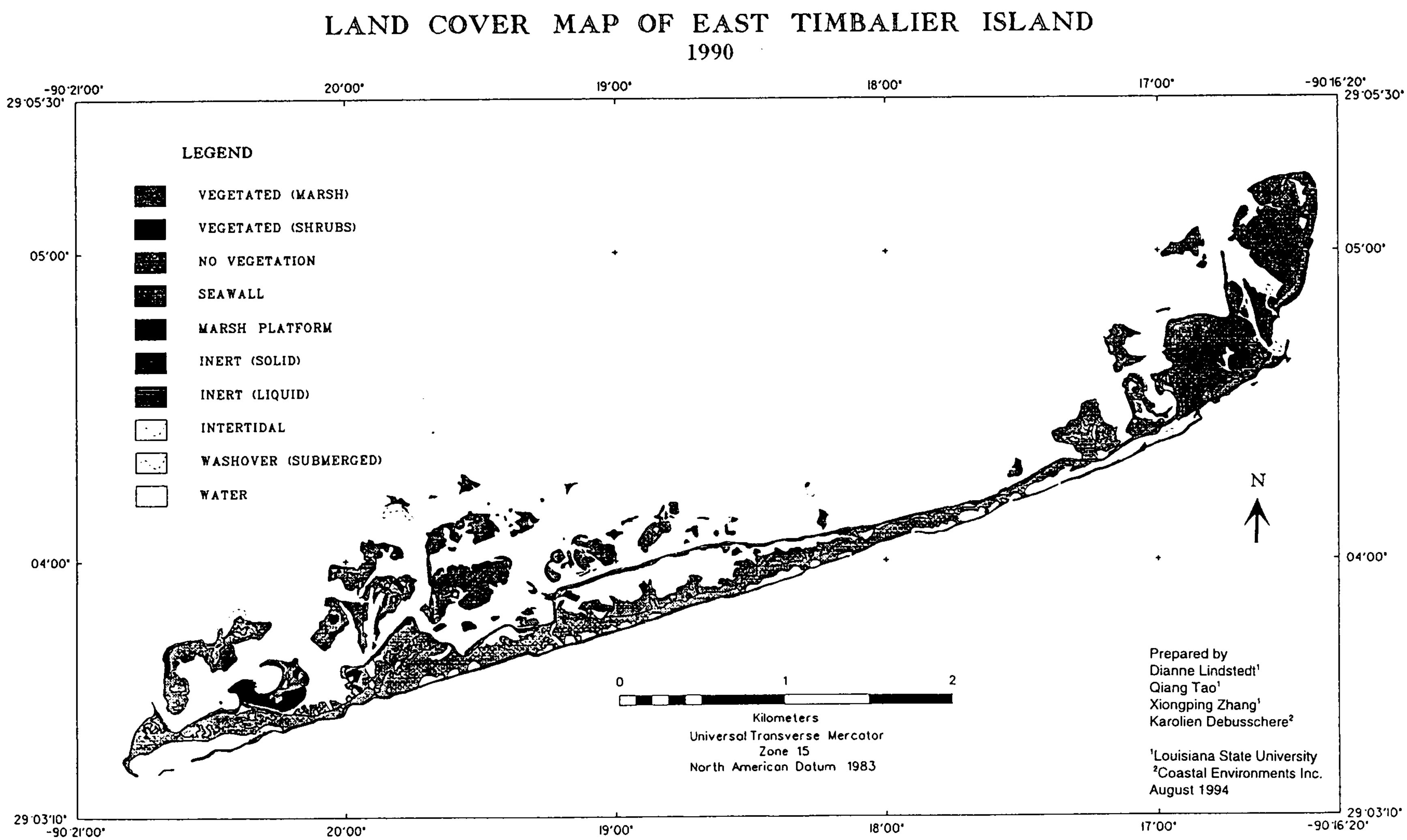

Figure 8: Land cover map of East Timbalier Island 1990.

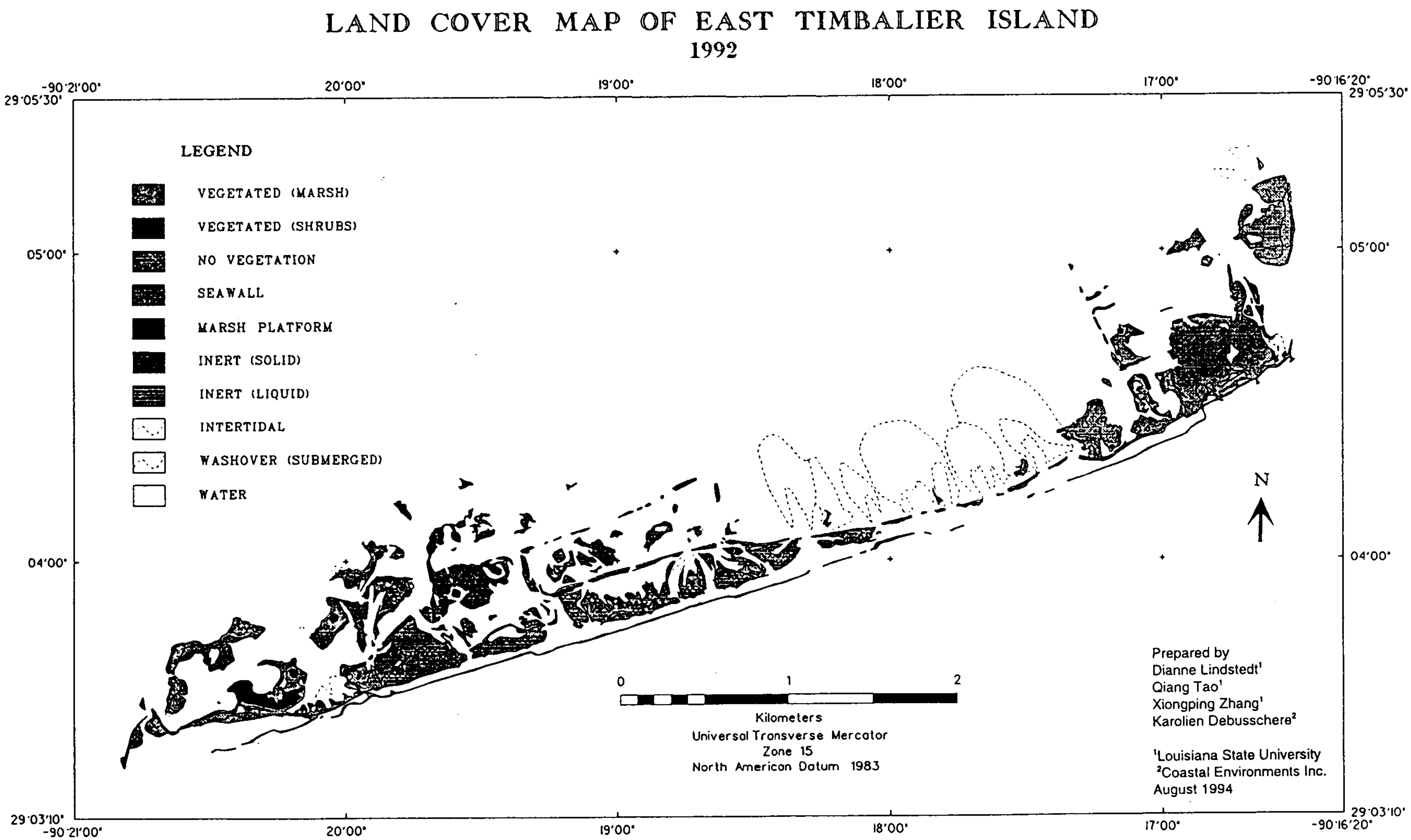

Figure 9: Land cover map of East Timbalier Island 1992.

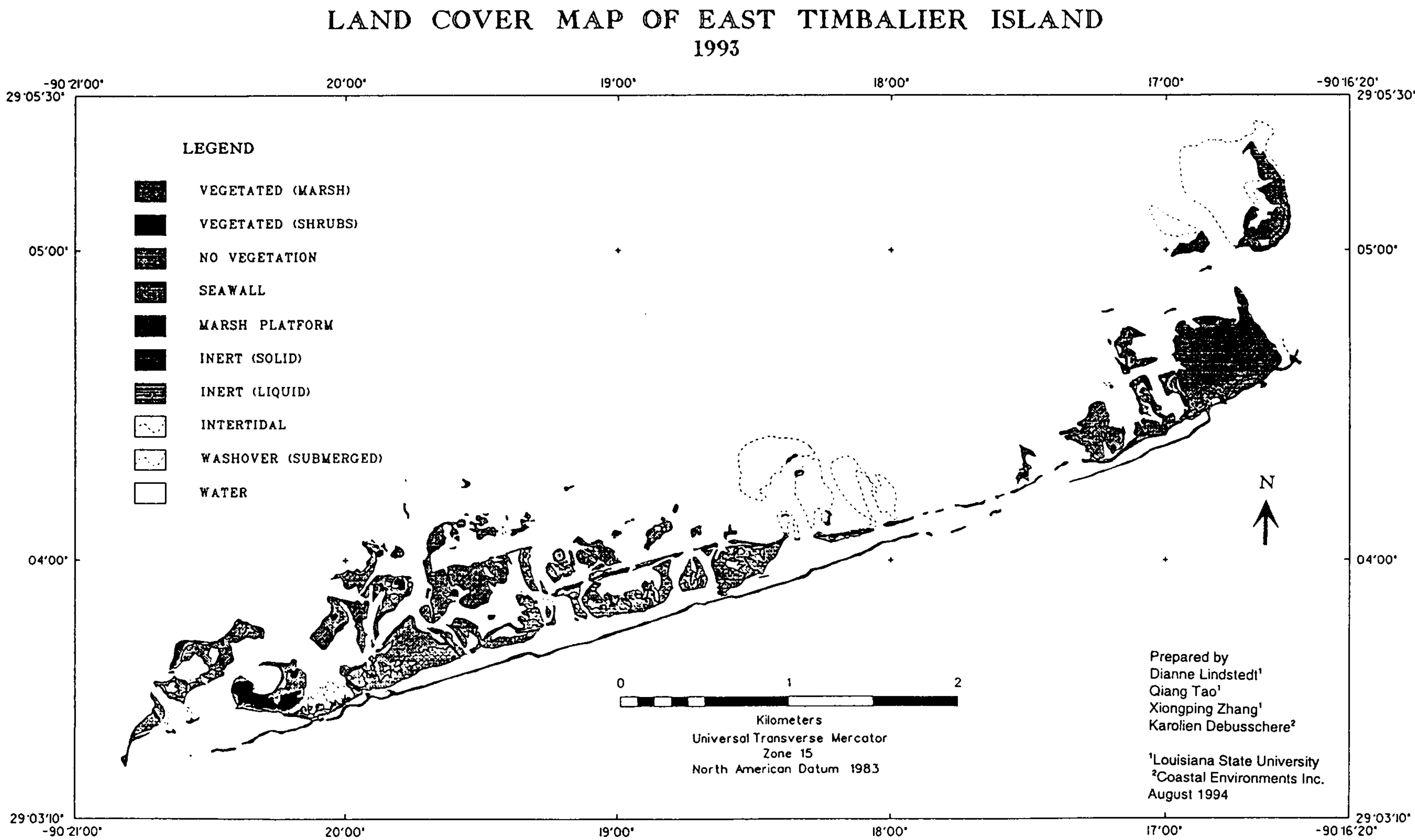

Figure 10: Land cover map of East Timbalier Island 1993.

Table 4. Land loss by land cover type in square meters between 1990 and 1993 for East Timbalier Island.

Land Cover	**1990-1992**	**1992-1993**	**1990-1993**
Vegetated Marsh	-352,341	-36,463	-388,804
Vegetated Shrubs	-24,061	-4,213	+198,848
No vegetation	-143,913	-83,138	-227,052
Submerged washover	+748,085	-286,050	+462,035
Water	-272,801	+6,984	+279,785
Seawall	-35,642	+7,730	-27,912
Marsh platform	-11,435	+7,566	-3,869
Intertidal	+27,057	+8,165	+35,223
Inert solid	-2,282	+159	-2,123
Inert liquid	-820	-245	-1,064
Total Land Area	**-570,494**	**-100,178**	**-670,672**

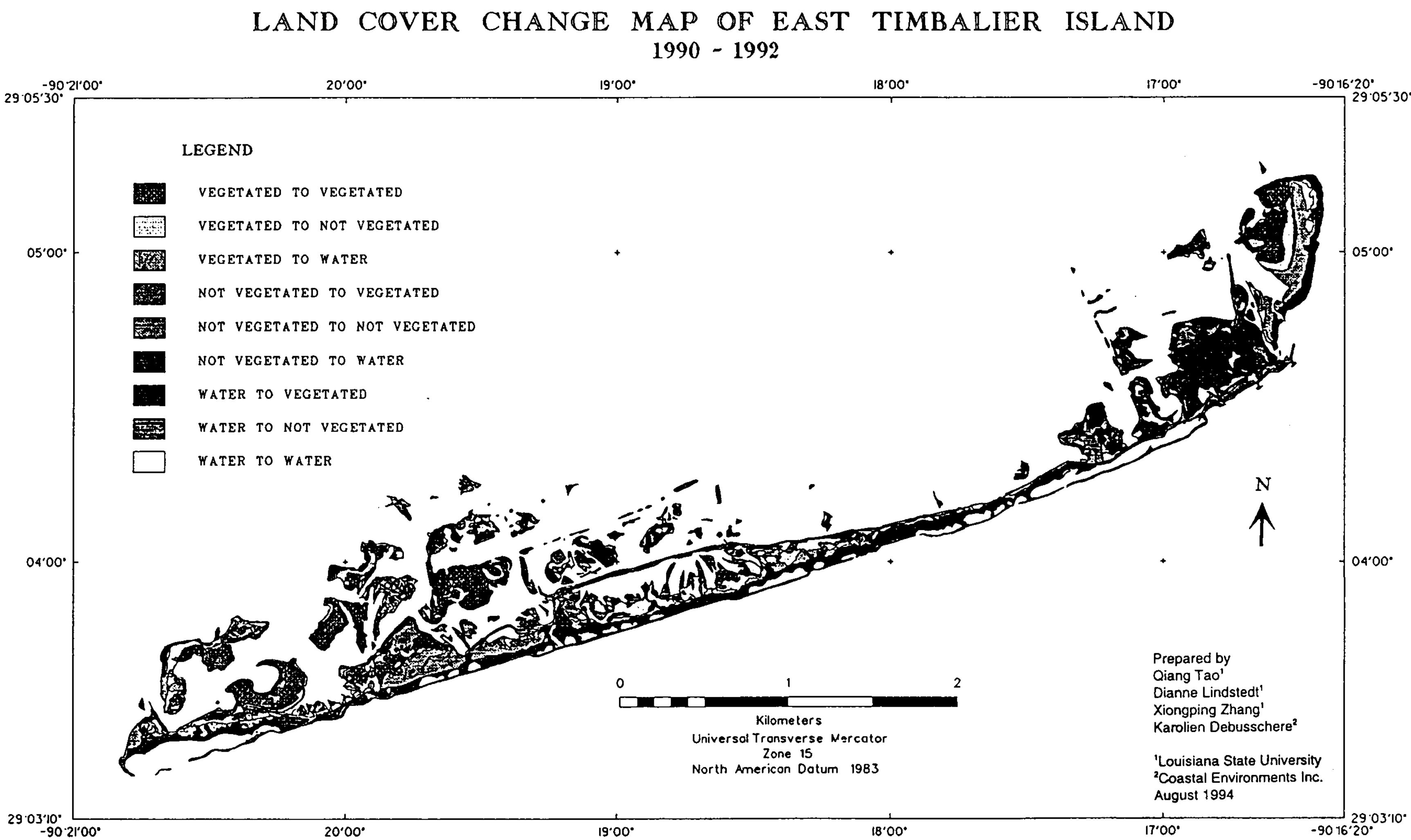

Figure 11: Land cover change map of East Timbalier Island 1990-1992.

LAND COVER CHANGE MAP OF EAST TIMBALIER ISLAND
1992 - 1993

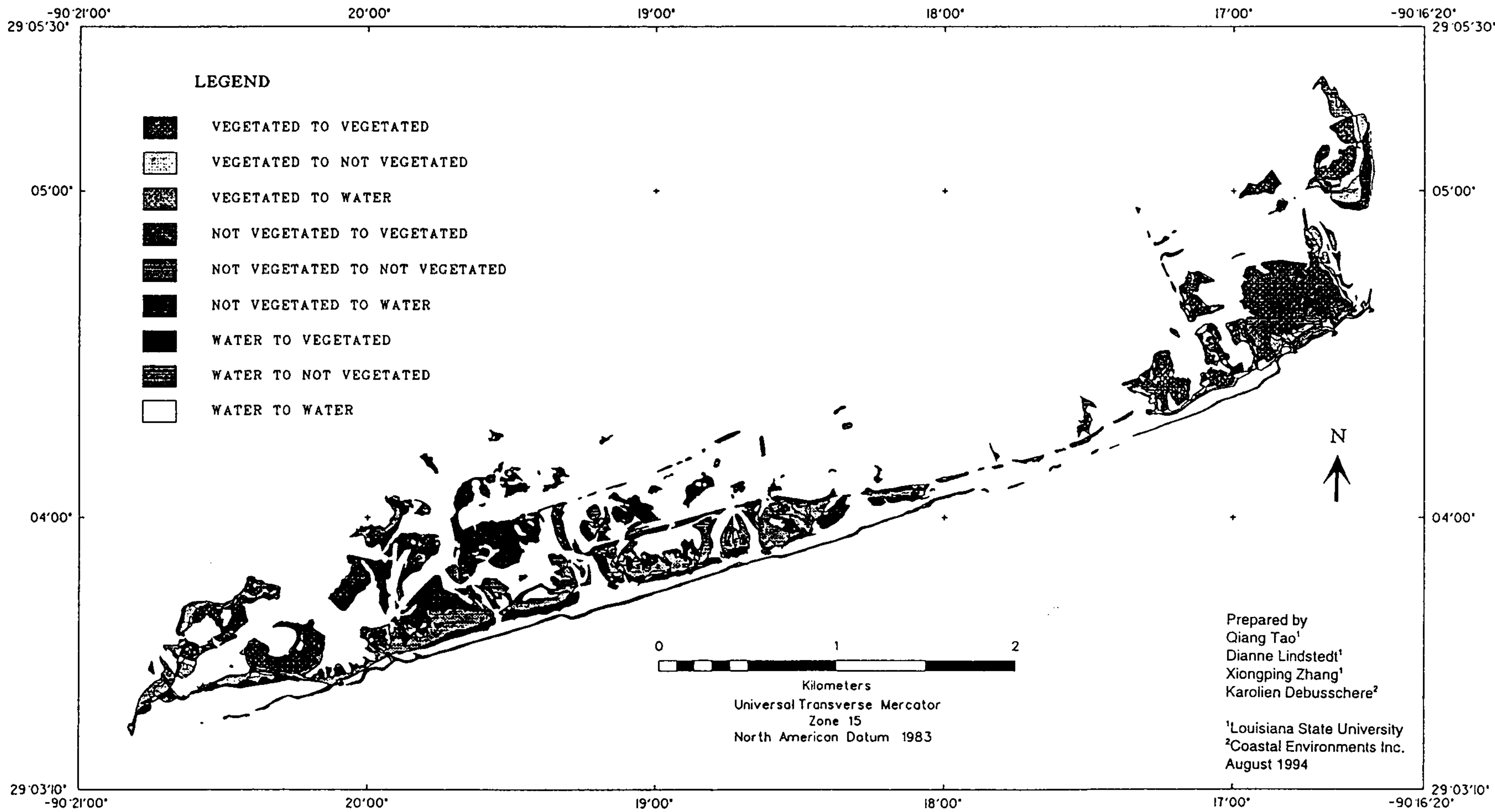

Figure 12: Land cover change map of East Timbalier Island 1992 -1993.

Table 5. Land cover change for East Timbalier Island between 1990–1992 and 1992–1993 in square meters.

LAND COVER CHANGE	**1990-1992**	**1992-1993**
Not Vegetated to Not Vegetated	291,348	342,088
Not Vegetated to Vegetated	126,062	92,424
Not Vegetated to Water	477,655	266,466
Change	**895,065**	**700,978**
Vegetated to Not Vegetated	232,155	83,967
Vegetated to Vegetated	842,230	813,242
Vegetated to Water	331,437	132,213
Change	**1,405,822**	**1,029,422**
Water to Not Vegetated	177,470	206,989
Water to Vegetated	62,087	91,508
Water to Water	117,573	560,007
Change	**357,130**	**858,504**

GPC Oil Spill Impact

Landscape Scale Analyses

The impact of the GPC oil spill on the East Timbalier Island was evaluated through a combination of remote sensing/image analysis procedures and replicated field surveys (1992 and 1993). Oiling data collected during the field surveys were mapped and superimposed over the land cover data to assess which land cover subcategories had been oiled in 1992 and were still oiled in 1993. In addition, the 1992 oiling data were superimposed over the 1992–1993 land cover change data to evaluate, from a landscape scale perspective, whether the GPC oil spill had caused changes in the island's land cover.

Oiling

The results of the oiling data reductions for the 1992 and 1993 field surveys are presented in tables 6–9 and figures 13–16. The oiling maps are enclosed as figures 17, 17A–C, 18, and 18A–C. Table 6 shows the area for each oiling category surveyed on East Timbalier Island based on the 1992 and 1993 field surveys. Table 7 provides the same information as a percent of total land area. Figures 13–16 and tables 8 and 9 provide the results of the site-specific data reduction process through which field survey information was reviewed for actual area oiled.

1992 Oiling

The total area impacted in 1992 was 446,936 m^2 or 26% of the total land area. Based on the field surveys, all oiling were surface oil. Based on the classification system used to compile the oiling maps, the majority of the oiling observed on East Timbalier Island was in the moderate category (94% of the total area impacted), covering 420,530 m^2. Isolated pockets of heavy oiling were concentrated on the east side of the island (Figures 17 and 17C) and the east side of the western portion of the island (Figures 17 and 17B). Light and very light oiling mainly occurred in relatively narrow bands along the perimeter of individual islands.

The more site-specific data reduction provided an estimate of 379,307 m^2 of total area oiled in 1992. According to these calculations 67,646 m^2, previously classified as oiled because they were located in the general zone of oil impact, were not observed to be oiled. The adjusted percentage of area observed to be oiled relative to total was 22%.

A total of 0.17% of the island was classified as heavily oiled, 18% was moderately oiled, 3% fell in the light category, and 0.002% was observed to be very lightly oiled. More than 97% of the oil observed on East Timbalier Island had an average thickness of less than 0.1 cm. The majority of the oil observed consisted of coat: 315,401 m^2 or 83% of the total oiled area; 54,077 m^2 or 14% consisted of stain/film. Only 681 m^2 or 0.18% of the total area oiled was pooled oil; 9,148 m^2 or 2% of the oil in the area was classified as cover.

1993 Oiling

In 1993 both surface oil and oil penetration were observed (Figures 18, 18A–C). Total surface area impacted was 3,186 m^2 or 0.19% of total land area (Tables 6 and 7). Surface oiling was classified as light (3,172 m^2) and very light (14 m^2). Oil penetration was observed in 1,196 m^2 or 0.07% of total land area and consisted mainly of "trace" in the upper few centimeters of the sediment. Oil penetration also was classified as light (11 m^2) and very light (1,185 m^2). Although the surface and oil penetration acreage is 4,382 m^2, oil penetration was observed in a 310 m^2 area where surface oil was documented; the total oiling impact for 1993 is thus 4,072 m^2 or 0.25% of the total land area of East Timbalier Island in 1993.

The more site-specific data reduction for the surface oiling provided an estimate of 1,088 m^2 of total actual surface area oiled in 1993 (Figure 16 and Table 8). Because the areal extent of the oil penetration cannot be determined without excavating a site, the acreage of the oil penetration was held constant. According to these calculations a total of 2,263 m^2 of surface and/or oil penetration was present during the 1993 field survey; 1,809 m^2, previously classified as having oil because they were located in the general zone of oil impact, were not observed to be oiled. The percent area observed to be oiled (both surface and penetrated) relative to total area now consists of 0.14 % (Table 9). Most of the surface oil observed had an average thickness of less than 0.01 cm (Figure 16).

1992–1993 Oiling Change

The 1992 and 1993 oiling maps and area calculations clearly indicate that very little oil remained on East Timbalier Island one year after the spill occurred. Some of this decrease in oiling could be attributed to erosion of oiled areas, whether whole land sections or erosion of the oiled fringe of an island. However, the majority of the oiled areas are still present and were no longer oiled according to the 1993 field survey observations. The reduction of oil over this one-year period is more likely due to the natural degradation of the oil in the environment and oil being flushed out of the marshes during high water.

Actual surface oiling was reduced from 379,307 m^2 to 1,088 m^2 between 1992 and 1993; oil penetration increased from 0 m^2 to 1,196 m^2. Most of the areas where oil was observed in 1993 were areas located in the interior sections of the marshes, where oil had been classified as pooled or cover and had been observed on the sediment versus on the marsh vegetation during the 1992 survey. These conditions are most likely responsible for the presence of oil penetration. In these areas pooled oil that became trapped in the interior marshes either penetrated the sediment over time or became covered by a thin layer of newly deposited sediment.

		Width of Oiled Area			
		Wide >6m	**Medium** 3–6m	**Narrow** 0.5–3m	**Very Narrow** <0.5m
Oil Distribution	**Continuous** 91–100%	*Heavy* 213,572	*Heavy* 44,902	*Moderate* 8,597	*Light* 67
	Broken 51–90%	*Heavy* 50,631	*Moderate* 3,897	*Light* 6,661	*Light* 0
	Patchy 11–50%	*Moderate* 108,506	*Moderate* 1,315	*Light* 2,466	*Very Light* 4
	Sporadic 1–10%	*Light* 2,445	*Light* 3,707	*Very Light* 0	*Very Light* 0
	Trace <1%	*Very Light* 0	*Very Light* 0	*Very Light* 181	*Very Light* 0

Figure 13. Initial surface oil cover matrix: total square meters oiled plus unoiled in each surveyed category for 1992.

		Initial Surface Oil Cover Category (from Initial Surface Oil Cover Matrix)				
		Heavy	**Moderate**	**Light**	**Very Light**	**Total Area per Oil Thickness**
Average Thickness	**Thick or Pooled > 1 cm**	*Heavy* 467	*Heavy* 173	*Moderate* 38	*Light* 3	**681**
	Cover 0.1–1.0cm	*Heavy* 2,349	*Moderate* 1,088	*Moderate* 5,689	*Very Light* 22	**9,148**
	Coat 0.01–0.1cm	*Moderate* 272,874	*Moderate* 38,698	*Light* 3,809	*Very Light* 20	**315,401**
	Stain/Film <0.01cm	*Light* 15,330	*Light* 37,906	*Light* 842	*Very Light* 0	**54,078**
					TOTAL	**379,307**

Figure 14. Surface oil categorization matrix: total square meters oiled for 1992.

		Width of Oiled Area			
		Wide >6m	**Medium** 3–6m	**Narrow** 0.5–3m	**Very Narrow** <0.5m
Oil Distribution	**Continuous** 91–100%	*Heavy* 0	*Heavy* 0	*Moderate* 0	*Light* 0
	Broken 51–90%	*Heavy* 0	*Moderate* 0	*Light* 185	*Light* 0
	Patchy 11–50%	*Moderate* 2096	*Moderate* 25	*Light* 31	*Very Light* 0
	Sporadic 1–10%	*Light* 691	*Light* 180	*Very Light* 14	*Very Light* 0
	Trace <1%	*Very Light* 0	*Very Light* 0	*Very Light* 0	*Very Light* 0

Figure 15. Initial surface oil cover matrix: total square meters oiled plus unoiled in each surveyed category for 1993.

		Initial Surface Oil Cover Category (from Initial Surface Oil Cover Matrix)				
		Heavy	**Moderate**	**Light**	**Very Light**	**Total Area per Oil Thickness**
Average Thickness	**Thick or Pooled > 1 cm**	*Heavy* 0	*Heavy* 0	*Moderate* 0	*Light* 0	**0**
	Cover 0.1–1.0cm	*Heavy* 0	*Moderate* 0	*Moderate* 0	*Very Light* 0	**0**
	Coat 0.01–0.1cm	*Moderate* 0	*Moderate* 0	*Light* 156	*Very Light* 0.7	**156**
	Stain/Film <0.01cm	*Light* 0	*Light* 932	*Light* 0	*Very Light* 0	**932**
					TOTAL	**1,088**

Figure 16. Surface oil categorization matrix: total square meters oiled for 1993.

Table 6. Oil impacted area by oiling categories for 1992 and 1993.

East Timbalier Island Oiling Map Categories	**OIL IMPACTED Area (m^2) 1992 Survey**	**OIL IMPACTED Area (m^2) 1993 Survey**	
	Surface	***Surface***	***Penetrated***
Heavy	2,455	0	0
Moderate	420,531	0	0
Light	23,870	3,172	11
Very Light	98	14	1,185
No Oil	1,225,418	1,626,144	1,629,020
Not Surveyed	58,022	0	0
Water	61,217	54,233	54,233
TOTAL LAND	**1,730,394**	**1,630,216**	
TOTAL OIL IMPACTED	**446,953**	**4,072**	

Table 7. Oil impacted area as a percent of total land area by oiling categories for 1992 and 1993.

East Timbalier Island Oiling Map Categories	**PERCENT OIL IMPACTED 1992 Survey**	**PERCENT OIL IMPACTED 1993 Survey**	
	Surface	*Surface*	*Penetrated*
Heavy	0.14	0	0
Moderate	24.30	0	0
Light	1.38	0.19	0.0007
Very Light	0.006	0.0008	0.07
No Oil	70.82	99.75	99.93
Not Surveyed	3.35	0	0

Table 8. Actual oiled area by oiling categories for 1992 and 1993.

East Timbalier Island Oiling Categories	**ACTUAL OILED AREA (m^2) 1992 Survey**	**ACTUAL OILED AREA (m^2) 1993 Survey**	
	Surface	*Surface*	*Penetrated*
Heavy	2,989	0	0
Moderate	318,387	0	0
Light	57,889	1,087	11.0
Very Light	42	0.7	1,185
No Oil	1,293,064	1,629,128	1,629,020
Not Surveyed	58,022	0	0
Water	61,217	54,233	54,233
TOTAL LAND	**1,730,394**	**1,630,216**	
TOTAL OIL IMPACTED	**379,307**	**2,263**	

Table 9. Actual oiled areas by oiling categories as a percent of total land area for 1992 and 1993.

East Timbalier Island Oiling Map Categories	**PERCENT ACTUAL OIL 1992 Survey**	**PERCENT ACTUAL OIL 1993 Survey**	
	Surface	*Surface*	*Penetrated*
Heavy	0.2	0	0
Moderate	18	0	0
Light	3	0.07	0.007
Very Light	0.002	0.00004	0.07
No Oil	75	100	100
Not Surveyed	3	0	0

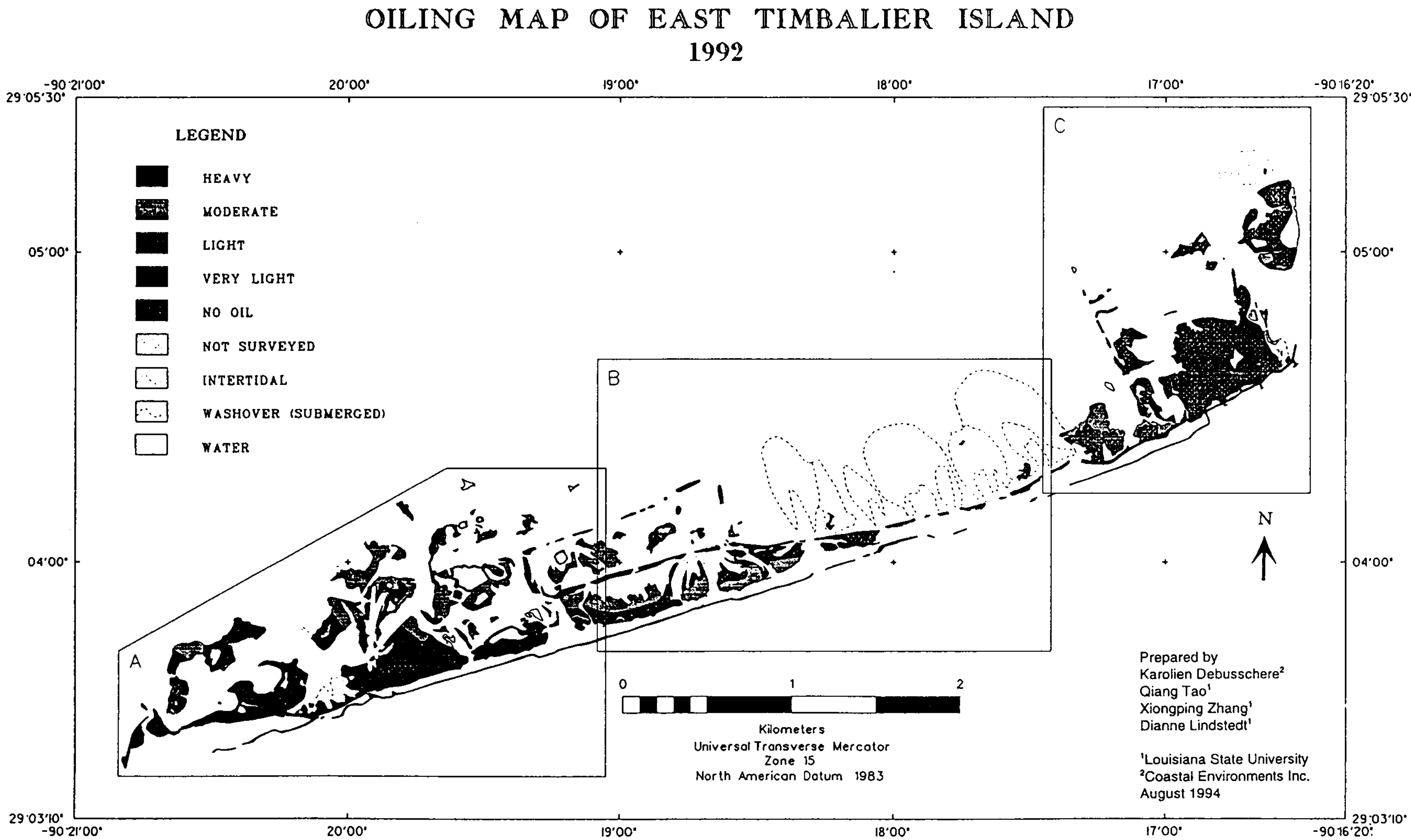

Figure 17: Oiling map of East Timbalier Island 1992.

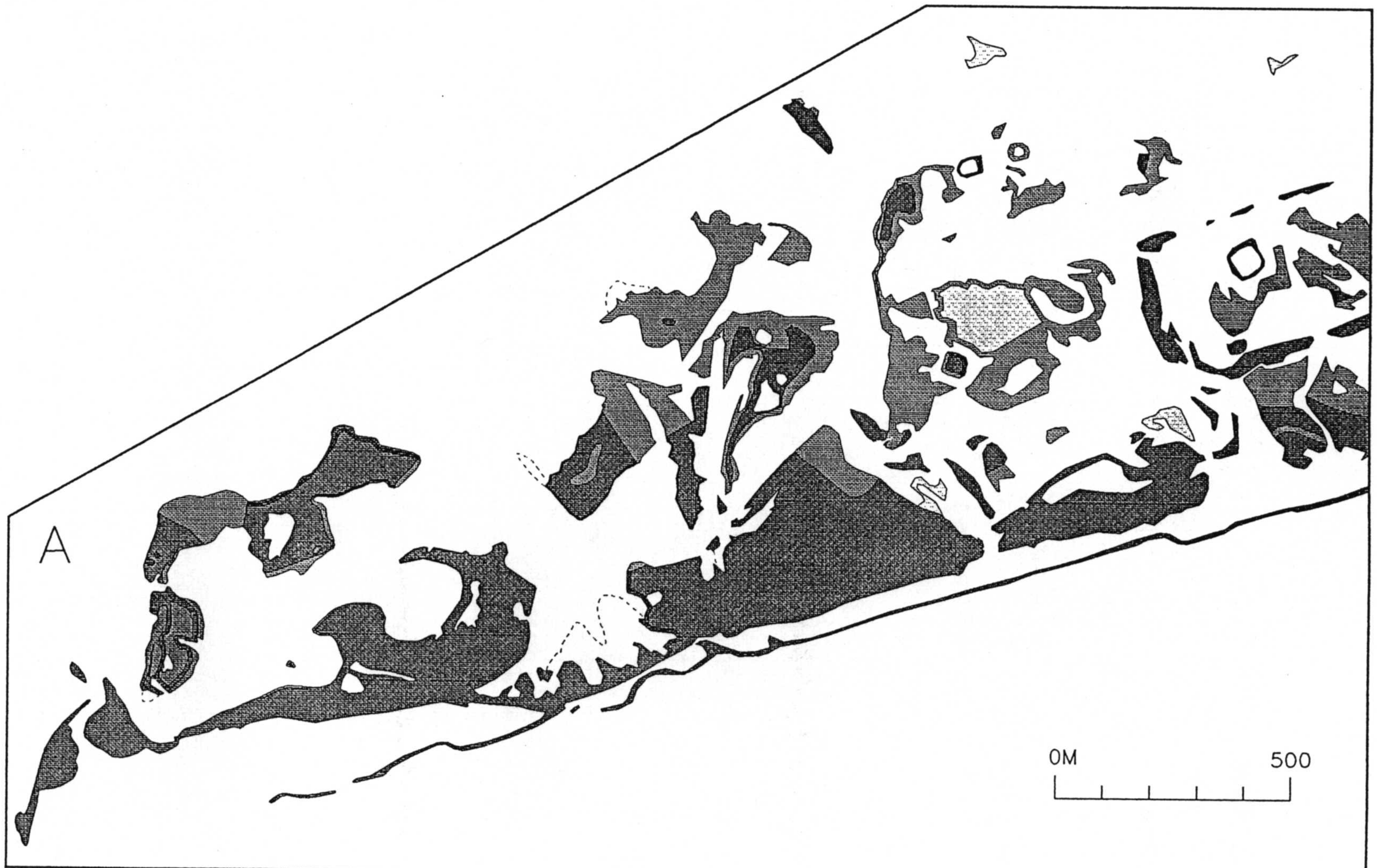

Figure 17A: 1992 oiling west side of island.

Figure 17B: 1992 oiling mid island.

Figure 17C: 1992 oiling east side of island.

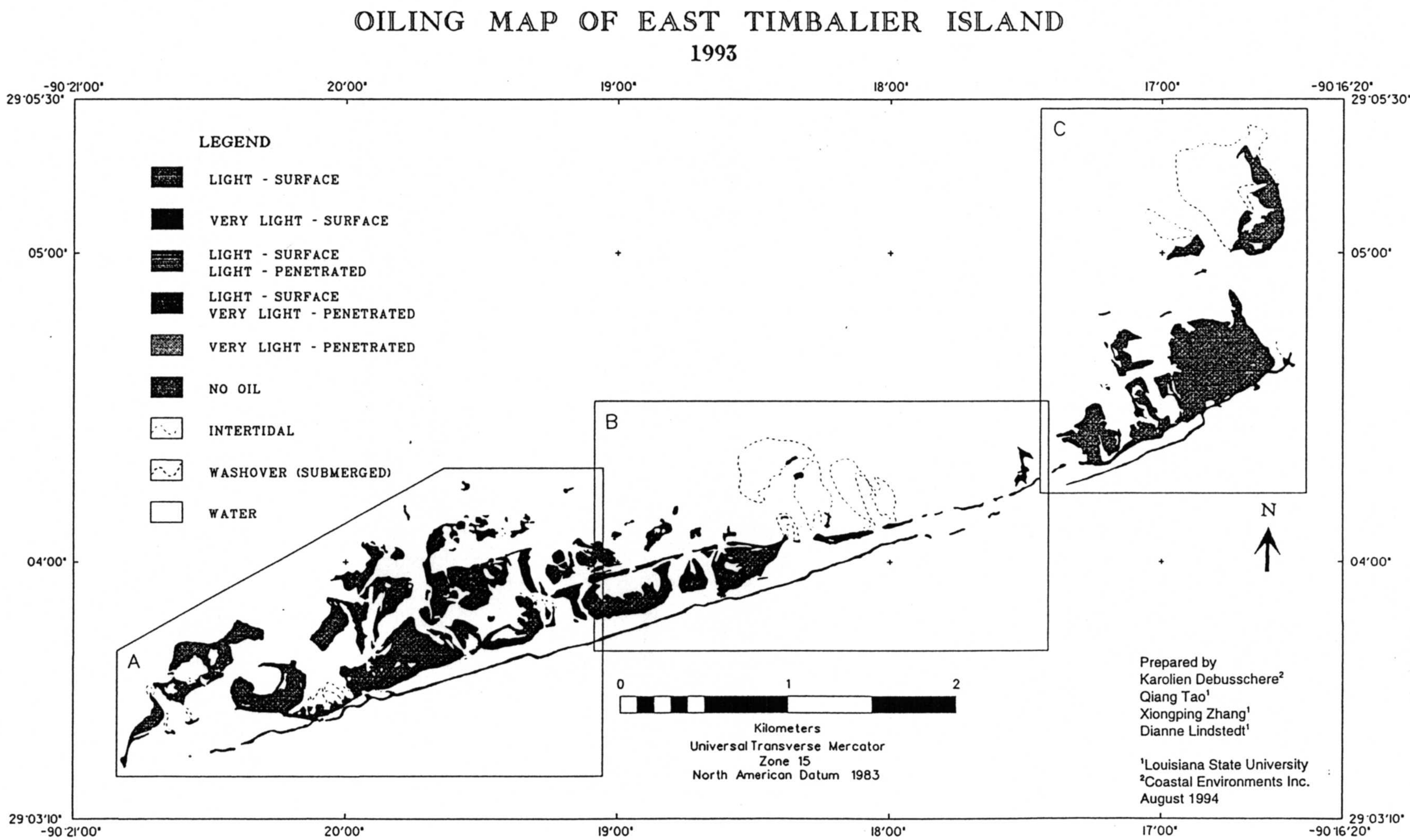

Figure 18: Oiling map of East Timbalier Island 1993.

Figure 18A: 1993 oiling west side of island.

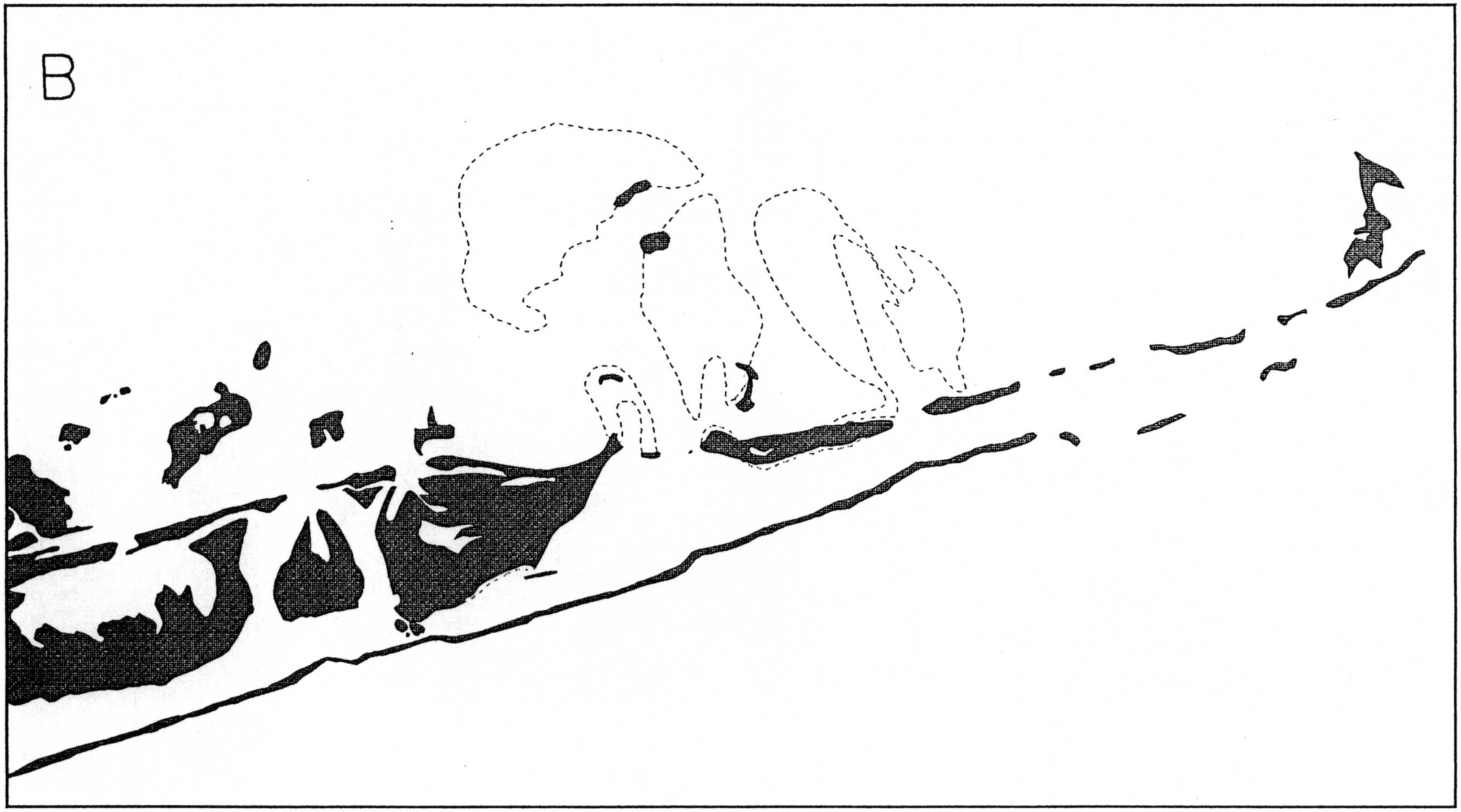

Figure 18B: 1993 oiling mid island.

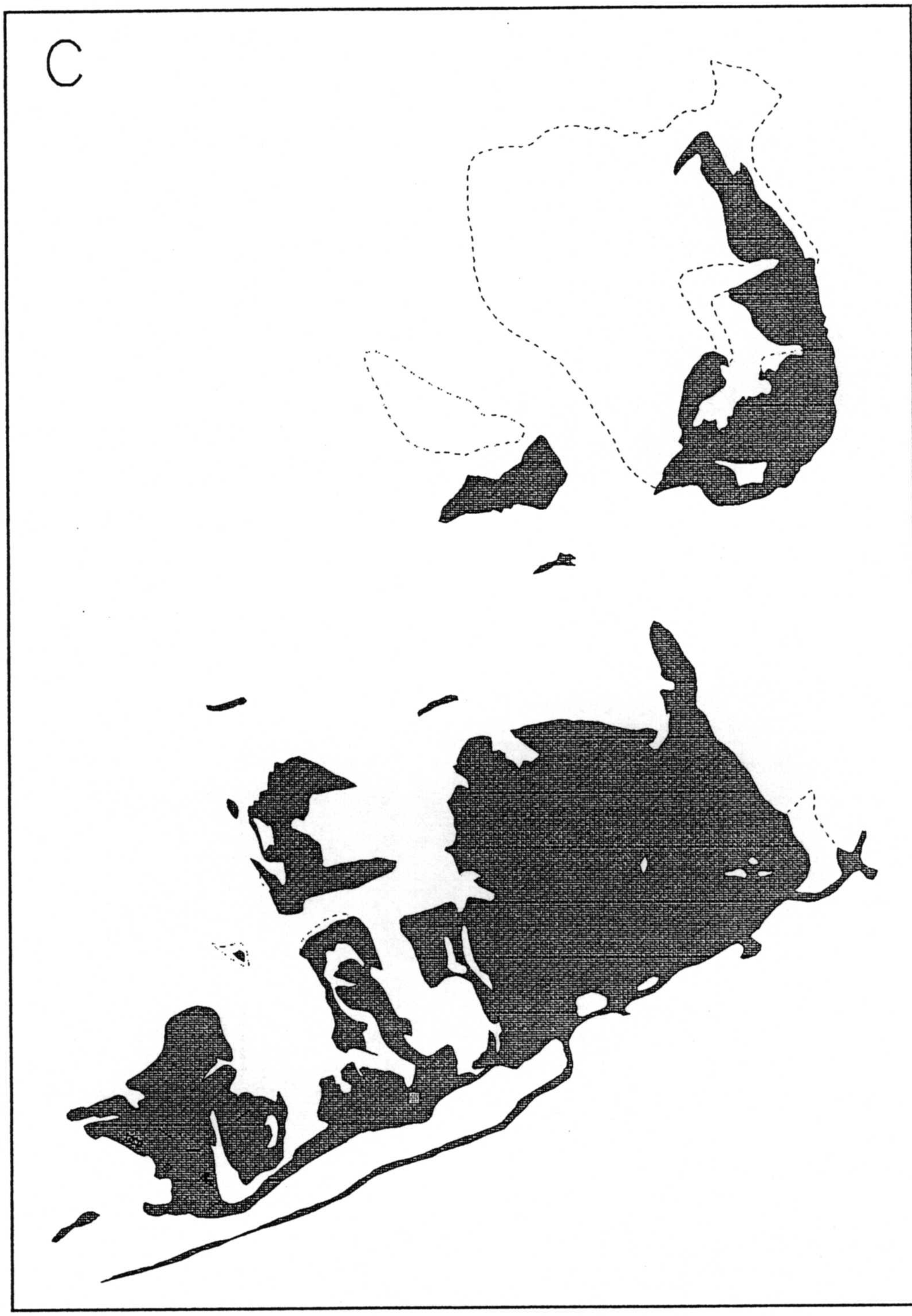

Figure 18C: 1993 oiling east side of island.

Oiling Impact

To determine which land cover categories had been impacted by each oiling category, the 1992 and 1993 oiling data were superimposed onto the 1992 and 1993 land cover maps, respectively (Figures 19–20). For that purpose, land cover subcategories were grouped according to vegetated areas, not vegetated areas, and water; oil impacted areas were reclassified as oiled or not oiled. In 1992, 67% of the oiling was observed in vegetated areas and 33% in not vegetated areas. Of the oil observed in 1993, 92% was found in vegetated areas and 8% in not vegetated areas.

To evaluate whether the presence of oil could be responsible for changes in land cover on the island, the 1992 oiling data were superimposed on the 1992–1993 land cover change maps for area calculations (Figure 13 and Table 10). Of the total not vegetated area that was oil impacted in 1992, approximately 39% changed to water and 18% became vegetated by 1993; 43% of the oiled unvegetated areas in 1992 remained not vegetated by 1993. Of the total vegetated area that was oil impacted in 1992, approximately 15% changed to water and 5% became not vegetated by 1993; 80% of the oiled vegetated areas in 1992 remained vegetated by 1993.

Based on this analysis, there are no large-scale impacts of the 1992 GPC oil spill on East Timbalier Island. This conclusion is further substantiated when considering the percent land cover change relative to the total area mapped as oiled in 1992 (Table 10). The data indicate that approximately 68% of the oiled area did not change land cover, i.e., oiled vegetated and unvegetated areas in 1992 remained vegetated or not vegetated in 1993, respectively. A total of 23% of the oiled area changed to water by 1993. However, this is not necessarily because of oil impact. Most of the oiled vegetated areas that became classified as water were located along the fringes of islands, which are areas most likely to be eroded (Figure 13). Therefore, this change in land cover can be largely attributed to natural erosion.

The oiled unvegetated areas that changed to water were mostly located to the west of the breached mid section of the island, between the two seawalls. This area had been greatly affected by Hurricane Andrew, and changes from not vegetated to water are more likely the result of the local coastal processes on the exposed sand deposits.

The change in land cover from not vegetated to vegetated in areas that were oiled in 1992 constitutes approximately 6% of the total area mapped as oiled in 1992. This change in land cover clearly cannot be interpreted as a negative oiling impact but rather are recovering areas. Where not only oil has degraded but has also been invaded by vegetation.

The only change in land cover that could potentially be attributed solely to oiling is the change from vegetated to not vegetated. This change category constitutes approximately 3% of the total area oiled in 1992 and approximately 5% of the total vegetated area oiled in 1992. To assess whether these areas had become not vegetated as a result of oiling impact, they were further investigated with respect to their relative location on a land mass (fringe or interior) and the 1993 oiling classification.

All of the polygons that changed from vegetated to not vegetated during this one-year period were observed to be unoiled in 1993. In addition, the majority of those areas were located along the fringes of islands at the western end of the island and to the west of the breached mid section of the island between the two seawalls. Both sections of the island are exposed to natural coastal processes, are overall very dynamic areas, and were characterized by major changes in land cover as a result of Hurricane Andrew (land loss and washover deposits). The changes from vegetated to not vegetated land cover in those areas cannot conclusively be attributed to oiling impact.

However, some of the areas oiled in 1992 that changed from vegetated to not vegetated land cover between 1992 and 1993 were located in the interior of a land mass or in sheltered areas. The majority of those areas were located on the eastern end of the island. Although these areas were no longer oiled in 1993, this change in land cover is probably the result of oiling impact.

The landscape scale analysis indicates that all land cover changes from vegetated to not vegetated cannot necessarily be attributed to oil impact. But the 1993 field investigations indicate that some impact of the oil spill on the vegetation on East Timbalier Island was not recorded on a landscape scale. In several areas where oiling had occurred in 1992, the 1993 field surveys determined that recruitment of vegetation was limited. These areas occur throughout the whole island (Figure 21). Several are located in areas that were heavily oiled in 1992 and where oil was present in 1993. These areas were either too small or too narrow to detect during aerial photointerpretation at a scale of 1:12,000. Some noted differences in the field were bare patches, bare patches with dead stalks, stunted plants, or very sparse regrowth of *Spartina alterniflora* (Figure 22).

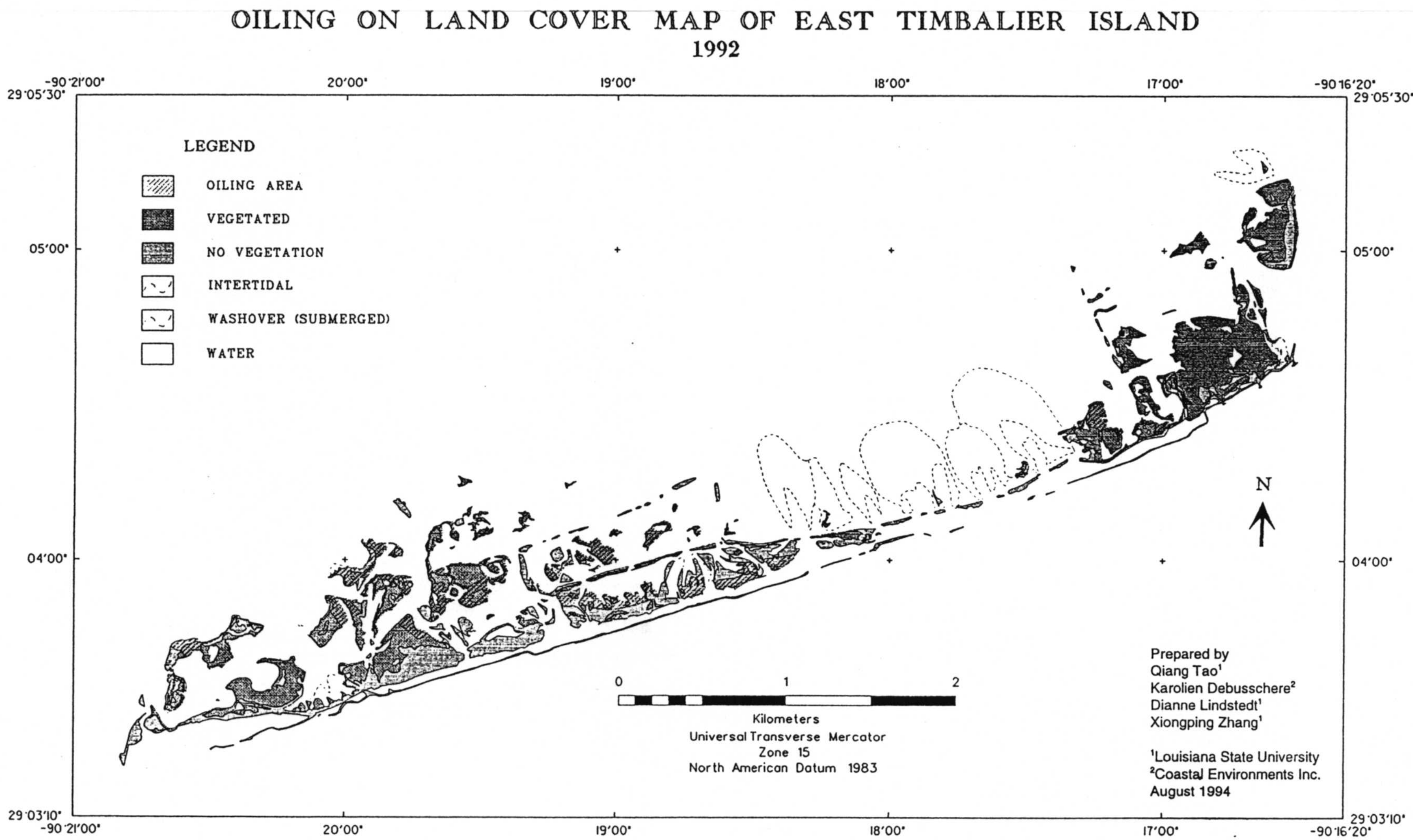

Figure 19: Oiling on land cover map of East Timbalier Island 1992.

OILING ON LAND COVER MAP OF EAST TIMBALIER ISLAND
1993

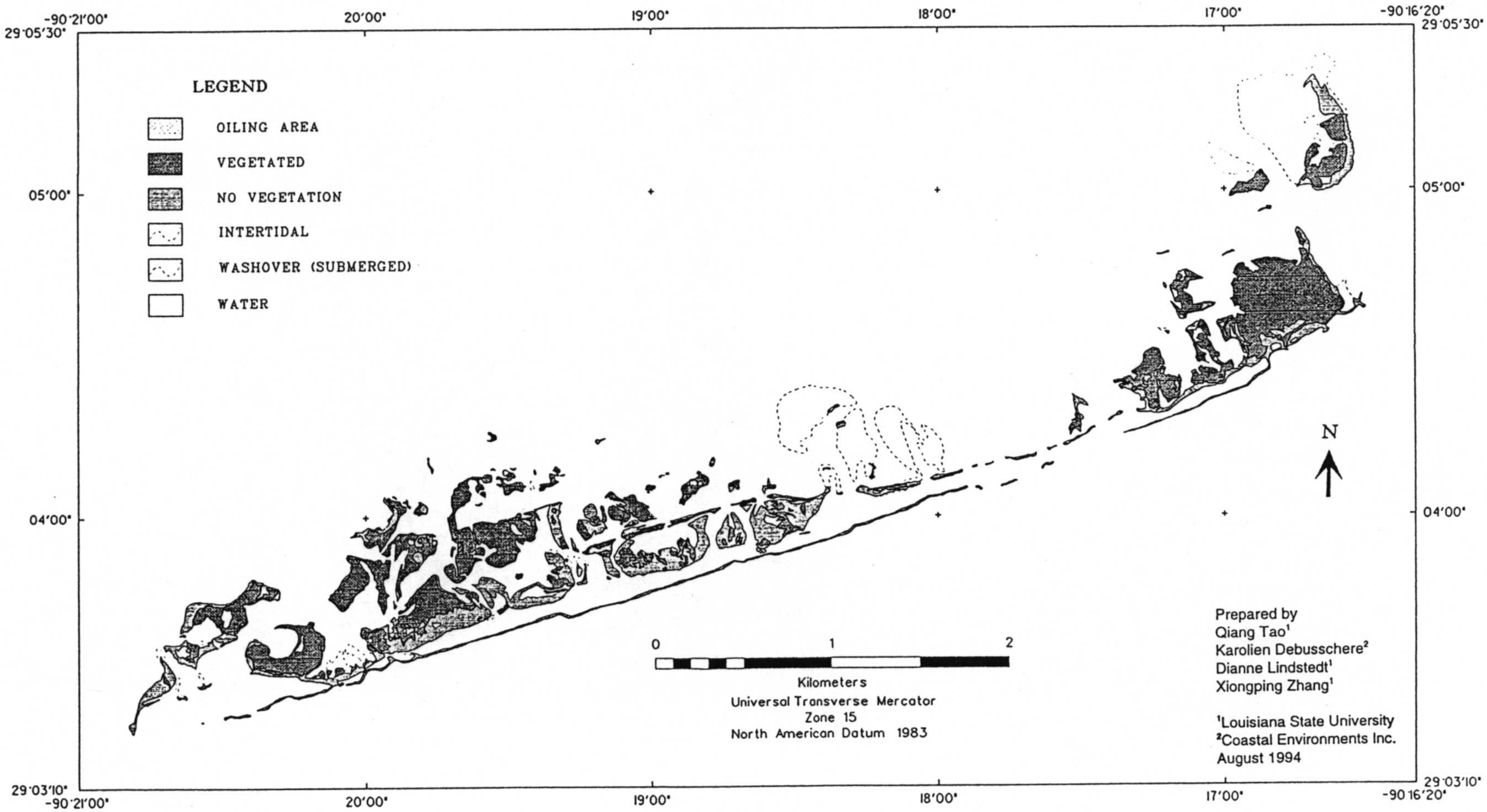

Figure 20: Oiling on land cover map of East Timbalier Island 1993.

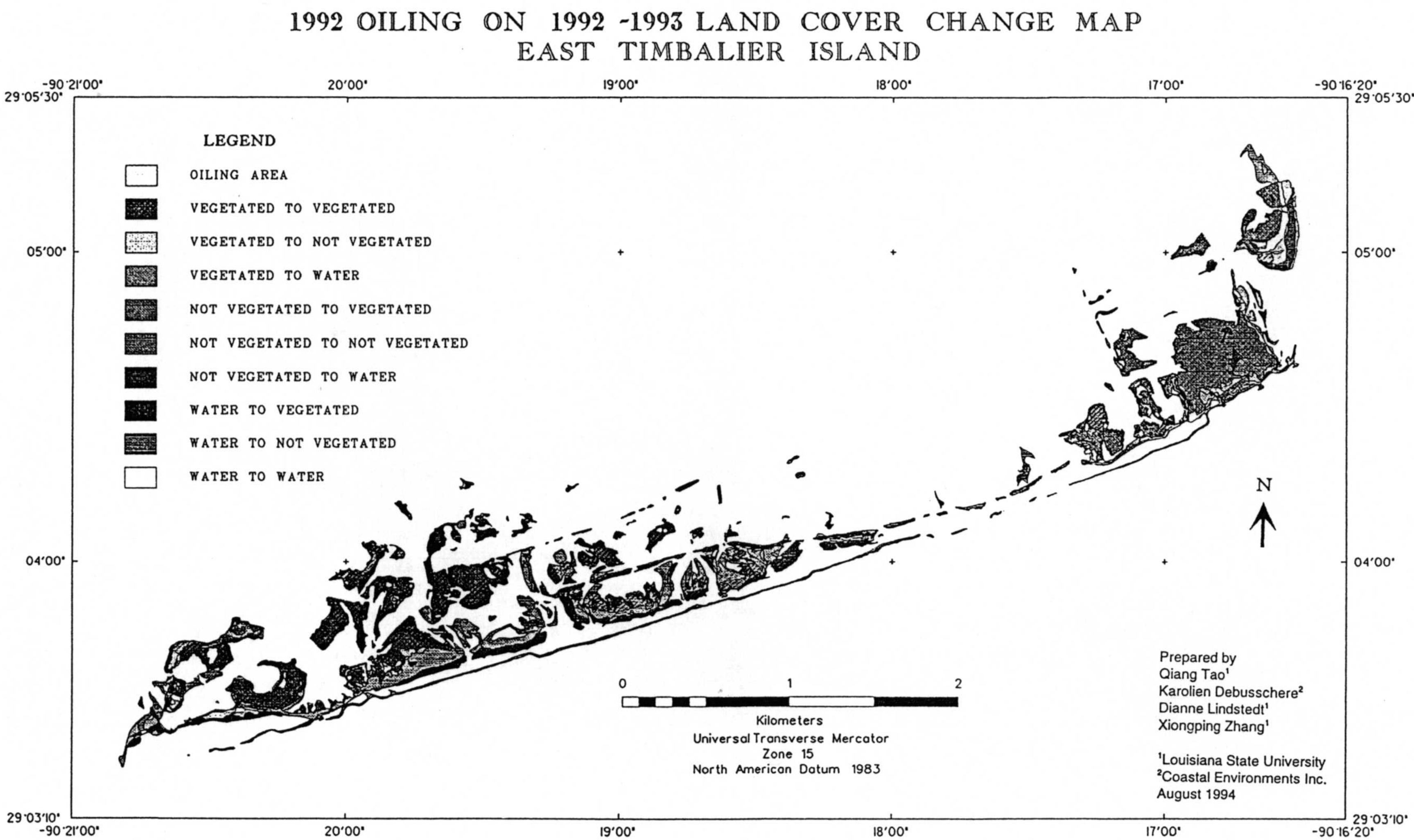

Figure 21: 1992 Oiling on 1992-1993 land cover change map East Timbalier Island.

Table 10. Summary of 1992 oil impacted areas on 1992-1993 land cover change map.

LAND COVER CHANGE	PERCENT
*Percent Land Cover Change of **Total Not Vegetated** Oiled Area in 1992*	
Not Vegetated to Not Vegetated	43
Not Vegetated to Vegetated	18
Not Vegetated to Water	39
*Percent Land Cover Change of **Total Vegetated** Oiled Area in 1992*	
Vegetated to Not Vegetated	5
Vegetated to Vegetated	80
Vegetated to Water	15
*Percent Land Cover Change of **Total Oiled Area** in 1992*	
Not Vegetated to Not Vegetated	14
Not Vegetated to Vegetated	6
Not Vegetated to Water	13
Vegetated to Not Vegetated	3
Vegetated to Vegetated	54
Vegetated to Water	10

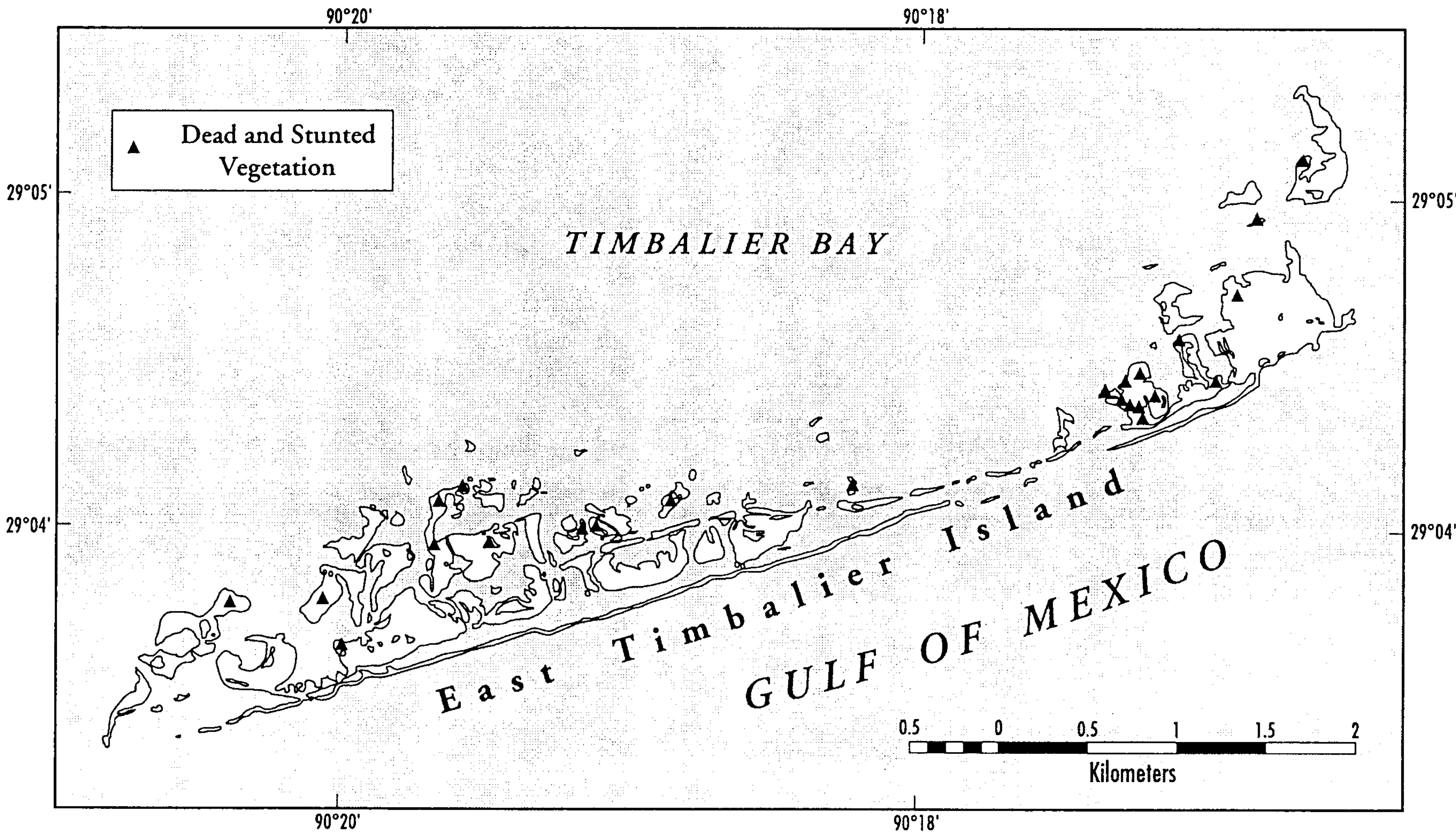

Figure 22. Locations where dead stalks, stunted vegetation, and bare areas were observed in November 1993 surveys.

Community Scale Analyses

Community scale responses of the backbarrier marsh vegetation to the GPC oil spill were evaluated at nine marsh sites, which were sampled 22 and 23 November 1993. Each site consisted of an oiled and adjacent unoiled location, where plant biomass, plant cover, and oil concentrations in the soil were determined. Statistical comparisons were made between oiled and unoiled plots at each marsh site to provide site-specific impact assessments, and between oiled and unoiled locations over all nine marsh sites, in order to provide a more integrated assessment of the impact over the island.

Plant Biomass

Live aboveground biomass was significantly lower in oiled compared to unoiled locations at four of the nine marsh sites investigated (Figure 23). However, at two marsh sites, 7 and 9, the oiled marsh had significantly greater biomass than the unoiled marshes (Figure 23). At three marsh sites, no significant differences between oiled and unoiled locations were evident (Figure 23). Thus, on a marsh-specific basis, it would appear that of the nine pairs of backbarrier marsh sites sampled on East Timbalier Island 14 months after the spill, four sites (1, 3, 4, and 6) were affected negatively by the oil; three sites (2, 5 and 8) were unaffected; and two sites exhibited a positive response to the spill.

However, when the mean live biomass of all oiled locations was compared with that of all unoiled locations ($n=9$), no statistically significant difference was observed (Figure 24). Although some specific marshes on East Timbalier Island had not yet completely recovered from the oiling, a number of marshes showed either no effect or a stimulatory effect to the oil, resulting in average island effect that was not significant. Thus, assuming that the selected marsh sites were representative of the conditions of the whole island (a reasonable assumption based on our observations of the backbarrier marshes of East Timbalier Island), the live aboveground biomass data indicate that marsh recovery was proceeding on the island; although, some specific marsh sites still showed reduced biomass because of the oil.

Dead aboveground biomass was not necessarily higher in oiled locations compared to unoiled locations (Figure 25). Of the nine pairs of marsh sites evaluated, two had significantly greater dead biomass when oiled (sites 8 and 9), two had significantly less dead biomass when oiled (sites 3 and 4), and five sites showed no differences in dead biomass (Figure 25). Because the field sampling took place 14 months (one growing season) after the spill, it is not surprising that much of the dead vegetation apparent immediately after the spill had decomposed and been removed by tides. The overall dead biomass means for oiled and unoiled locations also indicated no significant difference in this response to oiling (Figure 26).

Total (live plus dead) aboveground biomass had similar responses to oiling as live aboveground biomass except that a significant effect of oiling was not found at marsh site 1 (Figure 27). When total biomass was averaged over all marsh sites, oiling had no significant effect on total biomass (Figure 28), a response similar to that observed for live biomass (Figure 24).

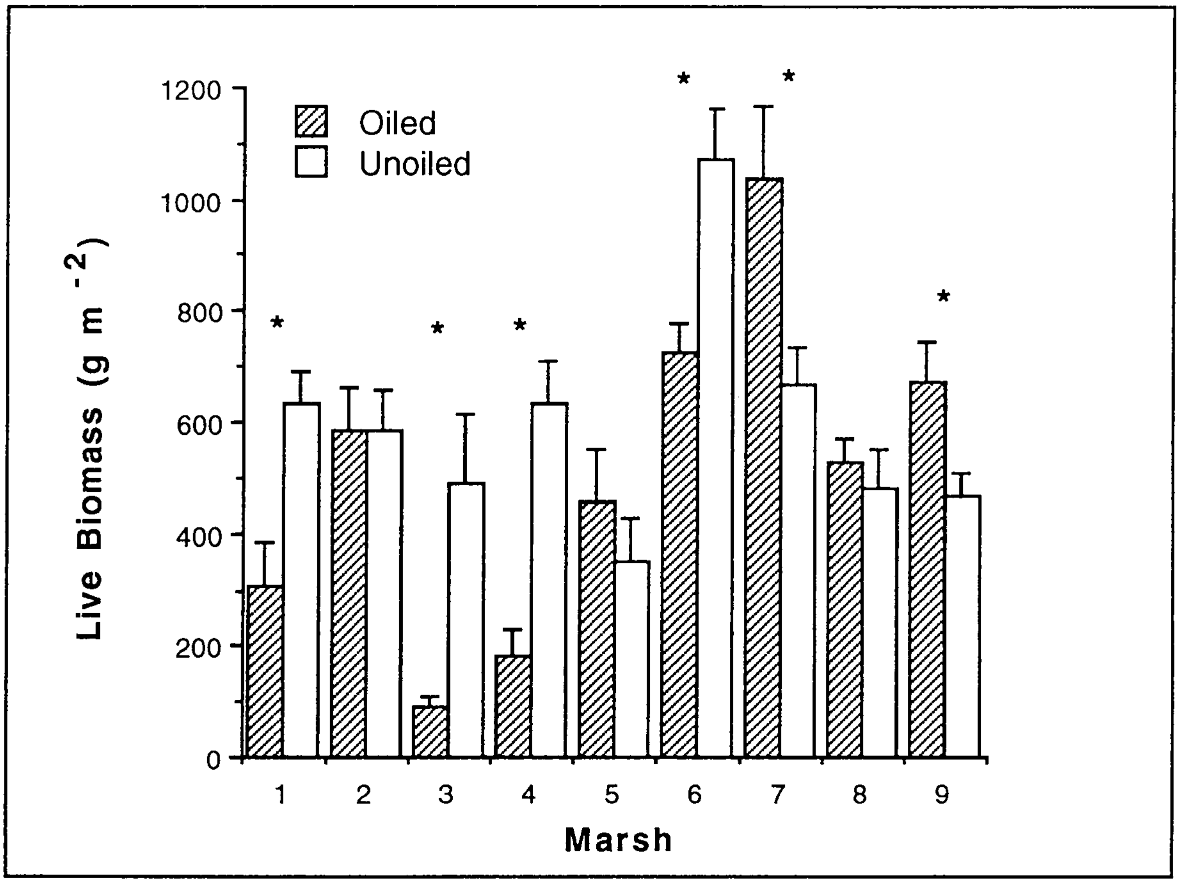

Figure 23. Live aboveground biomass of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=5, * indicates $p < .05$).

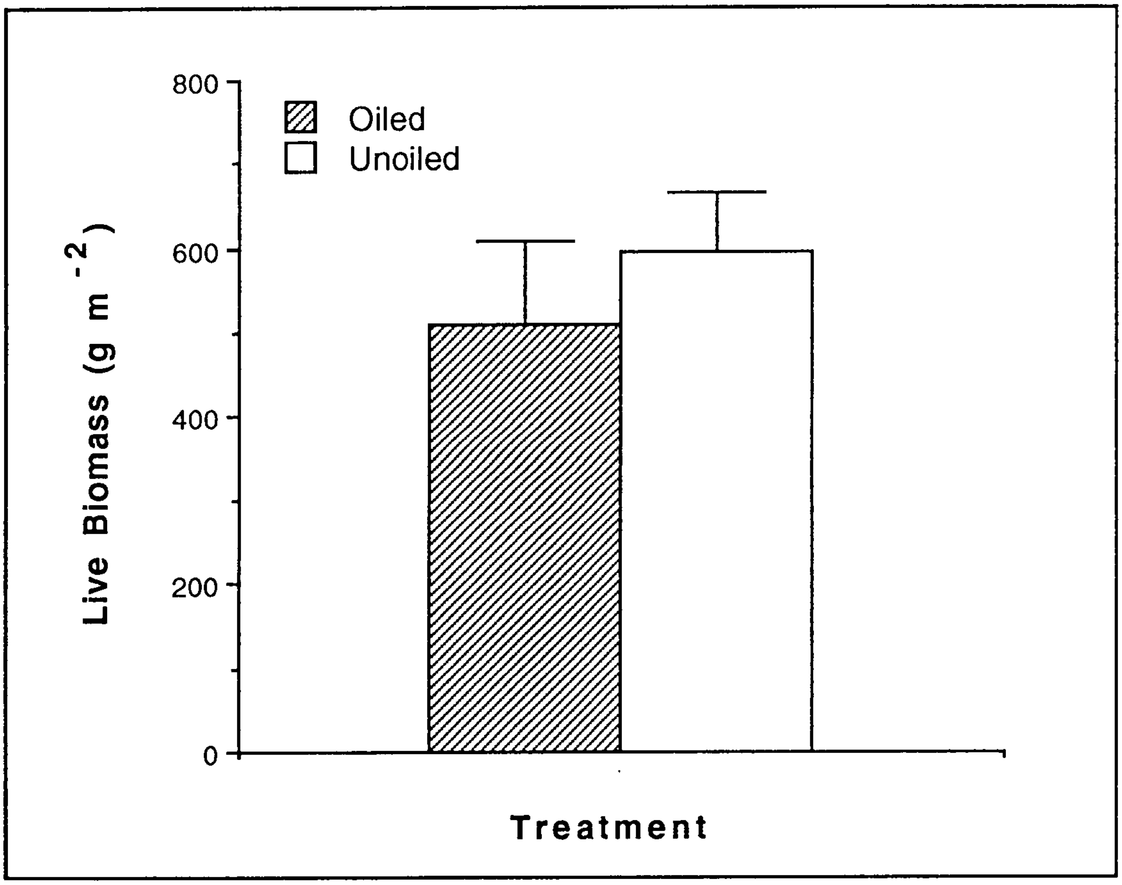

Figure 24. Live aboveground biomass of *Spartina alterniflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error; n=9, * indicates $p<.05$).

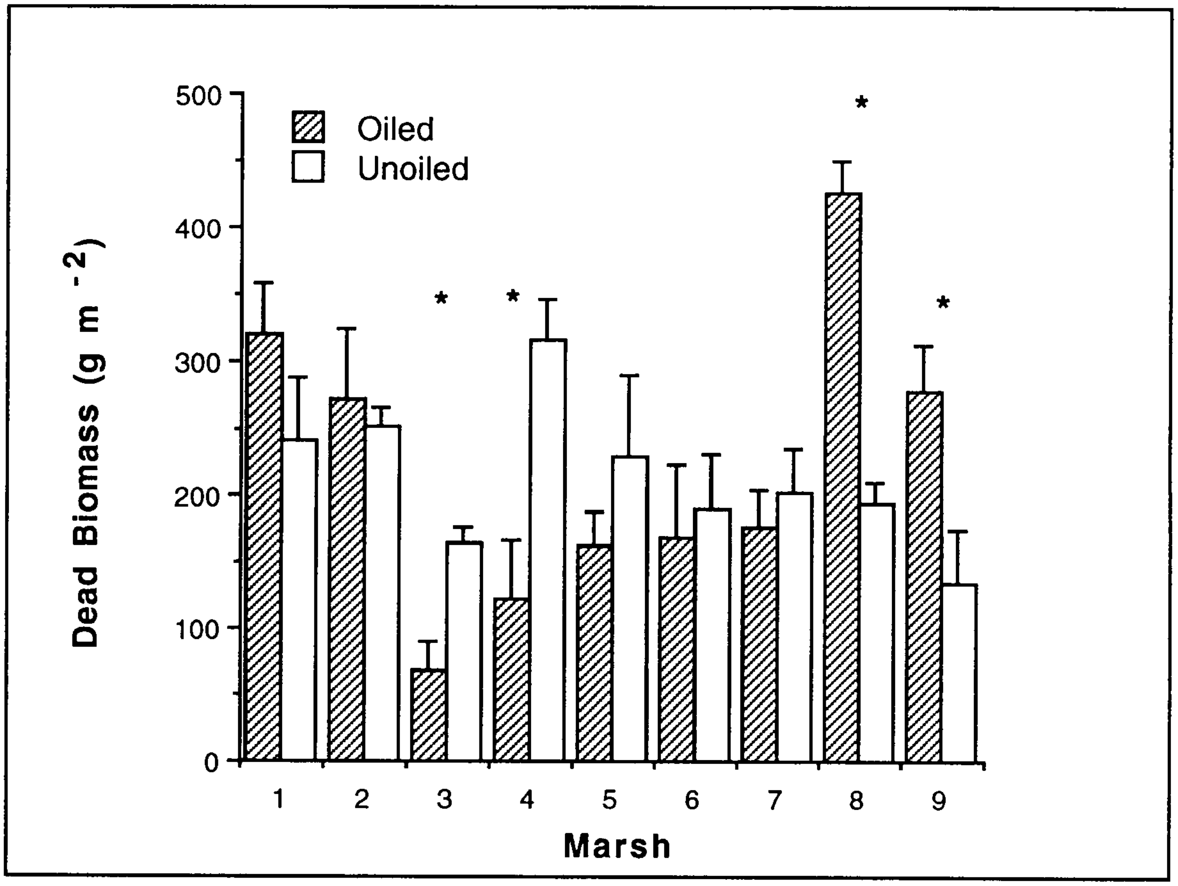

Figure 25. Dead aboveground biomass of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=5, * indicates $p<.05$).

The ratio of live-to-dead aboveground biomass can be a valuable means of identifying oil stress to vegetation and is often more sensitive than either biomass component alone (Lin and Mendelssohn unpublished data). The live-to-dead biomass ratio was significantly lower in oiled compared to unoiled locations at three marsh sites (1, 3, and 8) (Figure 29). Marsh sites 1 and 3 also had significantly reduced live biomass in the oiled compared to the unoiled marshes (Figure 23). Marsh site 8, however, exhibited no significant difference in live aboveground biomass between oiled and unoiled marshes (Figure 23); even though, the live-to-dead ratio was significantly lower in the oiled marsh (Figure 29). When averaged over all marsh sites, the live-to-dead biomass ratio was not significantly different between oiled and unoiled locations (Figure 30). Because the dead aboveground biomass was probably removed from the sampling plots by the tides during the 14 months between the spill event and the field sampling, the live-to-dead ratio, in this particular instance, is probably not a sensitive evaluator of the oil impact.

Plant height was significantly different between oiled and unoiled locations at four marsh sites (2, 3, 6, and 7) (Figure 31). At two of these marsh sites (3 and 6), plant height was lower at the oiled locations, while at the other two sites (2 and 7), plant height was significantly higher in the oiled locations (Figure 31). The marsh sites where oiling negatively affected plant height were the same sites exhibiting a significant oil effect on live biomass (Figures 23 and 31). Although these differences in plant height occurred on a marsh-specific basis, when averaged over the nine marsh sites, plant height, as was observed for plant biomass, was not significantly different between oiled and unoiled locations (Figure 32).

Plant Vegetative Cover

Plant vegetative cover was determined adjacent to each of the biomass clip plots to assess if the oil spill had an effect on the extent of vegetated marsh surface. Live vegetative cover was significantly lower at oiled locations compared to those unoiled at three of the nine marsh sites (Figure 33). Marsh sites 1, 3, and 4 had significantly lower live vegetative cover at the oiled locations compared to the unoiled (Figure 33). Marsh sites 1, 3, and 4 also had significantly lower live biomass at the oiled locations than for the unoiled locations (Figure 23). However, site 6, which exhibited a lower live biomass at the oiled location, showed no significant effect of the oil on live vegetative cover (Figures 23 and 33). When marsh sites were averaged to get an integrated response for the island, no significant difference in live vegetative cover between oiled and unoiled marsh locations was evident (Figure 34). Thus, when averaged over the whole island, live vegetative cover was not significantly different between oiled and unoiled marshes.

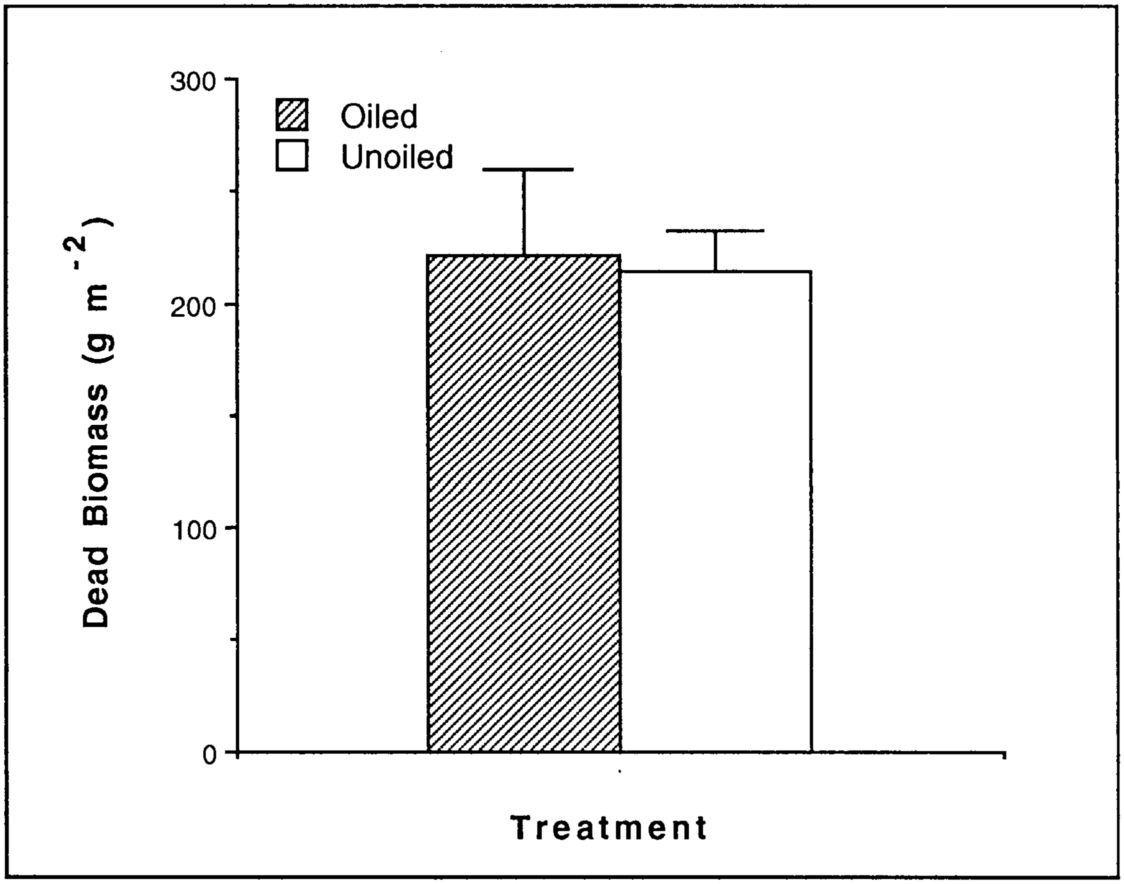

Figure 26. Dead aboveground biomass of *Spartina alterniflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9).

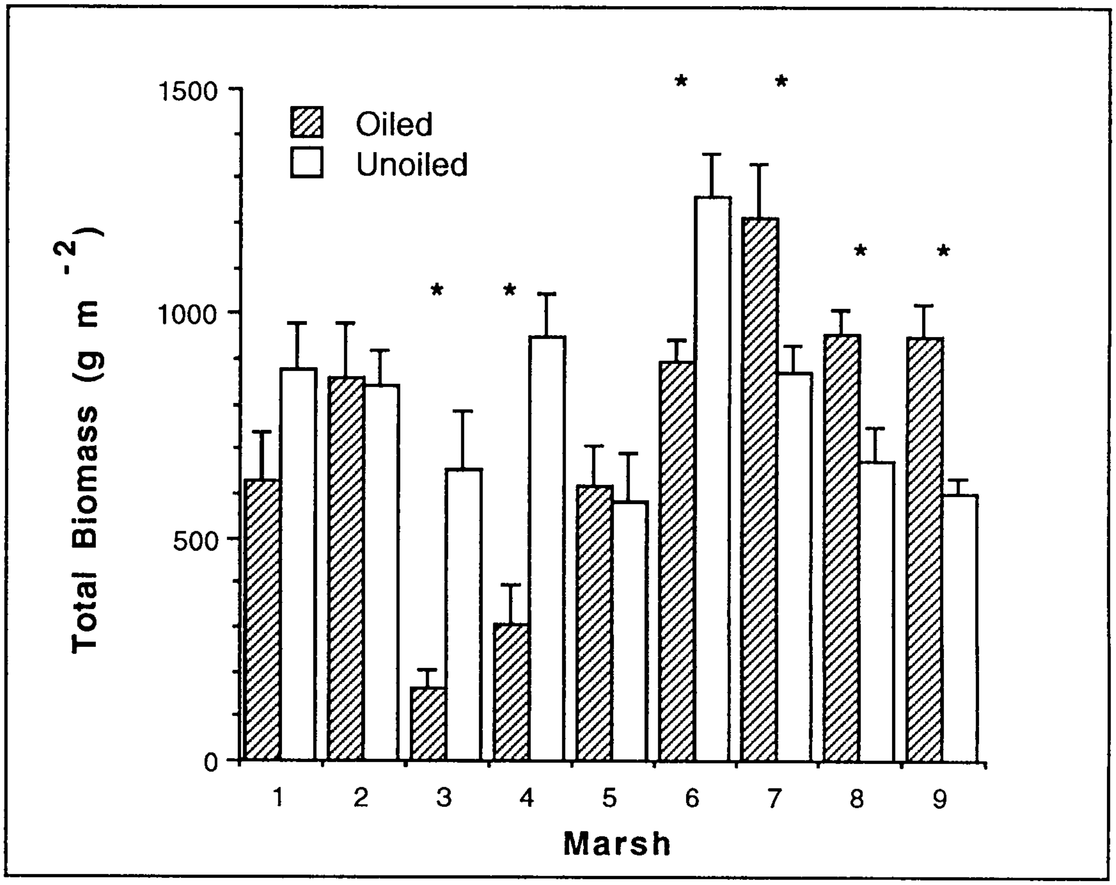

Figure 27. Total (live plus dead) aboveground biomass of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=5).

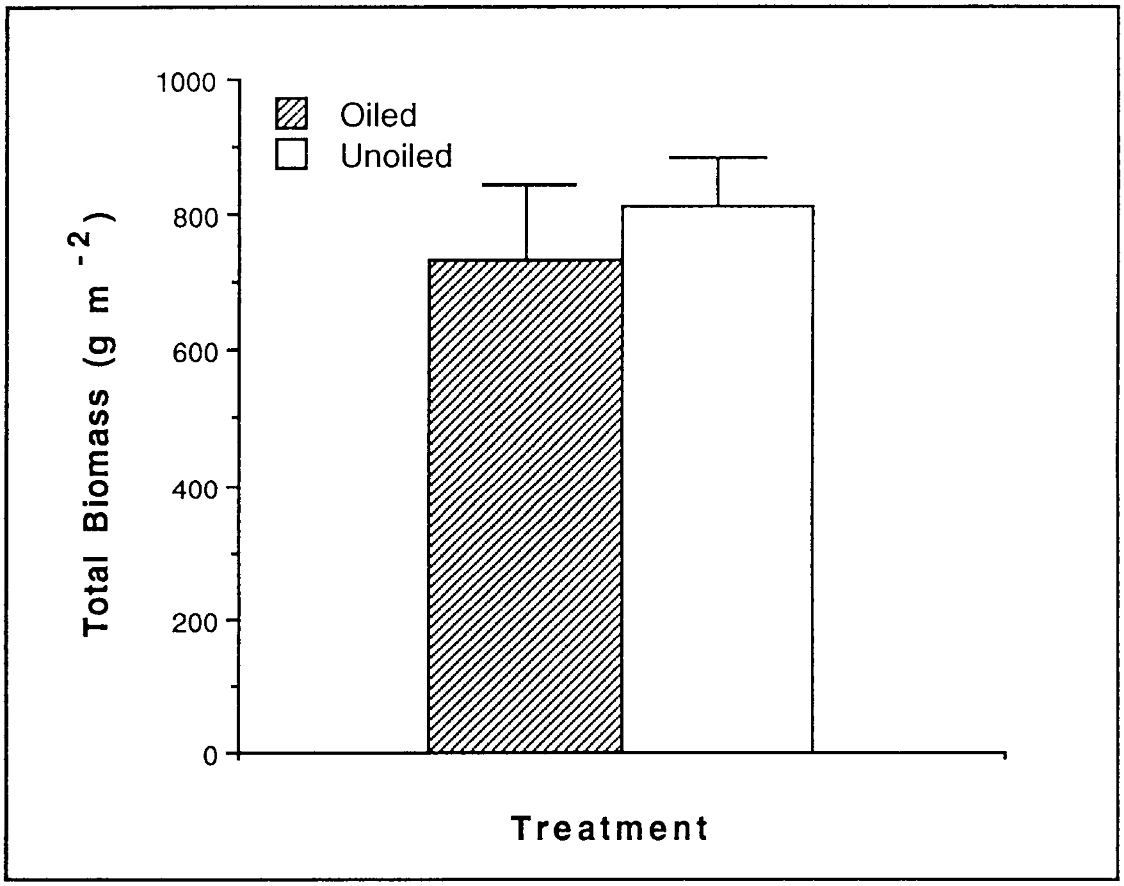

Figure 28. Total (live plus dead) aboveground biomass of *Spartina alterniflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9).

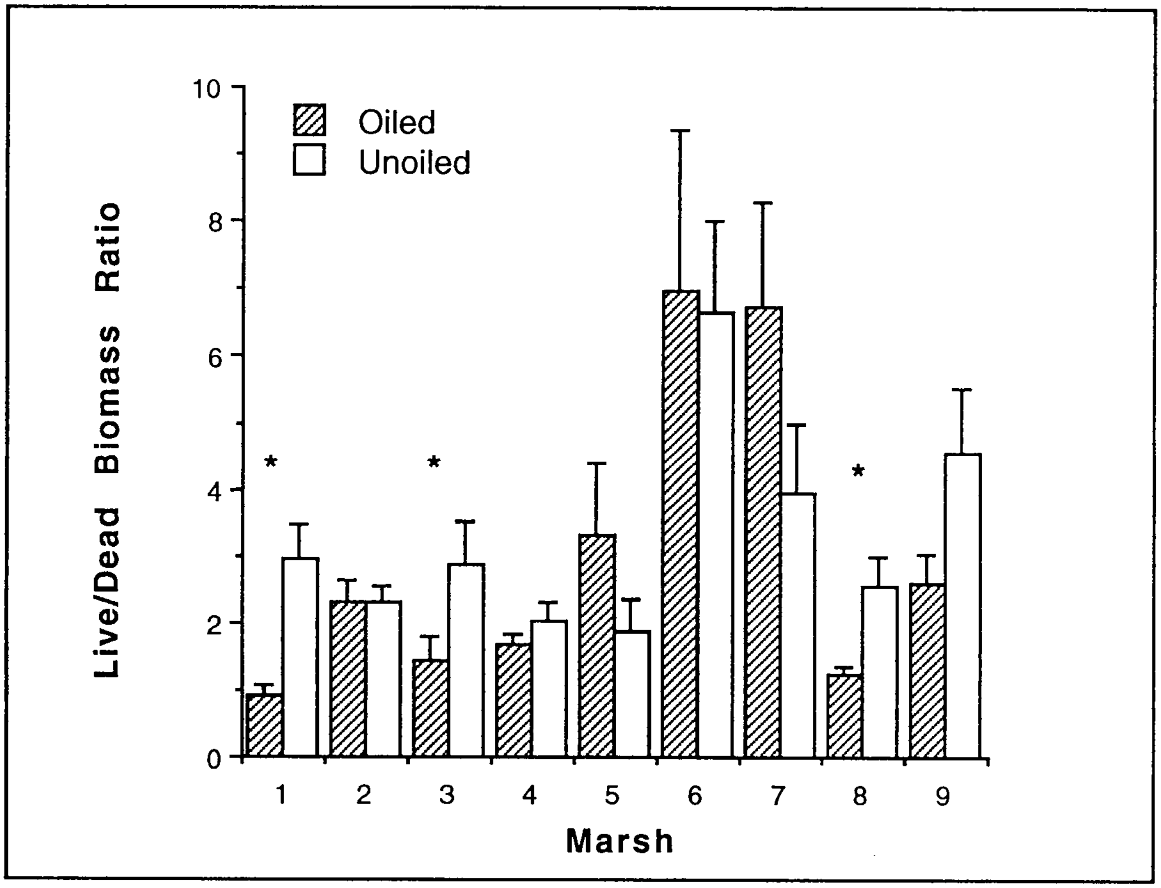

Figure 29. The live to dead aboveground biomass ratio of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=5).

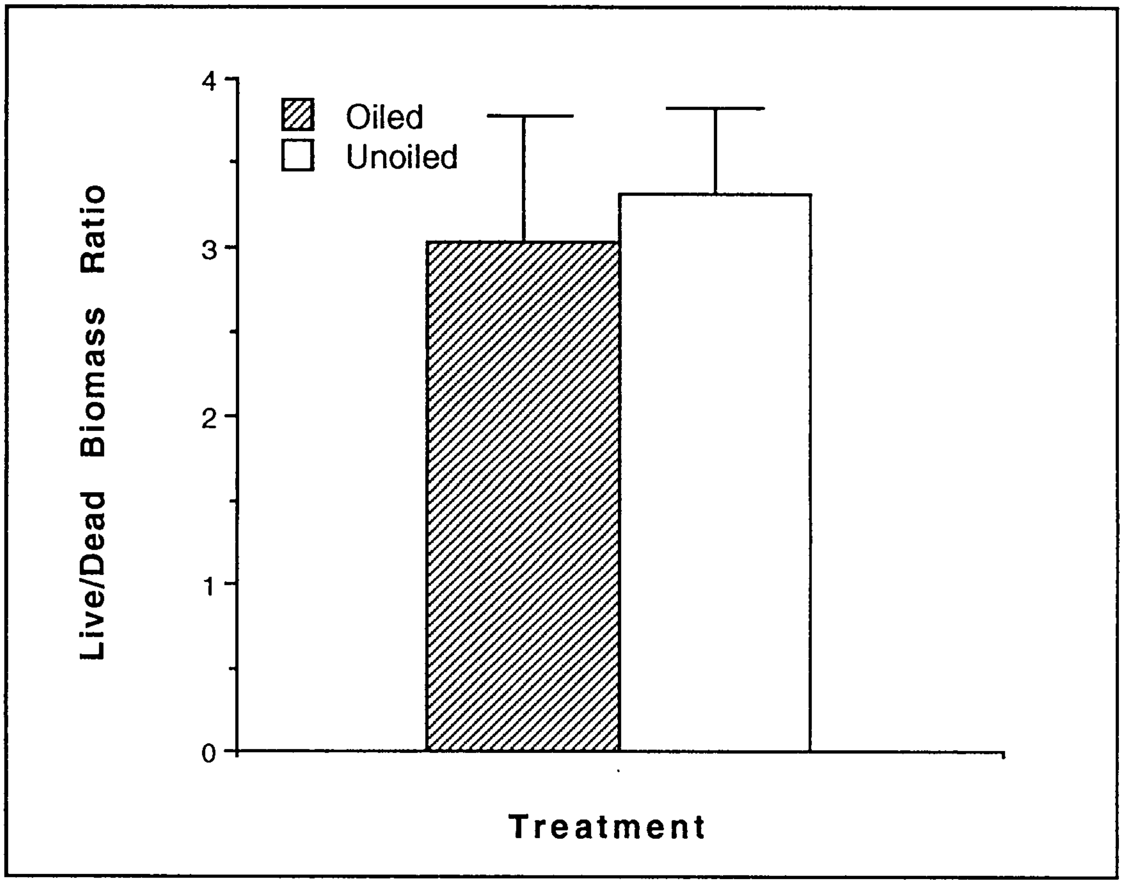

Figure 30. The live to dead aboveground biomass ratio of *Spartina alterniflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9).

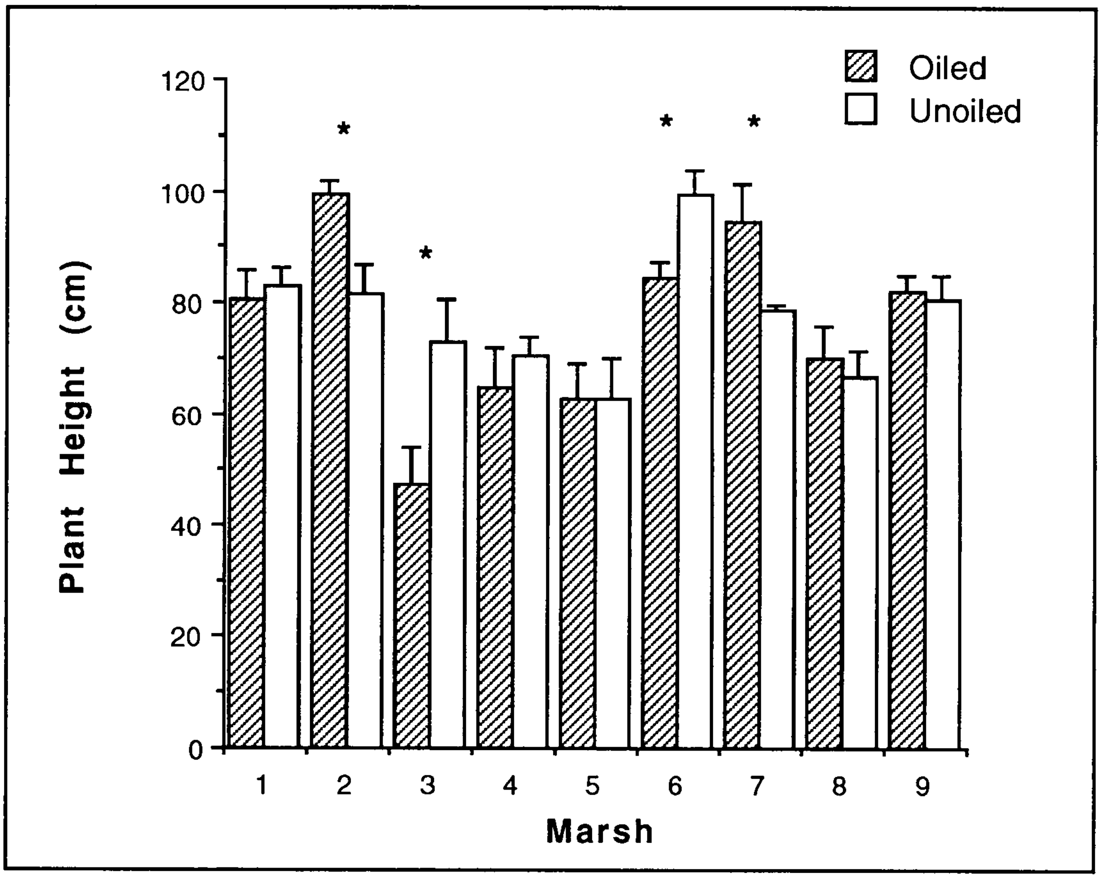

Figure 31. Height of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier (mean with standard error, n=5, * indicates $p<.05$).

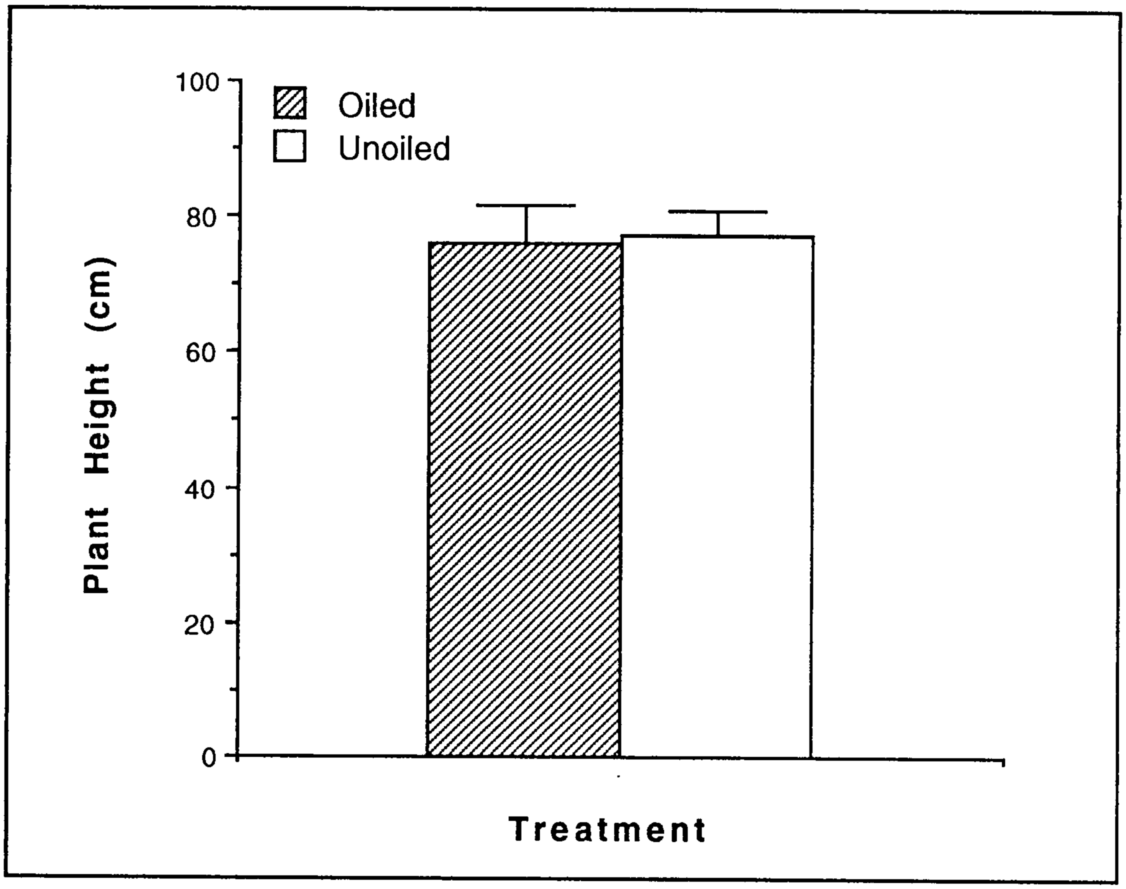

Figure 32. Height of *Spartina alterniflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9).

Dead vegetative cover was low at all marsh sites, regardless of oiling, and no significant differences between oiled and unoiled locations were found at any marsh site (Figure 35). In addition, when dead vegetative cover was averaged over all marsh sites, still no effect of the oil spill on vegetative cover was apparent (Figure 36).

Total vegetative cover responded to the spill in a similar way as total biomass with marsh sites 1, 3, and 4 exhibiting lower total cover in oiled compared to unoiled locations and marsh sites 8 and 9 having higher total cover at the oiled locations (Figure 37). However, at marsh site 1, total plant cover and total biomass responded differently; total cover was significantly lower at the oiled marsh compared to the unoiled marsh, while total biomass did not significantly differ between the oiled and unoiled locations at this marsh site. No significant differences in total vegetative cover between oiled and unoiled locations were found for marsh sites 6 and 7 (Figure 37), even though they differed in total biomass (Figure 27). Total vegetative cover, when averaged over all marsh sites, was not significantly different between oiled and unoiled locations (Figure 38).

Oil Concentration in the Soil

The oil content of the soil, when averaged over all oiled marsh locations and over all unoiled marsh locations, was significantly higher in the oiled marshes compared to the unoiled marshes (Figure 39). The oiled marsh sites averaged 2,690 ppm total hydrocarbons, while the unoiled sites averaged 1,120 ppm total hydrocarbons. Although this statistically significant difference between oiled and unoiled marshes 14 months after the spill was evident, there was a large range in oil concentrations in both oiled and unoiled marshes (oiled: 650 to 6730 ppm; unoiled: 640 to 3,520 ppm). Thus, even some of the "unoiled" marshes had hydrocarbon content in the soil, apparently a result of other spills and/or discharges from facilities in the surrounding area. In one instance (marsh site 6), the marsh used as the reference (unoiled) site, had received light oiling according to the post-spill survey (Debusschere et al. in preparation). This probably explains the elevated total hydrocarbon concentration (3,520 ppm) at this location.

To assess whether there was a relationship between the residual oil measured in the soil and the plant response 14 months after the spill, live biomass was regressed on soil oil content. No statistically significant relationship was evident (Figure 40). Oil content and live vegetative cover were also not statistically related (data not shown).

Community Scale Response

Based on the analysis of the plant biomass and vegetative cover in the nine sampling sites, the west and east end of the island responded differently to the GPC oil spill. Three of the 4 marsh sites that had lower biomass and/or plant cover at the oiled compared to the unoiled locations occurred on the eastern end of the island. Conversely, the marsh sites that showed a stimulatory effect in biomass or plant cover when oiled occurred on the west end of the island (marsh site 1 was an exception to this trend). The pattern of oiling was quite different at the two ends of the island (Debusschere et al. in preparation). On the west end of the island, oiling occurred primarily while water levels were high so that little oil came in direct contact with the sediment surface; oil was noted primarily on the upper portions of the aboveground vegetation. In contrast, on the east

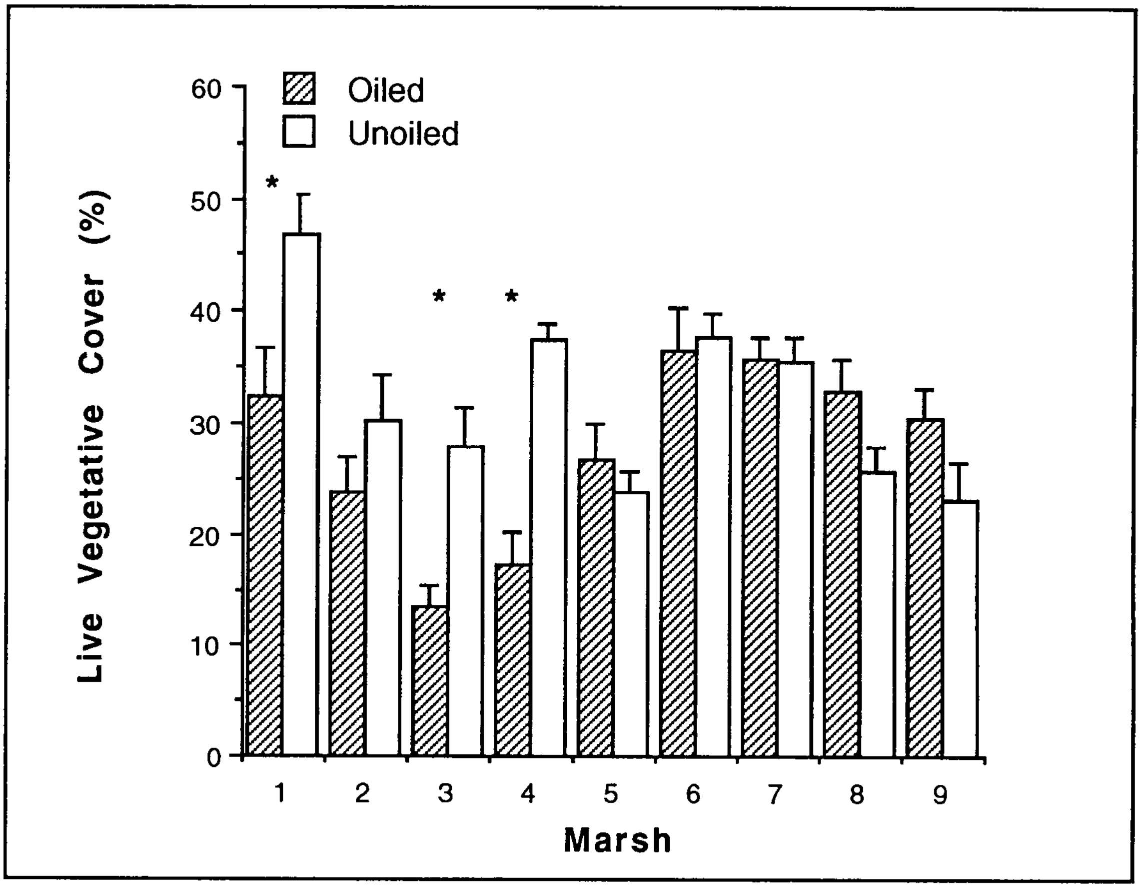

Figure 33. Live vegetative cover of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (mean with standard error, $n=5$, * indicates $p<.05$).

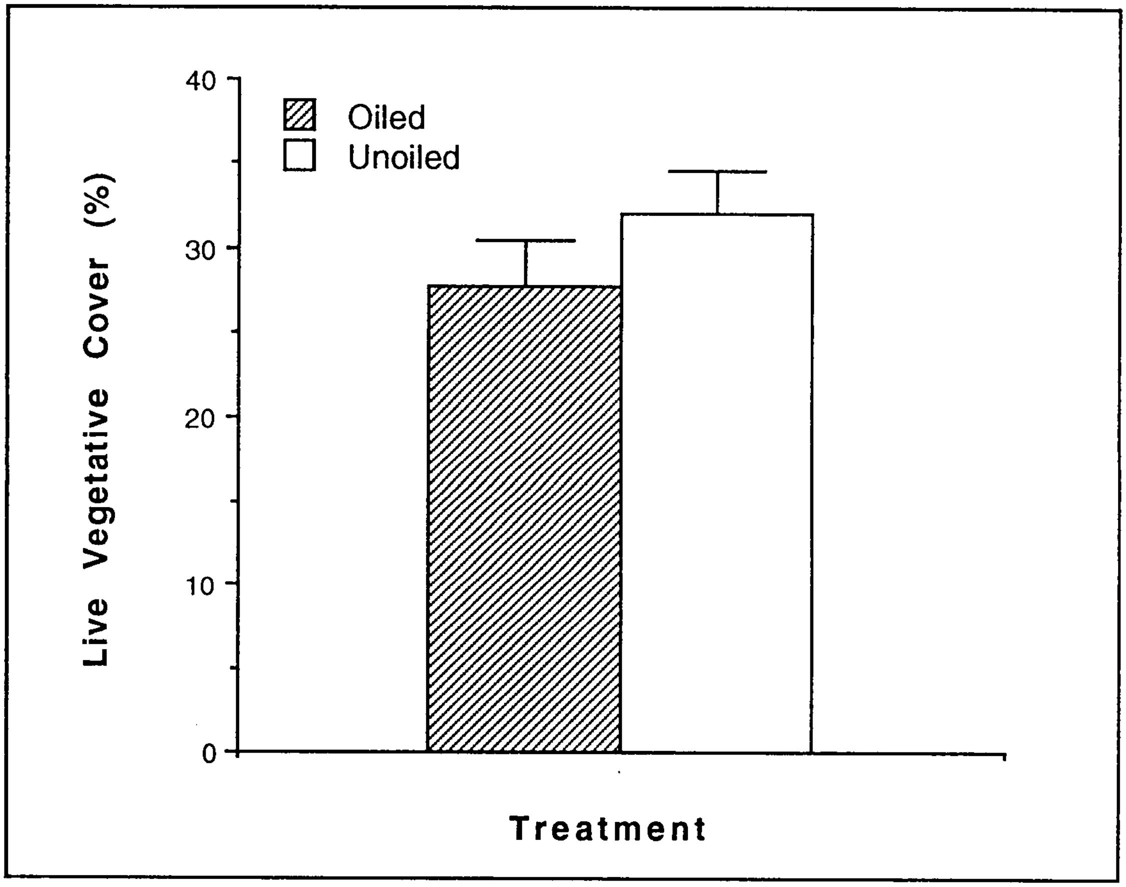

Figure 34. Live vegetative cover of *Spartina alteriflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9).

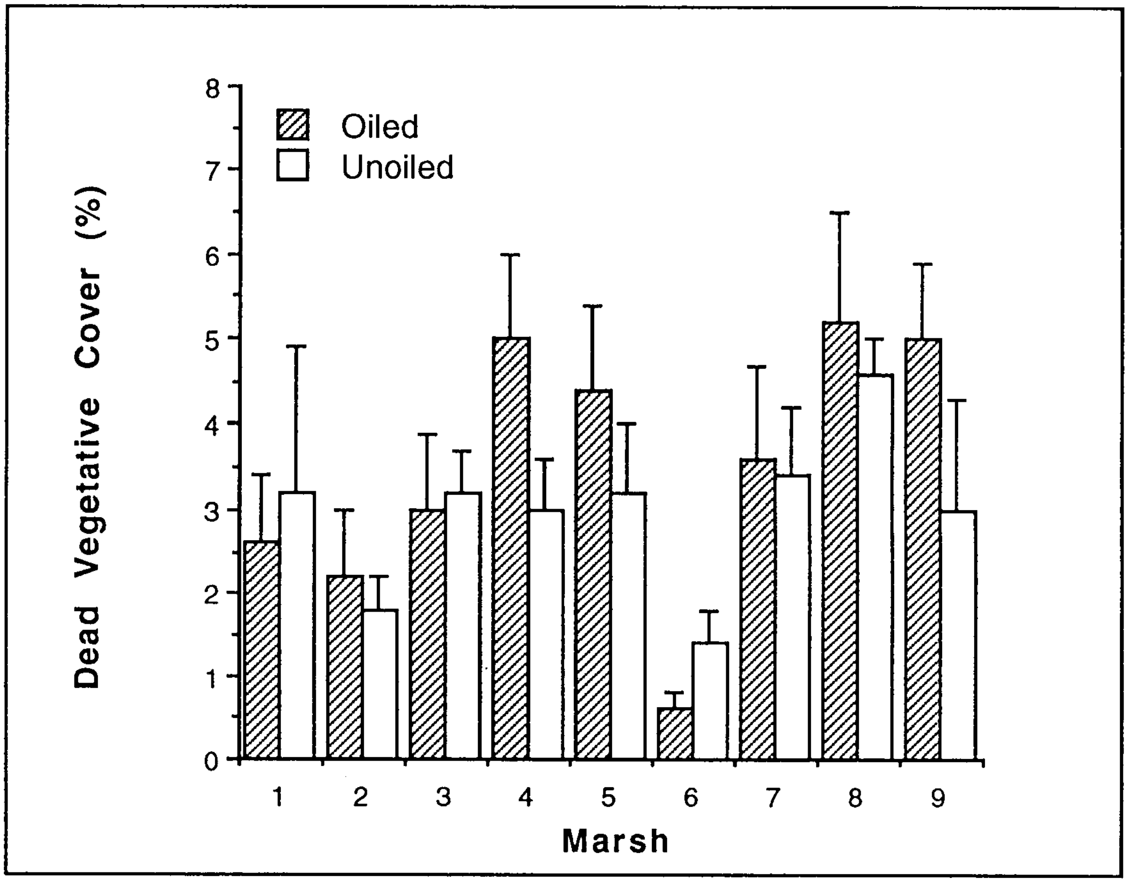

Figure 35. Dead vegetative cover of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=5).

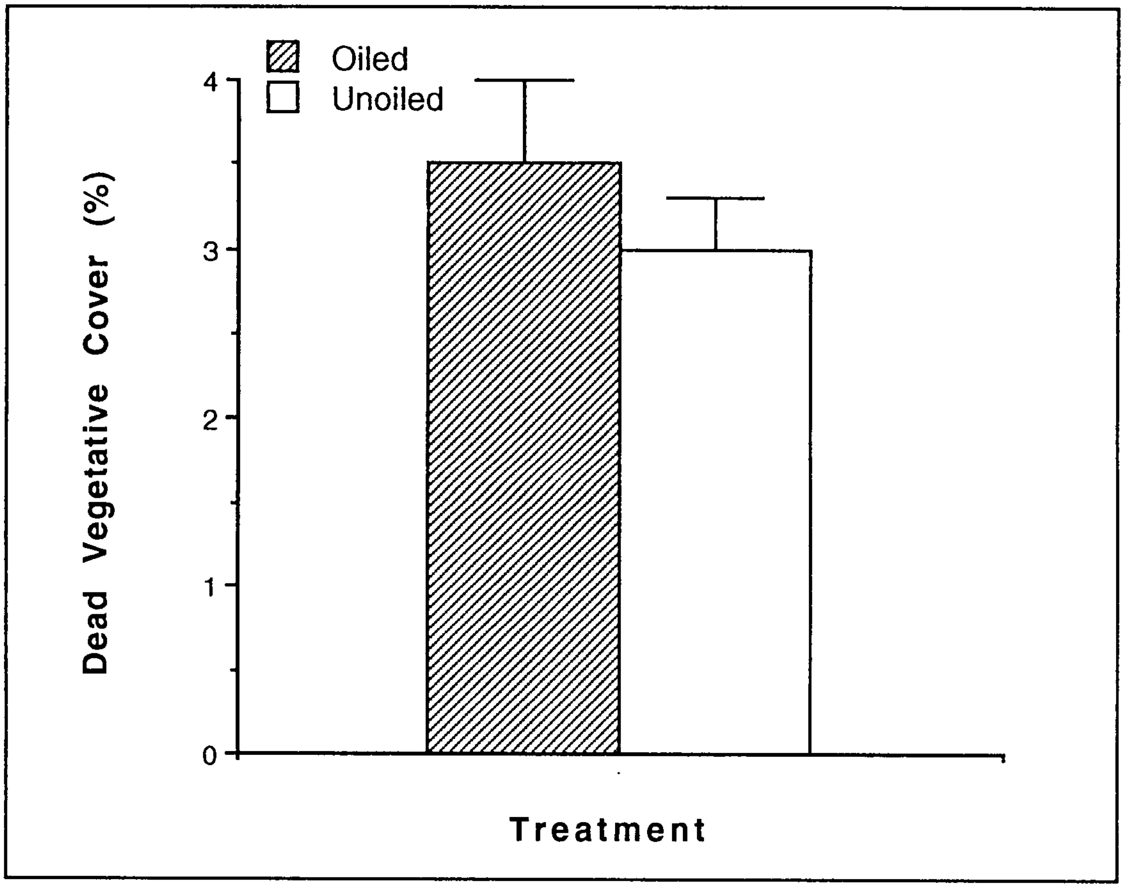

Figure 36. Dead vegetative cover of *Spartina alterniflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9).

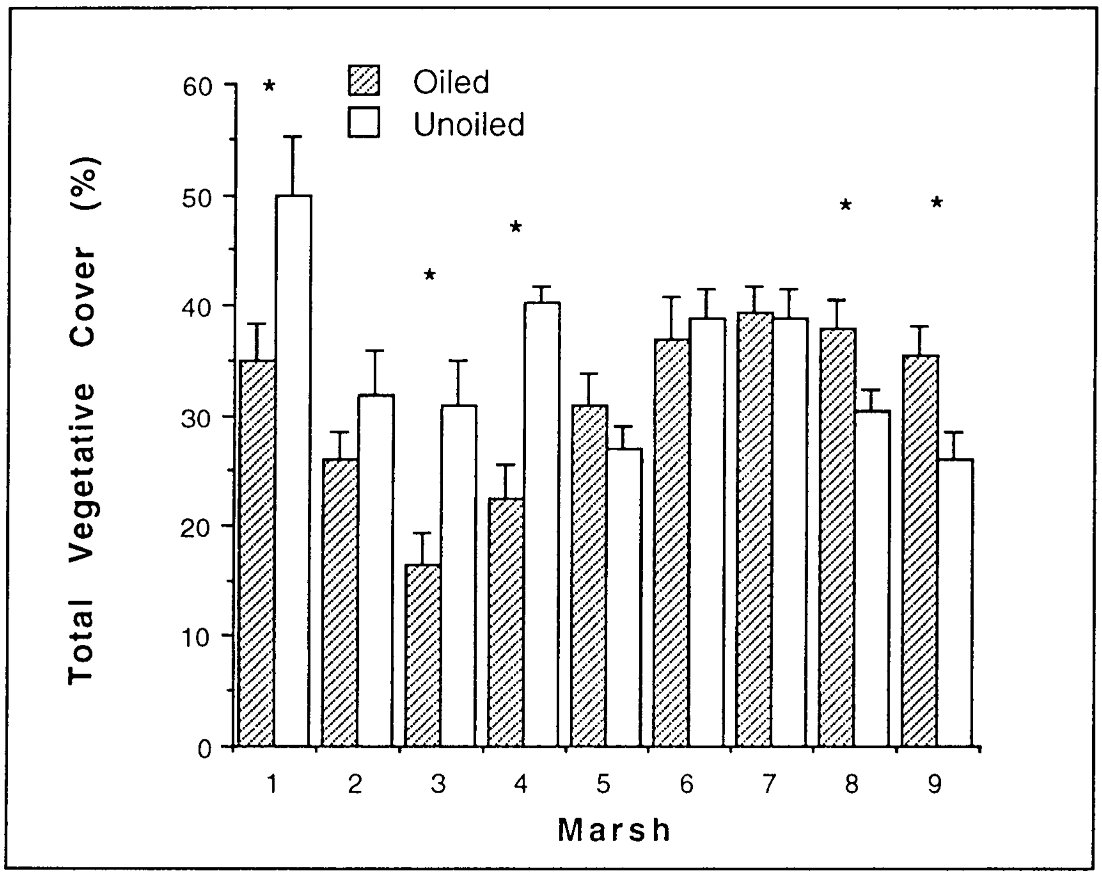

Figure 37. Total vegetative cover of *Spartina alterniflora* at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=5, * indicates p< .05).

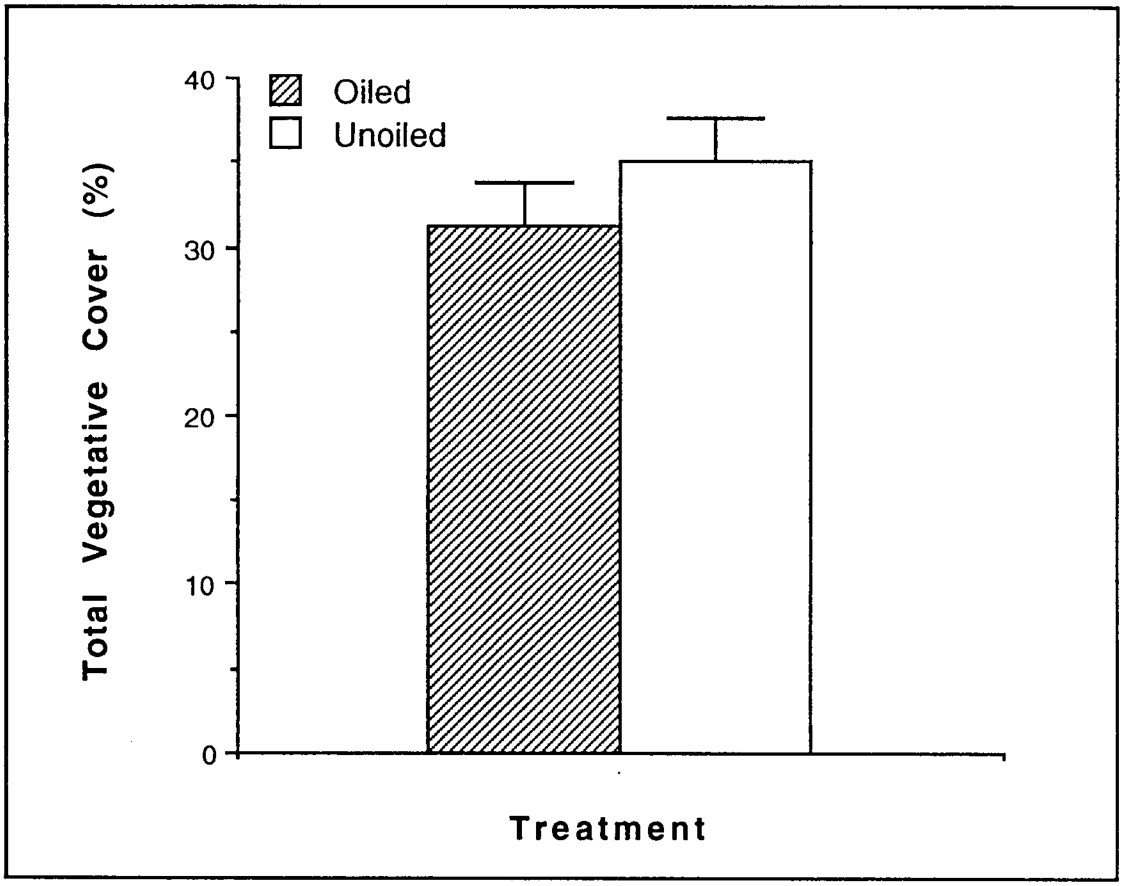

Figure 38. Total vegetative cover of *Spartina alterniflora* at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9).

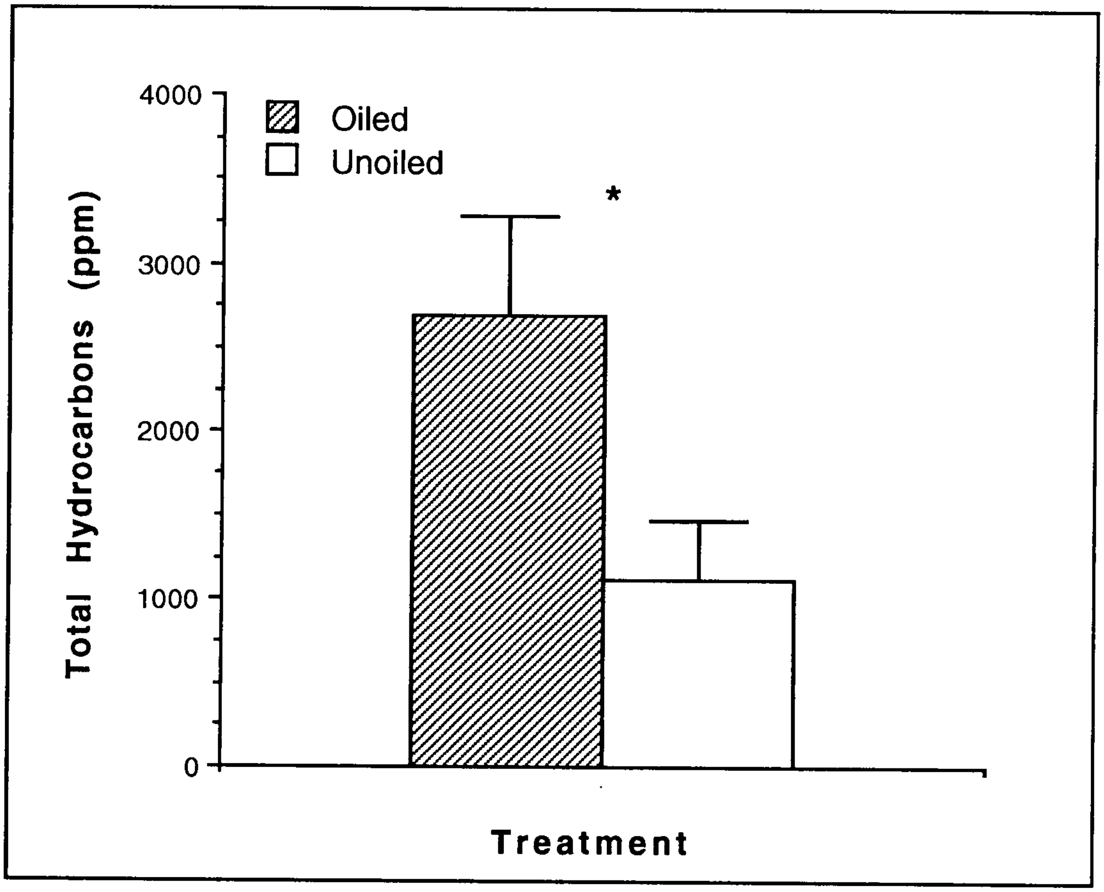

Figure 39. Total soil hydrocarbon content at oiled and unoiled locations averaged over all nine backbarrier marsh sites on East Timbalier Island (mean with standard error, n=9, $p < .05$).

end of the island, oiling occurred when water levels were lower and field surveys noted oil primarily on the lower portions of the aboveground vegetation and on the soil surface.

In some of our ongoing research with *Spartina alterniflora*, we have observed that the long-term impacts of unweathered south Louisiana crude oil are greatest when the oil penetrates the soil surface compared to contacting only the aboveground portions of the plant, even though the aboveground tissue may initially exhibit mortality (Lin and Mendelssohn unpublished).

A number of studies have investigated petroleum hydrocarbon impacts to wetland vegetation. Most of these studies were conducted in salt marshes, especially those dominated by *Spartina alterniflora*, and thus are relevant to the present investigation (Mendelssohn et al. 1990; Li et al. 1990; Delaune et al. 1979; Ferrell et al. 1984; Alexander and Webb 1985, 1987). Some studies found no impact to *S. alterniflora* following the application of up to 8 l/m2 of Louisiana crude oil to field plots with residual oil concentrations in the soil as high as 50,000 ppm (Delaune et al. 1979). In some cases, petroleum hydrocarbons even stimulated the growth of this species (Li et al. 1990; Hershner and Moore 1977). However, other studies have documented adverse effects of oil on this salt marsh grass. Alexander and Webb (1987) reported that oil concentrations in the soil greater than 10,500 ppm caused decreased live stem density of *S. alterniflora* and led to long-term impacts. Mendelssohn et al. (1990) reported that ca. 0.28 l/m2 of crude oil, which coated the aboveground vegetation, caused a 64% reduction in live vegetation cover of *S. patens* three months after an oil spill from a pipeline blowout in southeast Louisiana. The present investigation is in agreement with the literature, which indicates that relatively rapid recovery of marsh vegetation to oiling occurs, especially when the oil does not substantially penetrate the marsh soil.

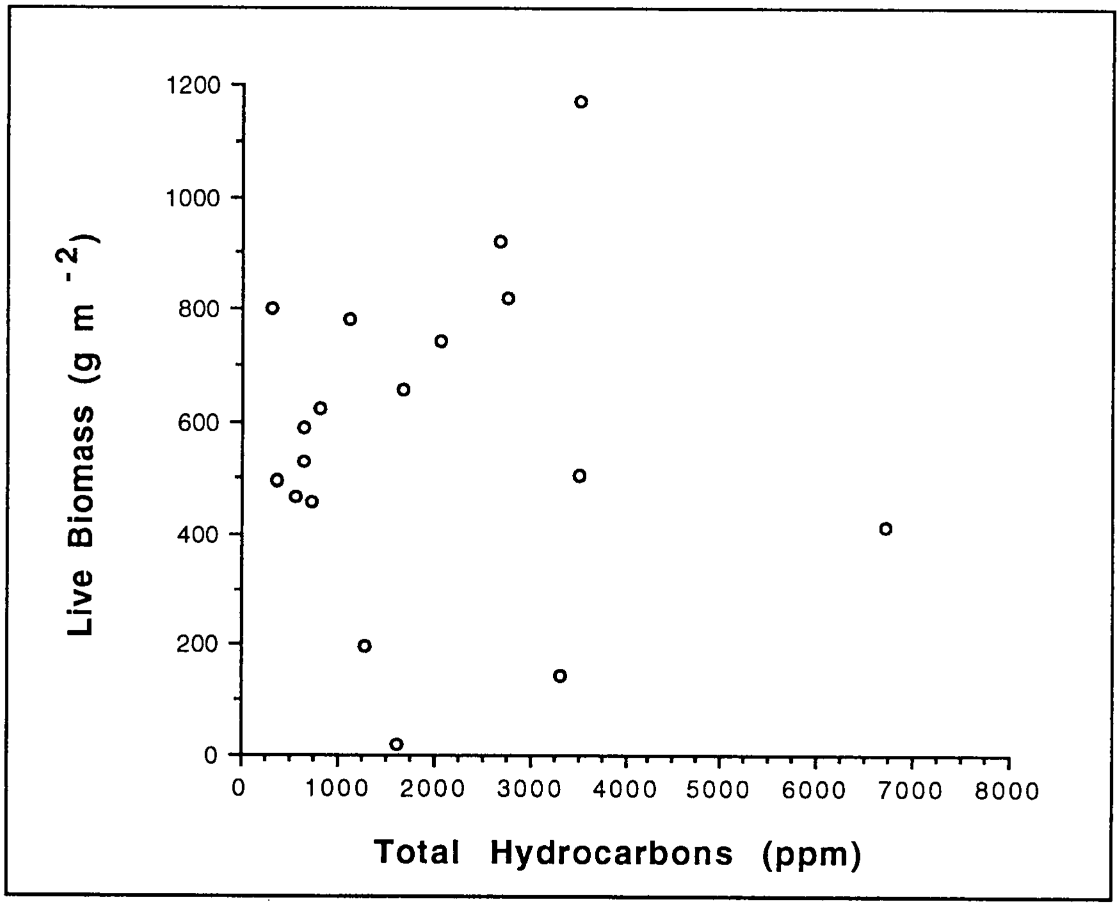

Figure 40. The relationship between live aboveground biomass of *Spartina alterniflora* and total soil hydrocarbon content at the oiled and unoiled locations of the nine backbarrier marsh sites on East Timbalier Island (n=18).

CONCLUSIONS

The acute and longer term effects of Hurricane Andrew and the Greenhill Petroleum Corporation oil spill were evaluated from a landscape scale and community scale perspective. In general, the landscape scale analysis indicated that Hurricane Andrew had a dramatic effect on the morphology and land cover of the island. In addition, landscape scale and community scale analyses showed that the Greenhill Petroleum Corporation oil spill had minimal negative effect on the island vegetation.

More specifically this study demonstrated that:

On a landscape scale

- The East Timbalier Island land mass decreased by 25% between 1990 and 1992, most of which can be attributed to Hurricane Andrew.
- The East Timbalier Island shoreline changed from continuous to fragmented between 1990 and 1992, most of which can be attributed to Hurricane Andrew.
- Between 1990 and 1992, 56% of the island's land cover changed, most of which can be attributed to Andrew.
- Most of the land loss and land cover changes during the study period occurred in the mid section and on the east and west ends of the island.
- Changes in land area and land cover between 1992 and 1993 continued to be dramatic and were occurring in the same areas as between 1990 and 1992 where Hurricane Andrew's impact had reshaped the island's morphology.
- The analysis indicates that the Greenhill Petroleum Corporation oil spill had minimal large-scale effects on land cover.
- In 1992, 26% of East Timbalier Island's total land mass was impacted by oil.
- In 1993, 0.19% East Timbalier Island's total land mass remained oiled.
- Surface and oil penetration were present in 1993. Oil penetration occurred in areas where the oiling was classified as pooled in 1992.
- Much of the erosion that occurred between 1992 and 1993 is more likely because of natural erosion than oil impact.
- The analysis identified some areas where oil did seem to have an effect on the land cover. These areas were located in the interior of a land mass or in sheltered areas. The majority of those areas were located on the eastern end of the island.
- The analysis was not able to identify small areas where field surveys noted that oil did seem to have an effect on the land cover.
- Field surveys enhanced the remote sensing/image analysis of oiling and hurricane impacts.

On a community scale

- The analysis was able to detect fine-scale vegetative responses.
- Live aboveground biomass was significantly lower in oiled compared to unoiled marshes at 4 of the 9 marsh sites investigated.

- Two marsh sites had significantly greater live aboveground biomass at the oiled locations compared to the unoiled, while the remaining marsh sites did not differ as a function of oiling.
- Vegetative cover generally showed similar trends as aboveground biomass.
- When plant biomass and cover were averaged over all marsh sites across the island, oiled marshes were not significantly different from unoiled marshes.
- Dead aboveground biomass, live to dead biomass ratio, and dead vegetative cover were not sensitive evaluators for oil impact in this particular case.
- The analysis indicated that oiling appeared to have a more negative effect on the east end marshes while the west end marshes were more positively affected.
- Oil concentration in the soil was significantly greater in oiled versus unoiled marshes; however, no significant relationship between oil content in the soil and vegetative response could be identified 14 months after the spill event.
- Although site-specific impacts, apparently because of the oiling, were identified, marsh recovery was apparent as evidenced by similar vegetative responses between the oiled and unoiled marshes, when averaged over all marsh sites that were sampled.

These conclusions clearly indicate that the landscape scale and community scale analyses of East Timbalier Island's response to the Greenhill Petroleum Corporation support and complement each others findings. In addition, the landscape scale analysis was able to estimate the impact of the Hurricane Andrew on the island. Furthermore, this investigation indicated that the post-hurricane coastal processes controling island morphology did not appear to have an effect on salt marsh recovery to the oil spill. This was probably due to the fact that the Greenhill Petroleum Corporation oil spill had minimal impact on the East Timbalier Island vegetation, while Hurricane Andrew had a dramatic effect on the island's morphology and land cover.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.