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APPLICATION OF DISTURBANCE THEORY TO ASSESS IMPACTS ASSOCIATED WITH A THREE-DIMENSIONAL SEISMIC SURVEY IN A FRESHWATER MARSH IN SOUTHWEST LOUISIANA

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Oceanography and Coastal Sciences

by

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TABLE OF CONTENTS

page

LIST OF TABLES

page

LIST OF FIGURES

page

ABSTRACT

This study examined various practical and theoretical aspects of disturbance in a coastal wetland marsh in southern Louisiana. A literature review approached disturbance ecology from both practical and theoretical perspectives and assessed its applicability to developing broad predictive models. However, specific knowledge of environmental variables, competitive relationships, and the interactive effects of multiple disturbances are required for meaningful usage of these models.

The Lacassine National Wildlife Refuge (LNWR) proved to be an ideal laboratory to test various aspects of ecological disturbance theory. I found that the primary disturbances affecting the LNWR have been hurricanes, droughts, water-level manipulations, prescribed burning, oil and gas recovery activities, grazing by *Myocastor coypus* (nutria), and managed cattle grazing.

The 1990's application of three-dimensional (3-D) seismic technology used in the oil and gas recovery business challenged landowners, government regulators, and industry to develop ways to recover these resources without damaging surface features. I developed a conservative estimate that an area exceeding 2.5 times the area of Louisiana's coastal wetlands was covered by overlapping seismic surveys in southern Louisiana from 1997 through 2002, equal to 22.5 km^2/year. I provided a general overview of 3-D seismic survey programs, potential adverse impacts, and management and restoration strategies. I also conducted a field study at the LNWR on vegetation in control and treatment transects before, and for two years after, a 3-D survey.

I found vegetative cover and the amount of dead plant biomass were significantly lower in treatment plots, but live biomass was not different in treatment and control plots.

Species richness was higher in treatment plots compared to control plots, but the live biomass and cover of the dominant species (*Panicum hemitomon*) was lower. The live biomass and cover of *Eleocharis spp*., a colonizing species, was greater in treatment plots compared to control plots. There was no significant effect of equipment type or traffic level within treatment plots for total live cover, total live biomass, or total dead biomass. Clear trends of the disturbance effects across disturbance types and habitats were not revealed. Furthermore, extrapolating the effects of a disturbance using the available general concepts should be done with caution because of the overriding influence of the site and species on disturbance effects.

CHAPTER 1

INTRODUCTION

The primary objective of this study is to assess the impacts associated with a three-dimensional (3-D) seismic survey in a freshwater marsh in southwest Louisiana. I conducted field measurements and reviewed existing theoretical models and concepts on disturbance to assess their general application to the management of disturbances in wetlands. This dissertation consists of six chapters, including this introductory chapter. The remaining chapters are introduced here.

Chapter 2, "Disturbance in wetlands: a literature review," reviews current models and concepts on disturbance theory, and presents a literature survey on common types of disturbances in wetlands. The chapter concludes with a discussion of the importance of specific knowledge of environmental variables and individual species characteristics when predicting the effects of disturbances.

Chapter 3, "Disturbance history at Lacassine National Wildlife Refuge," describes the general history of the refuge in terms of management practices and both natural and human disturbances. Historical disturbances are quantified, and resulting plant community dynamics are discussed. This chapter provides a basis from which to assess the effects of disturbance measured in Chapter 4.

Chapter 4, "Effects of 3-D seismic exploration on the plant communities of Lacassine National Wildlife Refuge: A two-year field study, describes the results of a field experiment designed to determine the effects of trampling by marsh buggies and airboats on plant communities in a freshwater marsh. The effects of these disturbances on vegetative cover, live and dead biomass, and species composition are reported.

Chapter 5, "Minimizing environmental disturbances associated with 3-D seismic surveys in coastal marshes," describes management techniques and operational factors

utilized to reduce disturbances caused by marsh buggy and airboat operation in a variety of marsh habitats. This chapter includes individual case studies of seismic surveys conducted in coastal Louisiana. Chapter 6 is a brief integrative summary of the entire study.

CHAPTER 2

DISTURBANCE IN WETLANDS: A LITERATURE REVIEW

INTRODUCTION

Disturbance is a natural phenomenon in many ecosystems and a source of much of the spatial and temporal heterogeneity seen across a landscape. The magnitude and frequency of disturbance are factors structuring many ecosystems (Beeby 1993). Evidence of ecosystem response to specific scales and intensity of periodic disturbances is visible in the species traits, which reflect the likelihood of disturbance (Beeby 1993). Some species survive only in patches formed by disturbances.

Disturbances provide ecologists with opportunities to test theory by monitoring the short-term responses of individuals or the long-term adaptations of populations, as well as changes in the structure and composition of communities at a larger scale. Furthermore, disturbance ecology has proven practical applications in forestry and grassland management. Many best management practices for human exploitation in these systems are rooted in disturbance theory. Examples include clear-cutting in forestry, managed livestock grazing, and prescribed burns in grassland management. Correspondingly, much of the classic disturbance theory was developed based on research done in these systems (Connell 1978; Paine and Levin 1981; Petraitis et al. 1989; Picket and White 1985; Rickleffs 1977; Sousa 1984). Noticeably scarce in the world of theoretical ecology are references specific to wetland systems. "Prior to the mid-1970s, the drainage and destruction of wetlands were accepted practices in the United States and were even encouraged by specific government policies" (Mitsch and Gosselink 1993). As Mitsch and Gosselink (1993) put it, ". . . the modern history of wetlands is fraught with misunderstanding and fear." Now wetlands are viewed as some of the most productive systems on earth and provide a multitude of critical functions. Wetlands have been found to prevent floods, cleanse polluted water and act as sinks for nutrients and carbon dioxide, recharge groundwater aquifers, and provide essential

habitat for fish and wildlife species (Mitsch and Gosselink 1993). Wetlands are unique habitats because of the significant role of hydrology and because of their position in the landscape between terrestrial and aquatic systems (Mitsch and Gosselink 1993). Legal protection, regulations, and management plans have followed as the significant values of wetlands gained recognition. This result has required that those responsible for protecting and managing these systems be able to predict the effects of certain human disturbances on these systems. These predictions often rely on theories developed in terrestrial systems. Wetland science has emerged as a distinct scientific discipline as the uniqueness of these systems has been revealed. Because application, rather than pure science, has driven the development of wetland ecology as a scientific discipline, one might expect the literature to be weighted heavily on impact studies and not on explicitly testing ecological theory.

The efficacy of wetland restoration may be improved if the ideas of disturbance theory are usefully developed within wetland science. Louisiana's wetland restoration program might be a prime beneficiary of this development. Coastal land loss in Louisiana has reached catastrophic proportions (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority 1998). The causes of wetland loss in Louisiana are complex and vary by region. Wetland loss can be caused by natural processes such as subsidence, storms, and herbivory, as well as human disturbances such as dredge and fill activities, canal construction, off-road vehicle traffic, and levee construction. In 1998, the State of Louisiana, in conjunction with the public, and local, parish, and federal agencies, developed a comprehensive restoration plan that attempts to integrate coastal management with coastal restoration based on ecosystem management. As the term implies, the intent of ecosystem management is to design restoration strategies based on ecological principles so that the restored coast will have the productivity, diversity,

and other features of a natural system. To reach this end, any effort at ecosystem management must, at a minimum, take into account both the role of natural disturbances in shaping and sustaining natural systems, and the role that human disturbances have on these fragile ecosystems. The effects of different historical disturbance regimes must also be taken into account when designing monitoring programs and interpreting data on the effectiveness of different restoration projects.

The goal of this chapter is to review current disturbance models and to identify general principles as they relate to disturbance theory in coastal marshes. I provide an overview of disturbance and then identify existing concepts and models developed for other ecosystems. Specific objectives of this chapter are to: (1) define disturbance, (2) review factors that determine plant community structure and succession in tidal freshwater wetlands (3) review existing concepts on disturbance, (4) review previous literature syntheses on disturbance in wetlands, (5) identify common disturbances in coastal marshes through a literature survey, and (6) identify current issues in wetland disturbance theory. I conclude with a discussion of general principles as they relate to disturbance theory in coastal marshes.

DEFINING DISTURBANCE

Disturbance is a loosely used term that may encompass events ranging from single treefalls to forest fires covering hundreds of square miles. Grime (1977; 1979) defined disturbance as a factor that removes biomass. Sousa (1984) similarly defined disturbance as "a discrete, punctuated killing, displacement, or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established." Pickett and White (1985) defined disturbance as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and

changes resources, substrate availability, or the physical environment." Two general types of disturbance can be distinguished: destructive events and environmental fluctuations (Pickett and White 1985). Smith (1990) broadly defined disturbance as a "relatively discrete event in time coming from the outside that disrupts ecosystems, communities, or populations, changes substrate and resource availability, and creates opportunities for new individuals or colonies to become established." Beeby (1994) further clarified the terminology and defines stress as "an applied stimulus, measured by its capacity to deflect some living component of the ecosystem." Bender et al. (1984) further divided stress into disturbance and perturbation. Perturbation is a planned manipulation, whereas, disturbance is an unplanned stress (Beeby 1994). Keddy (2000) rephrased the formal definition found in the *Oxford English Dictionary* (Concise Edition) as "a short-lived event that causes a measurable change in the properties of an ecological community." According to Keddy's definition, one must identify at least one measurable property (e.g., species diversity, species richness, species composition, or biomass) and show that it changed for disturbance to exist. Keddy's definition is adopted as the working definition throughout this chapter.

PLANT COMMUNITY STRUCTURE AND SUCCESSION

Elevation differences and flooding are the main controlling factors in the zonation of tidal freshwater marshes (Mitsch and Gosselink 1993). Species composition is not typically determined by seed availability because most species are in the seed bank throughout the marsh; however, species abundance is typically reflected in the seed bank (Mitsch and Gosselink 1993). Differences arise in the ability of specific seeds to germinate under different field conditions, especially flooding. Competition also plays a role in zonation. For example, some species produce chemicals that inhibit germination of other species

(Mitsch and Gosselink 1993). The complex interactions of these factors determine plant community dynamics in the marsh (Mitsch and Gossselink 1993).

Succession occurs when species become established or eliminated, or both. Basic knowledge of what drives community composition and succession is essential to understand and predict the effects of a given disturbance on the marsh plant community. While many of the models of succession were developed using forests and old-field communities as well as other terrestrial systems, there are three widely recognized models of succession in wetlands (Cronk and Fennessy 2001). These are (1) the coastal wetlands model (Penfound and Hathaway 1938), (2) the hydrarch model (Lindeman 1941), and (3) the environmental sieve model (van der Valk 1981).

Penfound and Hathaway (1938) proposed a model of succession for the coastal marshes. However, studies have not supported their idea that coastal wetlands are replaced by upland ecosystems (Cronk and Fennessy 2001). Two opposing factors, subsidence and accretion, are currently believed to determine successional pathways in coastal salt marshes (Cronk and Fennessy 2001). The hydrarch model was developed for freshwater depressional wetlands. According to this model, a wetland is a seral community succeeding from an open lake to a terrestrial community (Cronk and Fennessy 2001). This model has not been supported by research in freshwater marshes (Cronk and Fennessy 2001). Van der Valk (1981) proposed the environmental sieve model that uses life history traits to determine plant community composition under either flooded or drawdown conditions (Cronk and Fennessy 2001). The degree of flooding permits the establishment of only certain species at any given time.

EXISTING CONCEPTS ON DISTURBANCE

In The Ecology of Natural Disturbance and Patch Dynamics, Picket and White (1985) provide a comprehensive overview of patch dynamics theory as of 1985. This book synthesized the findings and ideas of researchers studying disturbances in various systems including marine intertidal communities; grasslands; and boreal, temperate, and tropical forests in an attempt to stimulate the generation of clear hypotheses and theory on disturbance. Unfortunately, they did not include a chapter specifically devoted to coastal marsh ecosystems. Features of disturbance such as patchiness, temporal distribution, variations in impact or magnitude, synergism between agents, and interaction with pre-existing stress were summarized into two broad concepts for further study: disturbance regime and patch dynamics.

To promote the development of a mechanistic disturbance theory, Pickett and White (1985) identified diversity and resource status as two parameters that could be used to develop predictions about disturbance. Diversity includes species richness, dominance, community structure, and genetic diversity. Resource status includes nutrient levels in soil, litter, and biomass. They identified two general hypotheses current in the literature at that time: the Intermediate Disturbance Hypothesis (IDH) attributed to Connell (1978), and Huston's (1979) Dynamic-Equilibrium Model that relates disturbance frequency to species richness if disturbance occurs frequently enough to prohibit competitive exclusion.

The focus of Picket and White's (1985) book was on predicting the effects of disturbances, on patch dynamics. The general concepts regarding patch dynamics are identified next.

Unpredictable Species Composition Within Gaps

Brokaw (1985) discusses tropical forest community structure in a synthesis of literature on plant regeneration behavior in relation to treefall gaps. Brokaw's main finding is that differences in disturbance types and dispersal mechanisms, the influence of community history, and various competitive hierarchies, make species composition within gaps unpredictable. Adding to the unpredictable nature of gaps in tropical forests is that similar species have different traits that enhance their ability to reach maturity in some situations, but restrict their ability to regenerate in all situations.

Correlation Between Predictability of Response and Scale

Connell and Keough (1985) suggested that there would be a lower predictability of species composition in patches formed by large, infrequent disturbances.

Natural Disturbance and Ecosystem Energetics

"Higher disturbance frequencies result in lower mean productivity, because at any given time there will be more patches in the less productive stand reinitiation stage. Lower disturbance frequency will also decrease mean productivity of the mosaic because a high percentage of patches will reach the less productive old-growth stage" (Sprugel 1985).

Phenomena of Stability and Resilience

Resilience is the degree that an ecosystem's species composition and structure can be disturbed and still return to pre-disturbance conditions (Holling 1973, cited in Denslow 1985). Stability describes the frequency that a system's species composition returns to pre-disturbance condition after it is disturbed (Holling 1973, cited in Denslow 1985). Unstable communities are often the most resilient because they are likely to contain species adapted to different environments resulting from disturbances (Holling 1973, cited in Denslow 1985). Species from more variable physical environments are more likely to tolerate novel

stresses than species from constant environments (Denslow 1985). Unstable communities are more likely to return to previous species composition following exotic disturbances than stable communities (Denslow 1985).

Source of Spatial Heterogeneity

Species diversity is likely to be maximized when the disturbance pattern resembles natural disturbance regime (Denslow 1985). The major point is that historical disturbance regimes determine the number of species available to colonize a plot. Denslow discusses how disturbances are a source of multiple levels of environmental heterogeneity that affects how resources are partitioned among coexisting species. The number of species available to exploit disturbed patches determines whether the disturbance will increase the number of coexisting species. Large-scale or frequent exotic disturbances can result in a homogenous landscape because relatively few species are able to exploit the rare habitat created. For example, fire, landslide, and windthrow result in a homogeneous landscape in tropical rain forests because these disturbances are rare in these systems and because few species are capable of colonizing the habitat created. In habitats where fire is common, these disturbances result in increased heterogeneity and species richness because pioneer species are adapted to these types of disturbances.

Intermediate Disturbance Hypothesis

This hypothesis states that species richness will be greatest in areas experiencing an intermediate level of disturbance (Pickett and White 1985). Although this generalization is supported by many observations in Picket and White (1985), this hypothesis does not specify what parameters will be affected. Additionally, the maximum level of disturbance for a particular ecosystem must be explicitly stated, and the metrics for quantifying the impact of a disturbance must be clarified (Pickett and White 1985).

The Relationship of Disturbance Frequency to Species Richness

This general concept has clear implications for the Intermediate Disturbance Hypothesis. Species richness should be maintained in ecosystems where disturbance occurs more frequently than the time required for competitive exclusion to occur (Pickett and White 1985).

COMPREHENSIVE REVIEWS OF DISTURBANCE IN WETLANDS

Keddy (2000), Middleton (1999), and McKee and Baldwin (1999), discuss specific wetland disturbance from different perspectives.

In his book Wetland Ecology Principles and Conservation, Keddy (2000) devotes four chapters exclusively to disturbance in general, and specifically, to water level fluctuation, herbivory and burial. These topics are presented from a community ecologist's perspective and appear to intentionally place more emphasis on theory than application, although both are intertwined throughout the text. The author describes how many examples of disturbances are discussed in relationship to gradients, and fewer disturbances as discrete events. However, he points out that some disturbances such as fire, herbivory, and wrack deposition are examples that may result in discrete patches, similar to treefalls in forested ecosystems. Keddy brings out an important point when he quotes two researchers (Walker and Wehrahan 1971) who noted that, in spite of its importance in controlling prairie wetlands, disturbance "could not be quantitatively measured, a shortcoming that still hampers many ecological studies" (Keddy 2000).

Middleton's (1999) text Wetland Restoration Flood Pulsing and Disturbance Dynamics complements Keddy's work well in that it is geared toward the emerging science of wetland restoration, while maintaining strong theoretical roots. For instance, an entire chapter is devoted to restoration theory where succession, invasion theory, and various

theories specific to riverine wetlands are discussed. As the title implies, the author focuses on the importance of incorporating flood pulsing and disturbance in restoration plans, but moves away from the theoretical aspect of restoration ecology into application by covering basic engineering concepts, case histories, and even dispersal strategies and germination requirements of specific plants.

McKee and Baldwin (1999) filled a gap identified in Keddy (2000) by providing a comprehensive literature review on wetland disturbance. Their chapter, part of a book titled Ecosystems of Disturbed Ground (Walker 1999), examined the role of disturbance in wetland structure and function using specific examples. It is a positive step towards identifying unifying principles or organization in wetlands. The authors identified a gap in the literature, caused not by a lack of references to studies on wetlands, but by a lack of studies that "explicitly examine disturbance, particularly by natural agents, as a force shaping the structure and function of wetlands" (McKee and Baldwin 1999). Their observation was consistent with that by Keddy (2000) who described the current state of wetland disturbance literature as being composed of diffuse studies with no central theme tying them together. McKee and Baldwin (1999) discussed species, population, community, ecosystem, and landscape responses to disturbances using an extensive literature survey to provide examples. By itself, their paper provides the most comprehensive review of current literature available. Their results indicate that half of the studies they reviewed indicated no change in species richness or dominance after disturbance. This finding was consistent across disturbance categories. The authors pointed out that, unlike other habitats, relatively few studies specifically investigated the effects of disturbance frequency or intensity on species diversity in wetlands, or explicitly examined the effects of disturbance on competition intensity in wetlands, although a number of studies infer this relationship

(Bertness and Ellison 1987; Lowe 1986). They referenced studies by Grace and Pugesek (1997), Mallik and Wein (1986), and Guntenspergen et al. (1995) that indirectly support the Intermediate Disturbance Hypothesis. The authors concluded that a theoretical understanding of patterns and processes of wetlands gained from drawing comparisons between systems with different kinds, rates, and magnitudes of disturbances will lead to stronger management practices and a greater protection of wetlands.

LITERATURE SURVEY

The results of 32 papers that investigated various disturbances to wetlands are summarized in Table 2.1 and discussed in this section. Many of these papers included multiple experiments in different habitats. Thirty-four investigations were conducted in fresh marshes, fifteen in salt marshes, and eleven in brackish marshes (Table 2.1). Forty-one were field experiments, seventeen were laboratory experiments, and two were field observations. Vegetative parameters measured included: percent cover, biomass, net primary productivity (NPP), relative abundance, species richness, and species composition. Species composition was affected as a result of disturbance in sixteen of the studies. Biomass was reduced in fourteen instances, while percent cover was reduced in ten. Eleven of the investigations reported increased species richness. The following section discusses these disturbances in more detail.

Storms

Hurricanes are a significant source of large-scale disturbances in coastal marshes. Unlike hurricane impacts in forested systems, where the primary disturbance is the creation of canopy gaps, hurricanes in coastal marshes result in multiple disturbances including: compression of the marsh surface, deposition of sediment, deposition of wrack, scouring, and salt burn (Visser et al. 1999).

These disturbances can result in severe damage, especially to previously-disturbed marshes or marshes under other pre-existing stress like those found in many parts of coastal Louisiana. Descriptive studies of the effects of hurricanes on marsh vegetation were conducted following many severe hurricanes along the Louisiana coast (O'Neil 1949; Webert 1956; Ensminger and Nichols 1957; Harris and Chabreck 1958; Chamberlain 1959; Morgan 1959; Wright et al. 1970).

O'Neil (1949) reported a 10% increase in open water area in Mississippi River delta marshes following a severe hurricane in 1947 and noted that, in other marshes along the Louisiana coast, burning prior to a storm could result in a completely altered plant community. He also noted severe damage to vegetation when saltwater became trapped within impounded marshes. Webert (1956) reported positive results of Hurricane Flossey on the marshes near the mouth of the Mississippi River. He reported the removal of the exotic species water hyacinth (*Eichhornia crassipes*) and establishment of species more desirable as wildlife food. Ensminger and Nichols (1957) reported substantial saltwater damage to vegetation in impounded marshes, whereas natural marshes showed little damage, presumably because of the rapid runoff and the mitigating effects of heavy precipitation which diluted the saline waters. Harris and Chabreck (1958) reported significantly more open water, especially in areas previously impacted by marsh buggies, and considerable changes in plant species composition at Marsh Island, Louisiana, following Hurricane Audrey. Chamberlain (1959) reported re-vegetation of most of the damaged areas in Cameron and Vermillion Parishes, Louisiana, within one year following Hurricane Audrey. He also reported an increase in annual species because of gaps created by the storm, but held the opinion that the species composition shift was temporary. Following Hurricane Camille, Wright et al. (1970) reported extensive physical damage to floating aquatic vegetation, but

Table 2.1. Results of a review of selected studies reporting effects of disturbance on wetland vegetation in North America. Disturbance types are classified as natural (N), anthropogenic (A), or simulated in the field or laboratory (S). Disturbances are classified as breakage/abrasion (BA), biomass removal (BR), burial by sediment (BS) water level fluctuation (WL), fire (F), grazing (G), trampling (TR), salinity (S), toxins (T), or interactions between two or more disturbance categories. A "/" indicates an interaction between the disturbance categories listed. Multiple disturbance types may be included for a single reference. The study types are categorized into field experiments (FE), field observations (FO), and laboratory experiments (LE). The wetland types are classified into salt marsh (SM), brackish marsh (BM), and fresh marsh (FM). The dominant plant forms affected by the disturbance are classified as graminoid (G) or mixture (M). The plant types are classified as perennial (P), annual (A), or mixture (M). Vegetation responses to the disturbance are percent cover (C%), biomass (Bio), net primary production (NPP), relative abundance of dominant species (RA), species richness (SR), and species composition (SC). The direction of change in response to the disturbance is indicated as positive (+), negative (-), or no change (0). Change in species composition is denoted by "Y". The general format for this table was adopted from McKee and Baldwin (1999).

Reference	Disturbance		Study	Wetland	Plant	Plant	Response[7]					
	Type	Category	type	type	form	type	C%	Bio	NPP	RA	SR	SC
Allison (1995)	A	BS	FE	SM	G	M	0			+		
Andersen et al. (1990)	A	G	FE	SM	G	M						Y
Baldwin et al. (2001)	S	WL	FE	FM	G	M					-	
	S	WL	FE	FM	G	M					+	
	S	WL	LE	FM	G	M					-	
	S	WL	LE	FM	G	M					+	
Baldwin and Mendelssohn (1998)	S	I	LE	FM	G	P			-			
	S	I	LE	FM	G	P			0			
	S	I	LE	BM	G	P			0			
	S	I	LE	BM	G	P			-			
Bozzo et al. (1990)	A	T	FE	SM	M	M	-					Y
Chabreck and Palmisano (1973)	N	S	FE	FM	M	M	-			-		Y
	N	S	FE	BM	M	M	-			-		Y
DeLaune et al. (1979)	A	T	FE	SM	G	P		0				
	A	T	LE	SM	G	P		0				
Evers et al. (1998)	N	G	FE	FM	G	P		-		-		Y
Ford and Grace (1998)	N	F	FE	FM	G	P	+	-		0	+	
	N	G	FE	FM	G	P		-				
	N	I	FE	FM	G	P		0		-	+	
	N	F	FE	BM	G	P	-	-				
	N	G	FE	BM	G	P		-				
	N	I	FE	BM	G	P		0		-	+	
Harris and Chabreck (1958)	N	BA	FO	BM	G	P	-					
			FO	BM	G	P	+					

Table 2.1 cont.

Reference	Disturbance		Study	Wetland	Plant	Plant	Response[7]					
	Type[1]	Category[2]	type[3]	type[4]	form[5]	type	C%	Bio	NPP	RA	SR	SC
Herchner and Moore (1977)	A	I	FE	SM	G	P		+				
Kenkel (1993)	S	T	FE	FM	G			+,-				
Kirkman and Sharitz (1993)	S	WL	LE	FM	G	P	+					
	S	WL	LE	FM	G	P	-					
Kirkman and Sharitz (1994)	S	F	FE	FM	G	P				0	0	Y
	S	TR	FE	FM	G	P				0	+	Y
Krusi and Wein (2001)	S	F	FE	FM	G	P		-				N
	S	I	FE	FM	G	P		-				Y
Kuhn et al. (1999)	A	WL	FE	SM	G	P		0	-		-	Y
Leeuw et al. (1992)	S	T	FE	SM	M	M	N	N				N
	S	TR	FE	SM	M	M	N	Y		-		Y
Lin and Mendelssohn(1996)	A	T	LE	FM	G	P		+				
	A	T	LE	BM	G	P		-				
	A	T	LE	SM	G	P		-				
Mallik and Wein (1985)	A	I	FE	FM	G	P	+			-	+	
	A	I	FE	FM	G	P	-			-	+	Y
Mendelssohn et al. (1990)	A	T	FE	BM	G	P	-					
Mendelssohn et al. (1997)	A	T	FE	FM	G	P		0				N
	A	T	FE	FM	G	P		-				N
	S	F	LE	SM	G	P		+,-				
Pezeshki et al. (1987)												
Racine et al. (1998)	A	TR	FE	FM	G	P	-					N
Schemnitz et al. (1973)	A	TR	FE	FM	M	P		0			0	
	A	TR	FE	FM	M	P			-		0	
Shaffer et al. (1992)	N	G	FE	FM	G	A	-					
Schmalzer et al. (1991)	A	F	FE	SM	G	P	+	0	-	-	+	N
	A	F	FE	SM	G	P	+	0	-	-	+	N
Smith and Kadlec (1983)	S	WL	LE	FM	G	M					+	Y
	S	WL	LE	FM	G	M					-	Y
Smith and Kadlec (1985)	N	F	FE	FM	G	P		0				
	N	I	FE	FM	G	P		-				
	N	G	FE	FM	G	P		0				
	N	I	FE	FM	G	P		-				
Smith and Newman (2001)	N	F	LE	FM	G	P		+				
Ungar and Woodell (1996)	N	G	FE	SM	G	M						Y
	N	G	LE	SM	G	M						T
Wilson et al. (1998)	A	TR	FE	BM	G	P	0					Y

only minimal damage to the root mat of the emergent marsh in the Mississippi River delta. He estimated that most of the disturbance was caused by receding waters following the storm.

Chabreck and Palmisano (1973) assessed the effects of Hurricane Camille on the marshes of the Mississippi River delta. Changes in species composition and total marsh area were not greatly affected at first; however, plant cover and relative cover by species were significantly reduced. They reported damages to floating marshes ranging from a reduction in size to complete destruction and removal of the vegetated floating mat. Chabreck and Palmisano (1973) attributed the loss of marsh and aquatic vegetation to the physical disturbance of the wind and water and less to the increased salinity. They also reported changes in the relative abundance of species one year after the hurricane, which indicated differential responses of vegetation to the disturbance.

Fire

Fires occur naturally in many wetlands and are widely used for marsh management. Fires create bare ground by removing existing vegetation and litter, increase insolation, and release nutrients such as phosphorus, calcium, magnesium, potassium, and chloride by ash deposition, and increase species diversity (Hoffpauer 1968; Faulkner and de la Cruz 1982; Keddy 2000; Smith and Newman 2001). Fires result in higher primary production rates, affect aboveground biomass and vegetative cover, and initiate changes in species composition.

The effects of fires may be further determined by interactions with other disturbances such as draining and flooding (Faulkner and de la Cruz 1982; Mallik and Wein 1985; Krusi and Wein 1988; Kirkman and Sharitz 1994), herbivory (Smith and Kadlec 1985; Ford and Grace 1998), and nutrient enrichment (Smith and Newman 2001). The

primary factors that determine the effects of fires include water level, timing of fire, rainfall, and tidal inundation following the fire. Hoffpauer (1968) described three types of prescribed burns in coastal Louisiana and Texas, distinguished principally by water levels and severity of burn. Wet burns (cover burn) occur when water levels are at or above the root horizon. Dominant vegetation returns quickly after a fire because the root system remains intact. Root burns occur during dry periods and damage the root system. In brackish marshes, this damage often leads to a shift in species dominance because the *Spartina patens* root system is nearer the surface and more susceptible to damage. Peat burns typically occur in fresh marshes that have a highly organic soil overlying a clay pan. The peat is burned down to the clay pan or subsurface water where it is extinguished, leaving a depression. Standing water from rainfall or tides can affect the regrowth of plants and result in temporary unvegetated mud flats or shifts to species more tolerant to flooding or salt stress (Hoffpauer 1968).

Faulkner and de la Cruz (1982) recorded increases in biomass and primary production of *Spartina cynosuroides* and *Juncus roemeranus* in a salt marsh in Mississippi. They attributed these changes to increased nutrient uptake as a result of increased insolation and mulch removal. Other researchers have reported decreases on aboveground biomass after a fire. Schmalzer et al. (1991) reported significant reductions in biomass, but not percent cover, following one year after a fire in a *Juncus roemeranus* and *Spartina bakeri* marshes in Florida. Ford and Grace (1998) also reported that above-ground biomass was reduced by one-third after a fire in *Spartina patens*, *Sagittaria lancifolia*, and *Panicum virgatium* communities in the Pearl River delta. Other researchers have investigated the interactive effects of multiple disturbances in addition to burning on community composition.

Prescribed burning, in combination with other practices, is often used to manage undesirable species and to increase primary production of desirable species. Mallik and Wein (1985) found that a combination of draining and fire reduced *Typha* dominance, whereas flooding and fire increased *Typha* coverage in a cattail-dominated fresh marsh near the Bay of Fundy. In a similar study, Krusi and Wein (1988) investigated the resiliency of *Typha* to an atypical disturbance regime of severe drainage and intense summer burns. They reported a reduction in standing crop of *Typha* with no major shits in species composition. Schmalzer et al. (1991) reported temporary changes in community composition and diversity in *Juncus roemeranus* and *Spartina bakeri* marshes in Florida following burning during flooded conditions. Their findings indicated that there were minor shifts in the relative abundance of dominant species and slight increases in richness within one year after the fire. They concluded that both marshes were recovering to their original condition one year later, but that if fire frequencies exceed the time required to recover, significant changes in community composition may occur. Kirkman and Sharitz (1994) addressed the role of seed banks, species responses, and mechanisms of persistence following fire and soil disturbance during a prolonged drought in South Carolina. Their results indicated that short-term responses to burning and soil disturbance were more evident at the species level than in community structural changes. At the patch level, dominance was not altered by either burning or tilling; however, the relative cover of some species was affected. Overall, burning did not affect species richness, evenness, or diversity, but did decrease the dominance of some species. Their important findings were that some dominant perennials persisted vegetatively following disturbance, but were absent in the seed bank. Less common species appeared to be recruited from the seed bank. Kirkman and Sharitz (1994) concurred with previous studies that observed that, under repeated disturbances over a long

period, individual species responses may result in longer-term community changes. Smith and Newman (2001) attributed community level changes in the Florida Everglades to peat fires, which reduced soil elevations and increased flooding. The increased flooding, coupled with the increased bioavailability of soil phosphorus, favored *Typha domingensis*. This shift in competitive advantage led to the eventual conversion of sawgrass communities to slough communities.

Smith and Kadlec (1985) reported significant reductions in net primary productivity by grazing in previously burned marshes adjacent to the Great Salt Lake in Utah and provided evidence of preferential grazing in response to increased protein in vegetation. Ford and Grace (1998) also investigated the interaction between grazing and burning using fenced plots and reported species-specific responses to fire. In this study, burning favored *Panicum virgatum* and *Sagittaria lancifolia*, while reducing the dominance of *Spartina patens*. Herbivory, on the other hand, favored *Spartina patens* and reduced the dominance of other species. These findings were supported by Mendelssohn et al. (1988) who reported that burning suppressed one species, while allowing an inferior competitor to increase in abundance. They also reported differential community responses to fire, with the greatest increases in species density occurring in the *Sagittaria lancifolia* community and less occurring in the *Panicum virgatum* community. Burning and fencing interacted significantly to affect species density in the three plant communities studied.

The effects of burning are variable depending on the plant community, environmental conditions such as water level, and interactions with other disturbances such as grazing and flooding. Burning resulted in increases in percent cover and species richness in the majority of the papers reviewed, whereas relative abundance and live biomass was reduced (Table 2.1).

Herbivory (Nutria and Waterfowl)

A number of studies have shown that vertebrate herbivores can retard or even reverse wetland succession (Hik et al. 1992; Shaffer et al. 1992; Evers et al. 1998; Mulder Rues 1998). Hik et al. (1992) demonstrated that grazing and grubbing by lesser snow geese delayed the rate of vegetation development resulting from isostatic uplift in salt marsh plant communities in Manitoba. At their study site, the assemblage of species in the upper and lower marsh consisted of *Puccinellia phryganodes* and *Carex subspathacea*. However, this assemblage is only present in the upper marsh as a consequence of intense grazing. As expected, species composition changed to *Calamagrostis deschampsoides* and *Festuca rubra* when grazing was ceased. However, when grazing was reintroduced, the species composition did not revert to the previous *Puccinellia-Carex* assemblage. The findings of this study supported the predictions of the multiple-state models of community structure in which feedback processes between consumers and the physical environment contribute to multiple states of communities within an ecosystem (Hik et al. 1992). "In this model, if the factor (disturbance) initiating a change reverts to its previous level, the system does not return to it's original state" (Hik et al. 1922).

The creation of new land in the emerging Atchafalaya Delta in Louisiana has provided an opportunity to investigate the importance of autogenic processes such as competition and herbivory in wetland primary succession. Shaffer et al. (1992) reported higher species richness and evenness in nutria-excluding treatments than in controls grazed by nutria and waterfowl. Additionally, Shaffer et al. (1992) attributed the trend toward decreased vegetation coverage at low elevations to herbivore activity. They hypothesized that the decreased cover was primarily the result of the flooding intolerance that *Sagittaria lancifolia* developed as a result of increased grazing by nutria. Shaffer et al. further

concluded that their findings were consistent with Grime's (1979) interpretation that no "adaptive strategy" exists for plants in environments of high stress and high disturbance. In a similar study at the Atchafalaya Delta, Evers et al. (1998) demonstrated that two groups of animals–waterfowl and the rodents nutria (*Myocastor coypus*) and muskrat (*Ondatra zibethicus*) have had a profound effect on the vegetation development on the fresh marsh islands of Atchafalaya and Wax Lake deltas in Atchafalaya Bay, Louisiana, through significant reductions in plant biomass and changes in species composition. In another study, Visser et al. (1999) attributed the lack of recovery at scours created by Hurricane Andrew in an oligohaline marsh in Louisiana to an interaction between herbivory and increased flooding.

A general trend, based on the literature survey, is that herbivory reduces biomass and alters species composition in affected areas (Table 2.1). These findings are predictable because of the physical nature of the disturbance and because preferential grazing favors less-palatable species. As with other disturbances, the interactions between grazing, hurricanes, and flooding stresses can result in species composition changes and/or marsh loss, depending on grazing intensity.

Hydrology

"The amplitude and frequency of water level fluctuation control the characteristic of wetlands, just as fire intensity and frequency control characteristics of forests" (Keddy 2000). The frequency and duration of flooding, coupled with species-specific abilities to cope with salinity stress, are major determinants of zonation patterns in wetlands. Mitsch and Gosselink (1993) provided a comprehensive introduction to the specific effects of hydrology on wetlands and suggested that, "Hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetlands

and wetland processes." Slight changes in hydrologic conditions may result in massive changes in species composition, richness and ecosystem productivity (Mitsch and Gosselink 1993). Waterlogging results in changes in soil oxygen content and other chemical conditions that limit the number of species that can survive in these environments. Only a relatively few of the thousands of vascular plants on earth have adapted to waterlogged soils. This is exemplified by the general increase in species richness along a wet to dryer gradient from marshes to bottomland hardwood forests (Mitsch and Gosselink 1986).

Current management practices and restoration efforts, especially in coastal Louisiana, have driven much of the research on wetland hydrology. Research has been directed towards species-specific responses to a projected sea level rise throughout the coastal zone. A significant amount of research also has been conducted on linkages between hydrologic alterations and coastal wetland loss in Louisiana, which is on the order of 25-35 square miles per year (Louisiana Coastal Wetlands Conservation and Restoration Task Force 1997).

Hydrologic conditions are a major influence on plant community development and primary productivity, and therefore, organic matter accumulation, decomposition, and organic matter export. Nutrient cycling and availability, and sedimentation are also influenced by hydrology. These factors all play a significant role in maintaining marsh elevation, which is vital to keep pace with the current and projected sea level rise.

The scales of disturbances caused by altered hydrology range from shifts in species composition resulting from minor manmade features like roads or ditches (Rheinhardt and Faser 2001) to the landscape-level changes seen in coastal Louisiana caused, in part, by the construction of levees and navigational canals (Boesch et al. 1994). Consequently, scientific investigations range from the role of seed banks in recovery of vegetation during

drawdowns (Smith and Kadlec 1983) to the effects of Mississippi River diversions into adjacent wetlands (Kemp et al. 2001).

The role of hydrology in community development and temporal variation in species composition is well documented (Lowe 1986; Baldwin et al. 1998; Kirkman et al. 2000; Baldwin et al. 2001; Rheinhardt and Faser 2001. Lowe (1986) attributed the patterns of zonation in shoreline vegetation at a floodplain marsh in Florida to variability in the hydrologic conditions, but suggested that fire was the primary determinant of the mosaic of communities observed in the interior marsh. Rheinhardt and Faser (2001) attribute invasion of woody species in wetlands on Lower Hatteras Island, North Carolina, to the manmade hydrologic barriers and to wildfire suppression. In field and greenhouse studies, Baldwin et al. (2001) found that flooding reduced freshwater marsh species richness by 26% and 50%, respectively, but that stem length was significantly increased in flooded plots (Table 2.1). They concluded that annual species were more affected by flooding than perennial species and that shallow flooding early in the growing season can reduce the abundance of certain annuals, thus reducing overall diversity.

Kirkman and Sharitz (1993) investigated the interactive effects of flooding and fire on three perennial grasses. *Panicum hemitomon* and *Leersia hexandra* displayed greater tolerance to flooding, whereas *Manisuris rugosa* showed greater tolerance to drought. These differences suggest mechanisms for community change that are associated with hydrologic fluctuations. Additionally, *Panicum hemitomon* growth was adversely affected by burning followed by flooding. These findings were supported by a similar study by Baldwin and Mendelssohn (1998) who investigated the effects of salinity and flooding coupled with a physical disturbance (clipping) on community structure. Community structure was affected most in response to both salinity and flooding following physical disturbance. Species

richness, however, was not affected in the absence of clipping. *Sagittaria lancifolia* biomass, but not *Spartina patens* biomass, increased in the absence of clipping. These findings suggest that changes in wetland vegetation in response to rising sea level depend on disturbance, with water level and salinity. Kirkman et al. (2000) proposed a model that describes the interactions of abiotic components and disturbances that influence patterns of plant development in a depressional wetland in southwestern Georgia. Fire and hydrology were determined to be major influences on ecosystem development because the occurrence of drawdowns directly influenced fire frequency, which determined species zonation.

Structural marsh management is sometimes used in Louisiana in an effort to prevent marsh loss. This movement alters the natural hydrologic regime by reducing salinity, tidal amplitude, and tidal scour using a system of levees and water control structures. The utility of this practice is a topic of debate in the coastal restoration community. A recent study by Kuhn et al. (1999) found that a managed salt marsh near Fourchon, Louisiana, had lower sedimentation rates, tidal amplitude, and annual primary production compared to an adjacent natural marsh. Organic matter content was significantly greater in the managed marsh, and soil bulk density was 60 percent greater in the reference marsh. They concluded that structural marsh management inhibited marsh surface accretion and that the impounded marsh was "functionally impaired" compared to the natural marsh (Kuhn et al. 1999).

The frequency and duration of flooding is a primary determinant of plant species composition in wetlands. In addition to directly influencing species composition based on specific plant tolerances, the flooding regime influences important abiotic factors such as soil chemistry, nutrient cycling, and sedimentation patterns. These factors contribute to a feedback loop that creates conditions for long-term plant community dynamics and succession.

Salinity

In Louisiana's coastal marshes, disturbance caused by exposure to increased salinity may result from several factors, including coastal submergence due to subsidence and relative sea level rise, pulses of saline waters into fresh and brackish marsh habitats during hurricane events, intrusions up deep navigation and pipeline canals, and brine discharges or spills during the exploration and production of oil and gas (Pezeshki et al. 1987a; Pezeshki et al. 1987b). Boesch et al. (1994) attributed a 433 km^2 increase in brackish and salt marsh types, and an equivalent direct loss of lower salinity marshes between 1968 and 1978, to saltwater intrusion associated with relative sea level rise. Some researchers have estimated that sea level will rise 46-100 cm by the year 2100 (Boesch et al. 1994). Penland et al. (1989) estimated that relative sea level (due in part to subsidence of Holocene sediments) may rise in coastal Louisiana 150-200 cm over the next century. These projections have prompted numerous simulation studies to determine the effects of increased sea level rise (flooding) and salinity (Parrondo et al. 1978; Pezeshki et al. 1987a; Pezeshki et al. 1987b; Baldwin et al. 1996; Baldwin and Mendelssohn 1998) on plant physiology, germination, competition and distribution.

Increased salinity has been shown to affect plant physiological processes. In a simulation study, Pezeshki et al. (1987a) reported a 40-65 percent reduction in stomatal conductance and a decline in net photosynthesis of between 51 and 70 percent by baldcypress (*Taxodium distichum*). The same researchers obtained similar results when subjecting a common freshwater marsh grass, maidencane (*Panicum hemitomon*), to the same simulation experiment. An exposure to salinities of 10 and 12 parts per thousand resulted in the plant's death.

Baldwin et al. (1996) investigated the effects of higher salinities and flooding on the viability of seed banks from an oligohaline marsh and found that both reduced seedling germination. Surprisingly, they also reported that the composition of the standing vegetation had little bearing on the species composition of the seed bank. Studies have shown that the colonization of gaps in salt marshes is primarily due to the expansion by neighboring plants, and not by the germination of buried seeds (Hartman 1988; Bertness and Ellison 1987 cited in Keddy 2000). The zonation of vegetation in salt marshes has been widely attributed to edaphic stresses such as salinity and flooding, rather than biotic ones (Parrondo et al. 1978). Parrondo et al. (1978) investigated the responses of three salt marsh species to increased salinity and drainage and then related these different responses to spatial patterns observed in the field. Their findings indicated that *Distichlis spicata* was the most tolerant to salinity compared to *Spartina alterniflora* and *Spartina cynosuroides*. These findings suggested that salinity may not play as big a role in determining species zonation in salt marshes as previously thought because *Spartina alterniflora* is the dominant species in Louisiana salt marshes, yet it did not display greater tolerance to salinity than the other, less dominant, species.

Significant variability exists in a plant's ability to cope with salinity stress. This variability contributes to the zonation patterns observed in coastal marshes. Likewise, disturbance caused by salinity increases affect coastal marshes at various spatial and temporal scales. Salinity pulses during storm events can significantly affect species composition in discrete areas, whereas long-term increases in salinity associated with subsidence or hydrologic alterations can result in gradual shifts in species composition.

Cattle Grazing

Disturbances caused by livestock grazing in salt marshes have been known to increase the number of gaps in vegetation, which may result in changes is species composition (Ungar and Woodell 1996). Many of the perennial species dominating salt marsh communities do not produce persistent seed banks. These seed banks are dominated by annual species (Ungar and Woodell 1996). Ungar and Woodell (1996) investigated the effects of different grazing intensities at four salt marshes in South Wales to determine the effects of grazing on species richness, relative seed densities, and percent aboveground cover of perennials and annuals. They found a significantly higher species richness in the seed banks and aboveground vegetation at lightly grazed marshes compared to ungrazed and heavily grazed marshes, which supported the Intermediate Disturbance Hypothesis. They found a higher relative aboveground cover of annual species at the grazed areas and that the seed bank of the heavily grazed marsh contained 100% annual species. Two annual species made up 100% of the seed bank in the heavily grazed marsh and only 8% in the ungrazed marsh. Perennial species made up approximately 80% of the seed bank in the ungrazed marsh. A comparison between the seed banks and aboveground vegetation revealed that the percent similarity was low in all marshes and that lightly and heavily grazed marshes had percent similarities of 9.9% and 13.7% respectively.

Andresen et al. (1990) compared the long-term effects of different grazing intensities in a German salt marsh. They found that grazing and trampling reduced canopy height, created a gradient in the structure of vegetation at low grazing intensities, and resulted in different species composition.

Cattle grazing in marshes is an accepted management practice that combines the effects of biomass removal, nutrient recycling, and selective seed dispersal with trampling.

Moderate grazing intensity appears to increase spatial heterogeneity by creating canopy gaps, which, in turn, favor increased species richness (Table 2.1).

Toxins

Coastal wetlands in south Louisiana hold vast quantities of petroleum resources. Hydrocarbon and brine releases occur frequently as a result of the intense oil and gas exploration, production, and transportation activities in coastal Louisiana,. A number of studies have investigated how petroleum hydrocarbon and brine impact wetland vegetation (Hershner and Moore 1977; DeLaune et al. 1979; Mendelssohn et al. 1990; Lin and Mendelssohn 1996; Mendelssohn et al. 1997). These investigations have provided mixed results due to the large number of factors influencing impacts and plant recovery, including the toxicity of material, vegetation susceptibility, water level, degree of exposure, cleanup method, hydrology, and soil properties.

Bozzo et al. (1990) reported that there was no marsh vegetation recovery near the source of a brine spill in a Texas salt marsh during a ten-month study. They reported that the observed shifts in species dominance were due to salt tolerant species colonizing impacted areas. Salt tolerant species, such as *Lycium carolinianum* and *Spartina alterniflora*, replaced species such as *Scirpus robustus* in areas where they previously were not present. Mendelssohn et al. (1990) reported a 64 % reduction in vegetation cover in a brackish marsh three months after a spill in southeastern Louisiana. *Phragmites australis* aboveground biomass was reduced in areas receiving no cleanup at Delta National Wildlife Refuge (Mendelssohn et al. 1997). Enhancement of plant growth was reported in areas receiving light cleanup. In another study, Lin and Mendelssohn (1996) tested the hypothesis that salt marsh plants are generally more resistant to stress by comparing the effects of crude oil on vegetation of fresh, brackish, and salt marshes. They reported that oil additions caused

higher growth of a fresh marsh species and impaired growth of brackish and salt marsh species. These researchers also attributed the differences between marsh types to differences in soil organic matter content, which affects sorption and penetration into the root zone. Significant increases in *Spartina patens* net productivity and seed head production was reported following an oil spill and associated cleanup operations in a Chesapeake Bay salt marsh (Hershner and Moore 1977). The findings of their study suggested that the physical disturbances associated with the cleanup operations may have been responsible for the increased flowering.

Toxins released from brine and hydrocarbons during oil and gas production may affect coastal marshes. Unlike salinity pulses associated with storm events, brine releases typically originate from a point source (either a spill or a discharge) and affect species composition in a limited area and for a protracted amount of time. The toxic effect of oil on marsh vegetation is variable and depends on spill quantities and qualities, species tolerances, soil types, nature and degree of coverage, and cleanup procedures.

Trampling by Vehicular Traffic

A number of researchers have investigated the effects of vehicular traffic on wetland vegetation (Harris and Chabreck 1958; Schemnitz and Schortemeyer 1973; Detro 1977; Whitehurst et al. 1977; Duever et al. 1981; Sikora et al. 1983; Duever et al. 1986; Kevan et al. 1995; Bass 1997; Nidecker et al. 1993; Chabreck 1994; Ensminger 1995; Ensminger et al. 1997; Racine et al. 1998; Hess et al. 1998; Wilson et al. 1998; Bass 2003). Whitehurst et al. (1977) used aerial photography to detect several stages of marsh destruction caused by marsh buggies in a saline marsh near Leeville, Louisiana. They documented over 2,414 km of marsh buggy tracks in a 15.8 km^2 study area. Vegetation recovered in trails where the soil was not severely compacted. Trails that received continued traffic became further

compacted and soil saturation and waterlogging were evident. They concluded that, if abandoned, these tracks would also eventually revegetate. However, with continued use, the most advanced stage of destruction resulted in increased subsidence and increase in open water.

Chabreck (1958) attributed increased marsh damages associated with Hurricane Audrey to marsh buggy trails that severed the vegetation root mat, thus making the marsh more susceptible to damage by the physical forces of the hurricane. Duever et al. (1981) investigated the effects of airboats and tracked vehicles on South Florida wetland habitats and found that vegetation height was the most impacted parameter, that biomass was moderately impacted, and that the percent cover was the least impacted parameter after one year. Schemnitz and Schortemeyer (1973) also investigated the short-term effects of various levels of tracked vehicle and airboat traffic on live biomass in the Florida Everglades. They found that biomass in the airboat treatments did not differ significantly from controls, except when the airboat made five passes on the same trail. However, tracked vehicles significantly reduced biomass in three of the six treatment plots. Racine et al. (1998) described the nature, magnitude, and distribution of disturbances caused by airboat trails over floating mat fen wetlands near Fairbanks, Alaska. They documented over 345 km of airboat trails and found that, on average, 30 cm of the 0.5-0.75 m thick floating mat had been eroded by airboat traffic. Additionally, only of 5% of the vegetation cover remained on the vehicle trails.

Chabreck (1994) assessed a seismic program at Sabine National Wildlife Refuge in Cameron Parish, Louisiana, and found that marsh buggies caused rutting in four of the twenty-one sites inspected, but that plant re-growth did not appear to be affected. Evidence of rutting by airboats was not observed, and long-term impacts were not expected. Nidecker

et al. (1993) developed a monitoring program to assess the impacts of 3-D seismic activity on wildlife and wetlands at Sabine National Wildlife Refuge. They concluded that vegetation quickly recovered on airboat and marsh buggy trails where compaction did not occur. Plant species dominance was not affected.

Wilson et al. (1998) found that seismic activity had no significant effect on the total emergent vegetation cover and that these were minor short-term species composition changes in a study at the Rockefeller Refuge in Cameron Parish, Louisiana. Hess et al. (1998) evaluated soil disturbance associated with the same 3-D survey and found no differences in disturbed and undisturbed soil elevations. Of the studies documenting the effect of vehicle traffic on fresh marsh vegetation, none have been conducted in Louisiana, which is where these vehicles are used extensively, especially during 3-D seismic surveys.

The effects of trampling by vehicles on marsh vegetation and soils have been documented in a variety of wetland habitats from South Florida to Alaska. Impacts depend on a number of factors including vehicle weight, number of passes, and soil and vegetation types. The effects range from severe rutting and eventual marsh destruction to minor effects such as crushing; reductions in plant height, live biomass, and cover; shifts in species composition; and increased richness (Table 2.1).

All these disturbances are commonly seen in wetlands, especially in coastal Louisiana. They constitute a significant source of spatial and temporal heterogeneity. An understanding of their effects is essential to interpret data from field experiments because much of landscape in coastal marsh ecosystems has been shaped by these disturbances over time.

CURRENT ISSUES IN WETLAND DISTURBANCE THEORY

Disturbance theory might be used to help predict the effects of a given disturbance on the community organization in terms of species richness, species composition, diversity, and competitive interactions. A fundamental concern of land managers is the initial impact of a given disturbance on the plant community and how the recovery patterns and rates change following a disturbance. Numerous biotic and abiotic variables and their interactions, as well as the scale of study, determine the effects of disturbance. Examples of biotic variables include a species' life history, growth forms, reproduction rates, stress tolerances, and competitive interactions. Abiotic factors affecting the impact of disturbance on plants include disturbance intensity, frequency, environmental factors (e.g., water level), and timing.

A conceptual model should maintain its predictive ability, regardless of the scale or ecosystem affected. It is at the landscape scale that disturbance theory has the most application in terms of managing ecosystems. Five prominent general concepts are discussed here and outlined in Table 2.2. The Patch Dynamics Concept (PDC) broadly attempts to predict community organization through hypotheses involving predation, competition, and disturbance (Table 2.2). The basis of this concept is that the temporal heterogeneity of disturbance in a community determines the types of species present and the rates of recolonization following a disturbance. This approach views every ecological system as a patch mosaic in which community dynamics differ by their degree of spatial and temporal heterogeneity (Barrat-Segretain and Amoros 1996). The PDC predicts that the resulting plant community is determined by life history strategies of the r and K-selected species affected by the disturbance. R-selected species are typically opportunist species with high reproductive potential (Beeby 1993). K-selected species are highly specialized,

competitively dominant, and sensitive to environmental changes (Beeby 1993). Huston's (1979) Dynamic-Equilibrium Model (DEM) predicts that: (1) species diversity patterns are based on the interaction of productivity and disturbance, which also takes into account disturbance frequency; (2) temporally variable disturbances create diversity across an otherwise homogenous landscape; (3) diversity is highest when the opposing forces of disturbance and productivity are in equilibrium; and (4) competitive exclusion determines diversity in undisturbed environments. Similarly, the Intermediate Disturbance Hypothesis (Connell 1978) predicts that the maximum diversity will be maintained when disturbance prevents competitive exclusion, and that maximum species richness is attained at intermediate size, frequencies, and intensities of disturbance. This theory is based on the widely accepted view that competitively inferior species benefit from disturbances by the removal of biomass, which lessens competition for space while increasing the availability of resources such as sunlight and nutrients. It is described as the competitive reduction hypothesis (CRH) (Table 2.2). Furthermore, it is also widely accepted that there exists a tradeoff between a species' competitive ability and it's stress tolerance. Competitively superior species typically are less tolerant to stressors such as flooding or salinity. This tradeoff accounts for the species gradient observed in many wetlands that is determined by flooding and salinity stress and is a primary determinant by which species colonize gaps created by a disturbance event. A species' dispersal ability, growth rate, and tolerance to environmental conditions or stresses present in the gap determines the initial colonization of the gap following its creation. These and other factors determine the vegetative dynamics within the gap. It is at this scale that many models are developed and tested.

Much of the current theoretical research on wetland disturbance focuses on gap dynamics and competitive interactions resulting from disturbances. Here I highlight several

relevant articles involving empirical studies specifically designed to test and advance current disturbance theory and several field studies conducted to investigate competitive interactions and succession following disturbance. Barrat-Segretain and Amoros (1996) tested the predictions of the PDC on experimentally cleared patches in former channels of the Rhone River, France, that had different flooding (disturbance) frequencies. The PDC makes predictions based on historical disturbance frequency, which determines the community composition of an area. According to the PDC, species in disturbed areas will exhibit traits that enable them to exist under the historical disturbance regime of those areas. Specifically, the PDC predicts that frequently flooded areas will have high species richness and will be rapidly re-colonized by r-strategy species through a "competitive lottery" process. This process may result in a different plant community compared to before the disturbance occurred. Conversely, recovery in channels rarely flooded takes longer and is controlled by the dominant, K-strategy species. The resulting plant community would be similar to the one before the disturbance. Lastly, intermediately flooded plots would have characteristics of both other sites.

The findings of the study by Barrat-Segretain and Amoros (1996) supported the PDC. The most frequently disturbed site recovered species richness and cover rapidly because these species possess traits that favor the rapid establishment of bare patches such as good vegetative reproductive and dispersal abilities - both traits typical of r-strategy species. As predicted by the PDC, the less frequently disturbed site was less resilient. Vegetative cover re-establishment in the gap was by both r-strategy and K-strategy species. Furthermore, the absence of new colonizer species led the authors to label this a "dominance-controlled" community. Similarly, the site having an intermediate frequency of disturbance displayed intermediate resilience to the experimental disturbance and was

colonized by predictable, r-strategy species. Pollock et al. (1998) also used flooding frequency as a source of temporal heterogeneity to test Huston's (1979) DEM (Table 2.2). However, they expanded the scale to include a 1000 m^2 study area as well as 1 m^2 study areas in the Kadashan River basin study in southeast Alaska.

Pollock et al. (1998) specifically tested to see if disturbance frequency and productivity are reliable predictors of species richness between wetlands, and if predictions are affected by scale. Their findings supported the predictions of the DEM at the community scale, but not at the micro-plot scale. Both productive, rarely disturbed sites, and unproductive, highly disturbed sites had low species richness. The most diverse communities were located at intermediate levels of productivity and flood frequency. Furthermore, the unproductive, frequently flooded sites were dominated by r-selected species, while the unproductive sites were dominated by slower growing, K-selected species such as shrubs and clonal herbs.

The DEM predicted 36% of the variation in species richness at the microplot scale. At this scale productivity accounted for most of the variation in species richness, which indicates that disturbance frequency is not an important factor in determining species richness at the small scale. The findings of Pollock et al. (1998) suggest that interactions between vegetation and the environment and community structure are scale dependent, which can dramatically influence the conclusions of a study. Competitive interaction is a basic tenet in many disturbance theories. It is widely accepted that disturbance removes biomass, which reduces competitive intensity, and allows inferior species to colonize. Suding and Goldberg (2001) proposed and tested an alternative hypothesis, called the competitive change hypothesis (CCH) (Table 2.2). As the name suggests, the CCH predicts that disturbance not only reduces competition, but can alter competitive hierarchies within gaps. This model

Table 2.2. Ideas and applications of current disturbance theory to coastal wetlands. This table includes five prominent general concepts in disturbance theory. General predictions, applications, limitations, and supporting and contradicting studies are provided.

Concept	General Predictions	Applications/ Limitations	Supporting/Contradicting Studies
Patch Dynamics	Community organization based on predation, competition, and disturbance; communities determined by life history strategies of r and K-selected species; resiliency and species composition based on historical disturbance frequency	Flooding, burning, storms, trampling; Common species have advantage at patch level; therefore, competitive lottery scale-dependent	Barrat-Segretain and Amoros 1996
Dynamic Equilibrium Model (Huston 1979)	Predicts diversity based on interaction of productivity and disturbance; landscape-scale spatial heterogeneity increased by periodic disturbances; predicts highest diversity when opposing forces of disturbance and productivity are in equilibrium; competitive exclusion determines species diversity in undisturbed environments	Conceptually useful; however, generally developed for landscape-scale predictions Disturbance regimes difficult to quantify under natural conditions; should incorporate small-scale spatial variation	Pollock et al. 1998
Intermediate Disturbance Hypothesis (Connell 1978)	Disturbance maintains diversity by preventing competitive exclusion; maximum species richness maintained at intermediate frequency, size, and intensity	Generally useful; however, limited because intermediate levels not defined; does not address variable interactions among communities	Petraitis et al. 1989; Kirkman and Sharitz 1994; Pollock et al. 1998; Abugov 1982 Contradicting: Collins et al. 1995; Grace and Pugesek 1997; Luken et al. 1992

Table 2.2 cont.

Concept	General Predictions	Applications/ Limitations	Supporting/Contradicting Studies
Competitive Reduction Hypothesis	Disturbance reduces species density and allows inferior species to colonize patches; no change in competitive hierarchy; based on tradeoff between competitive ability and stress tolerance	Burning, grazing, trampling; Useful for disturbances that are within the natural disturbance regime; do not affect abiotic factors such as soil conditions, stress levels; Not applicable to severe burning, rutting, salinity modifications, eutrophication	Wilson et al. 1998; Bass 1997
Competitive Change Hypothesis (Suding and Goldberg 2001)	Competitive hierarchy shifts under disturbed conditions; species associated with disturbed habitats may out-compete species not characteristic of disturbed habitats due to mechanisms such as reduction in biomass, size, structure, species composition, and soil condition	Severe burning, overgrazing, soil rutting, eutrophication; alterations to hydrologic and salinity regime, hurricanes	Supporting: Suding and Goldberg 2001

predicts that disturbances alter environmental conditions within the gaps to favor colonizer species, which are better competitors under the disturbed conditions. Their study found that neighborhood changes (biomass and neighbor species) affected competitive intensity. However, abiotic soil alterations caused shifts in competitive hierarchies. Their results indicated that predictions of the effects of a particular disturbance should include biotic and abiotic characteristics. The CCH has practical applications linked to disturbance intensity and vegetation recovery thresholds. For instance, vehicular traffic in a marsh would open gaps in the vegetative canopy, thus allowing colonist species to grow. These species composition changes are short-lived, and colonist species are not expected to replace the competitively superior species. However, if the disturbance affected abiotic characteristics, such as soil conditions, then species rankings would be affected. Similarly, prescribed marsh burns conducted when a thin layer of water is on the marsh surface typically result in surface burns where roots are not affected and regrowth is rapid by the same species. However, if burning is conducted when water levels are low, peat burns may occur where roots and substrate are damaged, leaving holes in the marsh. Under these altered conditions, species composition shifts to a floating or submerged aquatic plant community adapted to these changed conditions. Allison (1995) conducted simulated sedimentation disturbance experiments in a California salt marsh and found that competitively inferior species did not gain an advantage over dominant species following a disturbance. Disturbed patches were re-colonized by pre-disturbance plant assemblages. Because competition and stress tolerance are primary determinants of zonation patterns in marshes, disturbances that alter competitive interactions can potentially cause large-scale species composition changes. Emery et al. (2001) challenged the trade-off theory that species are either stress tolerant or dominant competitors. Their findings revealed that competitive outcomes were reversed when

nutrient limitation stress was removed in two Rhode Island salt marshes. Furthermore, they showed with transplant experiments that this reversal was independent of where the interactions took place along the tidal gradient. The stress tolerators were consistently the best competitors in fertilized treatments. These findings were supported by Bertness et al. (2002) who reported shifts in competitive hierarchies in New England salt marshes stemming from the elimination of nutrient competition because of nitrogen eutrophication from shoreline development. Their findings indicated that nitrogen eutrophication from shoreline development shifted the competitive balance among marsh plants by eliminating nutrient competition. *Spartina alterniflora,* a competitively superior, but nitrogen limited species, displaced *Spartina patens*, a stress-tolerant species found at the low end of the marsh elevational gradient. Conversely, monocultures of *Phragmites sp.* displaced the *Spartina alterniflora* at the higher end of the marsh elevational gradient.

Disturbances such as eutrophication affect competitive interactions based on nutrient limitations, not space. On the other hand, disturbances that create discrete patches introduce abiotic factors such as sunlight and soil salinity, which determine the species that will re-colonize the area. These physical factors are dependent on the size of the patch. For example, a large gap would conceivably receive more direct sunlight compared to a small gap because of the difference in the relative degree of shading from surrounding vegetation. This difference in shading may determine the species capable of colonizing the patch.

Bertness and Shumway (1994) investigated the effect of patch size on secondary succession in salt marshes. They found that smaller disturbance patches have less stressful physical conditions and colonization is determined by competitive interactions. Larger patches with high soil salinities were colonized by salt-tolerant species which facilitated colonization by competitively dominant species. The important findings of their study were

that patch size strongly influences secondary succession dynamics and that succession models must take into account the size of the disturbance when predicting species compositions. Furthermore, extrapolating results of small-scale experiments to large-scales may be misleading. Therefore, patch size should be considered as an important variable when predicting the trajectory of secondary succession.

These models provide a general framework to help organize concepts on the effects of disturbances on plant communities. The PDC (Table 2.2) is a broad attempt to explain how plant communities are assembled based on hypotheses on predation, competition, and disturbance. For organizational purposes, the IDH, CRH, and the CCH can be viewed as subsets of the more general PDC. The IDH is also a broad concept that is most useful if *a priori* data is available to help define what an "intermediate" level of disturbance is with regard to the disturbance agent and the inertia and resiliency of the plant community and soils. The CRH and CCH make predictions based on competitive abilities and life-history traits of the species affected. The CCH is a useful tool to predict effects on the competitive hierarchies if there is adequate data on how a given disturbance will alter site conditions (soil, salinity, and nutrient levels), and specific plant tolerances to these changes. These tolerances affect the competitive interactions between species, and tradeoffs between stress tolerators and superior competitors determine community compositions. In summary, all of these models provide insight into the effects of disturbance on plant communities, but the idiosyncrasies among sites and species preclude the broad application of these models.

Wetlands are subjected to disturbances that range in scale, intensity, and frequency. The literature surveyed included large-scale disturbances such as flooding and saltwater intrusion caused by hurricanes to small-scale disturbances caused by vehicle traffic. An important point that many of the articles had in common was that the effects of disturbances

were often unclear, especially when multiple disturbances interacted. Large-scale natural disturbances such as hurricanes can result in physical damages and flooding that affect thousands of hectares as well as numerous small patches. The patch-dynamics resulting from these disturbances are often predictable based on the competitive interactions of the plant species affected and the historical frequency of similar disturbance events. The timing, frequency and factors such as water level and salinity also determine the initial level of disturbance and trajectory of succession within the patch. Disturbances that occur at a frequency greater than the time it takes for species to recover often result in shifts in species composition.

CONCLUSIONS

McKee and Baldwin (1995) were accurate in their assessment that no unified theory on the effects of disturbance on wetland plant communities exists. Based on the literature reviewed here, I conclude that broad theoretical concepts such as the Intermediate Disturbance Hypothesis, Patch Dynamics Concept, and the Dynamic Equilibrium Model can be useful tools to predict the effects of disturbances on wetland plants if the models are refined to account for the site-specific environmental factors, competitive interactions, and interaction with multiple disturbances. It is apparent why a unified theory on wetland disturbance has not been established: wetlands are complex systems. Effects of disturbances cannot be adequately assessed using these simple models because the characteristics of the disturbance, of the site, and the species are too variable. Extrapolating disturbance effects from small to large scale, or across landscape types, is not yet appropriate. For example, the results of a study on the effects of vehicle traffic during 3-D seismic surveys in a fresh marsh in the Louisiana Chenier Plain probably would not apply to the same disturbance in brackish or saline marshes in the Mississippi River Deltaic Plain because of differences in

pre-existing stressors, soil types, and plant communities.

This study identified a need to refine existing models to predict the effects of specific disturbance types using empirical studies conducted across wide range of habitats, conditions, and intensities to determine where similarities and differences exist.

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CHAPTER 3

DISTURBANCE HISTORY AT THE LACASSINE NATIONAL WILDLIFE REFUGE

INTRODUCTION

Disturbance plays an important role in the formation and maintenance of natural systems. Plant species composition is determined, in part, by the intensity, scale, and frequency of disturbance. An understanding of the disturbance regime under which vegetative communities have developed and/or persisted increases the ability of scientists, land managers, and regulators to predict the effects of future anthropogenic and natural disturbances on that system.

The objectives of this chapter are to: (1) identify and assess the impacts of historical disturbances at LNWR (refuge), (2) quantify and map disturbance events, and (3) identify disturbance-initiated plant community changes over the life of the refuge.

Study Area

The Lacassine National Wildlife Refuge is located in Cameron Parish in southwest Louisiana. Figure 3.1 is a color-infrared aerial orthophotograph of the LNWR showing the general location and important features on the refuge. The LNWR was established in 1937 with the primary purpose of providing wintering habitat for migratory waterfowl (U.S. Fish and Wildlife Service 1997). The LNWR consists of 14,164 hectares (ha) (35,000 acres) of fresh marsh. The dominant feature at the LNWR is a 6,475-hectare impoundment referred to as the Lacassine Pool (Pool). The Pool provides the primary migratory resting-place for concentrations of up to 800,000 ducks and geese (US Fish and Wildlife Service 1997). The habitat is theoretically managed for all wildlife species, but an emphasis is placed on providing habitat for waterfowl (US Fish and Wildlife Service 1997). Figure 3.2 is a map of the LNWR showing the habitats on the refuge in 1958.

Figure 3.1. Color infrared aerial orthophotograph of Lacassine National Wildlife Refuge showing relevant site features.

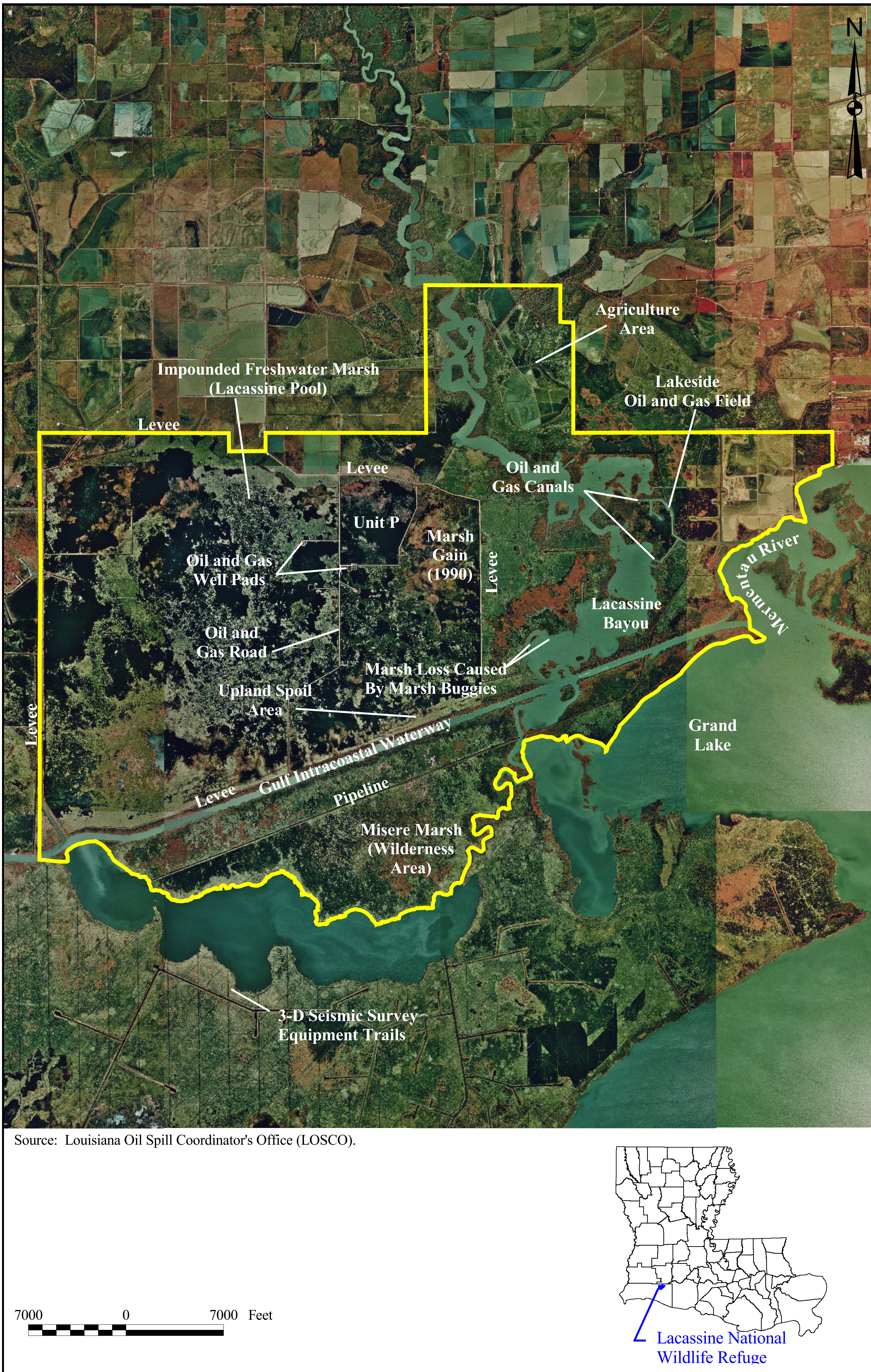


Figure 3.1. Color infrared aerial orthophotograph of Lacassine National Wildlife Refuge showing relevant site features.

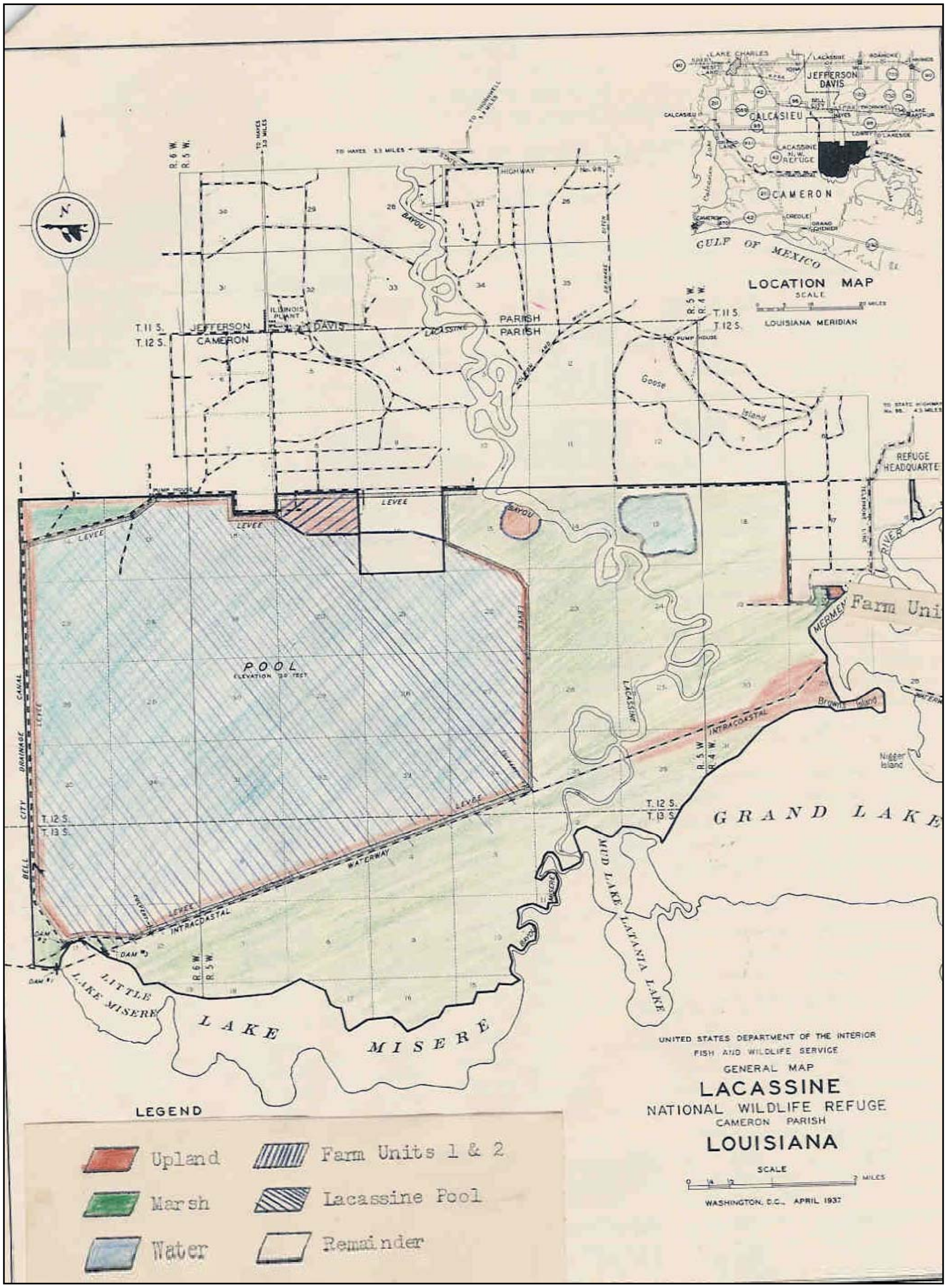


Figure 3.2. 1958 habitat map of the Lacassine National Wildlife Refuge showing the location of Lacassine Pool, agricultural and upland areas, marsh, and open water (U.S. Fish and Wildlife service 1958).

Physical Setting

Vegetation

The two dominant plant communities at the LNWR in 2001 were open-water (floating-leafed/ submerged aquatic) and emergent fresh marsh communities. The most abundant species in the emergent community are *Panicum hemitomon* and *Sagittaria lancifolia*. The floating-leafed or submerged community is comprised of *Brasenia schreberi*, *Nymphoides aquatica*, *Nymphoides odorata*, and *Eleocharis equisetoides* (Fruge 1974). Latin names for vegetation are used throughout this chapter. Common names are provided in the species list located in Chapter 4. Table 3.1 includes a summary the dominant species traits and susceptibilities to disturbance.

Table 3.1. Species traits and susceptibilities to disturbance of the dominant plants at the Lacassine National Wildlife Refuge. The majority of the information provided in this table was obtained from the United States Department of Agriculture, National Resources Conservation Service Plants Database website at http://plants.usda.gov/topics.html.

Wetland Plant Community	**Plant Traits**	**Susceptibility to Disturbance**
Emergent Fresh Marsh		
Panicum hemitomon	perennial grass, year round growth, forms dense mats, extensive rhizomes, brittle stems, high biomass production, rapid vegetative reproduction	stem breakage, highly tolerant of flooding and fire, moderately tolerant of shade, low tolerance to salinity
Sagittaria lancifolia	perennial herb, growth from rhizomes, spongy leaves	tolerant of flooding, low tolerance to salinity
Open Water (Floating-Leafed/ Submerged Aquatic)		
Nymphaea odorata	perennial herb, growth from rhizomes, floating leaves	highly tolerant of flooding and fire, low tolerance to salinity
Brassenia schreberi	perennial herb, growth from rhizomes, floating leaves	low tolerance to salinity
Nymphoides aquatica	perennial herb, growth from rhizomes, floating leaves	highly tolerant of flooding and fire, low tolerance to salinity
Eleocharis equisetoides	perennial grass, summer and fall active growth, moderate growth rate, slow vegetative reproduction	highly tolerant of flooding and fire, low tolerance to salinity, intolerant of shade

Soils

The primary soil present throughout the LNWR is Allemands muck. Allemands muck is an organic soil commonly found in fresh marshes (U.S. Department of Agriculture 1995). The organic muck layer is typically approximately 30 inches thick, has a low load-bearing capacity, and has a high potential for subsidence. Extreme acidity, subsidence, and low strength are limiting characteristics of this soil under drained conditions. This soil is also susceptible to peat burns and vehicular rutting and is generally too soft for livestock grazing. Also present at LNWR is Ged mucky clay and Larose muck. Ged soil is a mineral soil typically found on the natural ridges and Larose soil is a mineral soil found adjacent to Bayou Lacassine. Table 3.2 provides general physical descriptions and limitations of these soils.

Table 3.2. Primary soil types at the Lacassine National Wildlife Refuge (USDA 1995).

Soil Type	**Location**	**Description**	**Limitations**
Allemands muck	throughout LNWR, Lacassine Pool, adjacent to Bayou Lacassine, marshes south of GIWW (Gulf Intracoastal Waterway)	organic soil, very fluid, organic layer approximately 30'' thick, then a very fluid mucky clay to a depth of 37 inches	low load –supporting capacity, high potential for subsidence, not suited for cultivation, livestock grazing, or pasture
Ged mucky clay	natural ridge (Jim's Ridge) in Lacassine Pool	mineral soil, mucky surface layer approximately 4 inches thick, firm, clayey subsoil	low load –supporting capacity, moderately well suited for livestock grazing
Larose muck	adjacent to Bayou Lacassine just north of and south of the GIWW	mineral soil, very fluid mucky surface layer approximately 6 inches thick, very fluid, mucky and clayey underlying material to a depth of 82 inches	low load –supporting capacity, medium subsidence potential, not suited for crops or pasture, cannot support weight of grazing cattle

Hydrology

Water levels in the un-impounded portion of the refuge are controlled by rainfall over the Mermentau River Basin and by wind-driven tides from Grand Lake and Lake

Misere (U.S. Fish and Wildlife Service 1987). Water level in the natural marsh is also periodically affected by agricultural practices; i.e., water is pumped from underground sources to flood rice fields and is discharged into the Mermentau River. The hydrology in the Pool is controlled by rainfall and by stop-log water control structures that permit the water levels to be lowered to outside levels. Water is not pumped from nearby canals to avoid the introduction of nuisance exotic plant species into the Pool. Because rainfall is the only hydrologic input, the Pool is susceptible to droughts.

DATA SOURCES

Information about historical disturbance was obtained from the series of LNWR narrative reports (NRs) (US Fish and Wildlife Service series of tri-annual reports from 1937 through 1963) and (US Fish and Wildlife Service series of annual reports from 1964 through 2000). These NRs are filed chronologically at the LNWR headquarters in Lake Arthur, LA. These reports represent an excellent historical record of management activities, climatic events, oil and gas exploitation, and natural resource management and utilization on the refuge. These reports began with the establishment of the refuge in 1937 and are continuous through the present with the exception of 1973. From 1937 through 1963, these NRs were completed on a tri-annual basis. Beginning in 1964, these reports were completed annually. Summaries of these narrative reports are located in Appendix A. A timeline of significant events at LNWR from 1935 through 1999 is in Appendix B.

Historical landscape change data was obtained from Britsch and Dunbar (1996). A report, Hydrologic Investigation of the Louisiana Chenier Plain (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2002), provided anecdotal information on the causes of landscape change at the LNWR. This information was based on interviews with

experts in the fields of biology, ecology, and wildlife management who possess an intimate knowledge of events that have affected the LNWR and the Mermentau Basin.

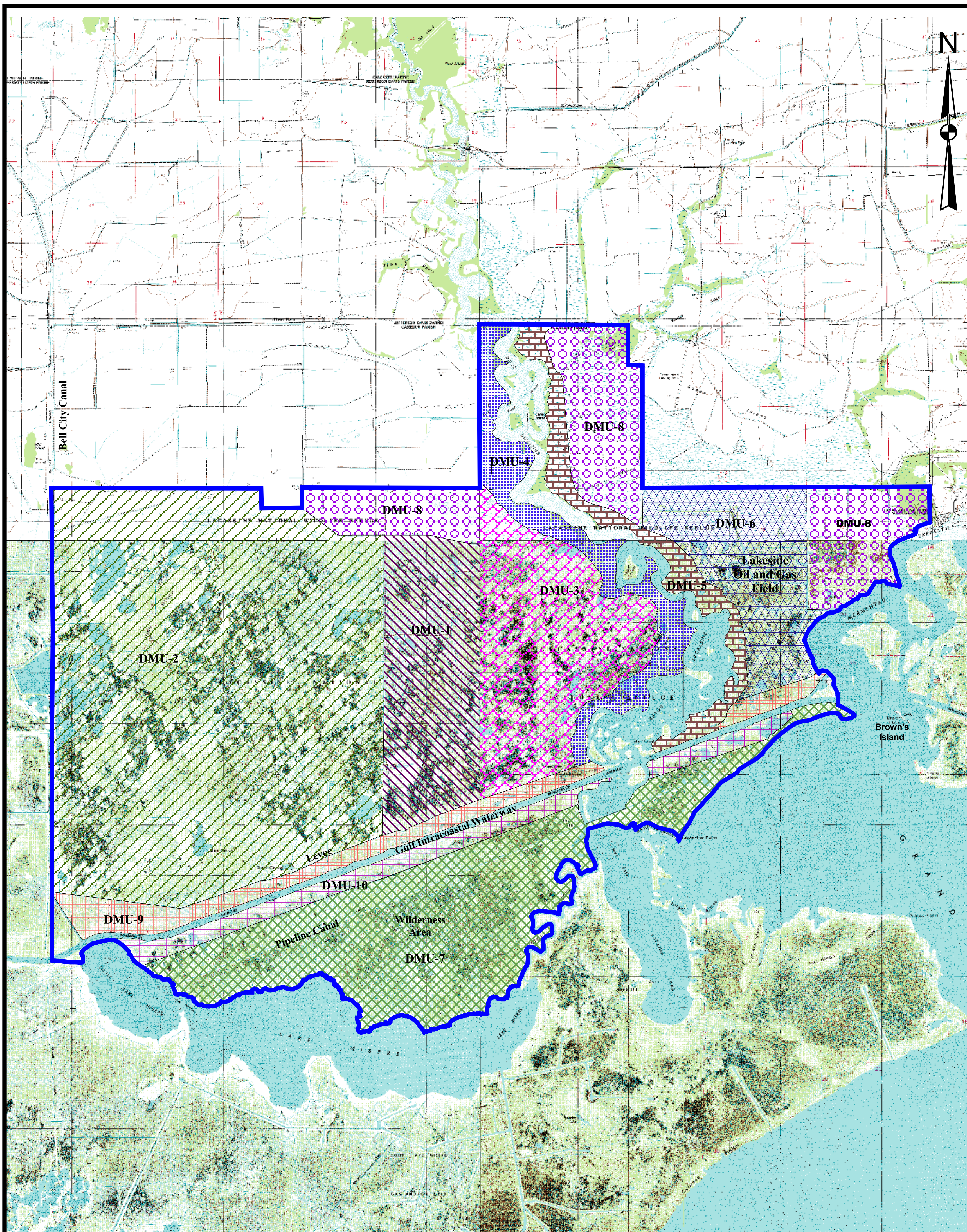
Disturbances are grouped into management practices, oil and gas activities, and weather. Offsite activities that may have affected the LNWR provide background information on the ecology of the refuge, but are not discussed in detail. Management practices at the refuge include water level manipulation in the Pool (1944 to present), prescribed burning (1939 to present), livestock grazing (1940 to 1985), herbicide application (1940s to present), ditch construction (1942 to 1983). Oil and gas exploration and production began on the LNWR in the 1940s. These activities include canal dredging, road construction, and geophysical surveys. The LNWR has also been affected by natural events such as hurricanes, droughts, and saltwater intrusion and by introduced species such as *Sapium sebiferum* and nutria (*Myocastor coypus)*. Offsite activities that have affected the hydrology on the LNWR include the diversion of freshwater out of the Mermentau River by rice farmers and the construction of water control structures at the mouth of the Mermentau River.

I divided the LNWR into eleven disturbance mapping units (DMUs) during this study to spatially quantify disturbances on the LNWR. The DMUs are depicted on the LNWR map in Figure 3.3 and described in Table 3.3.

DISTURBANCE AGENTS

The following section describes the primary disturbance agents at the LNWR over the past 65 years. Table 3.4 is a timeline of significant disturbance events, including management practices. These disturbances are quantified using the DMUs. Figure 3.4 is a series of timeline graphs showing the frequency and duration of the primary disturbances at the LNWR.

Figure 3.3. Map showing the disturbance mapping units (DMUs) at the Lacassine National Wildlife Refuge.



Source: U.S.G.S. 7.5 minute topographic maps.

7000 0 7000 Feet

Figure 3.3. Map of the Lacassine National Wildlife Refuge showing the locations of the disturbance mapping units (DMUs) that are described in table 3.3. These DMUs were used to spatially quantify the natural and human disturbances on the refuge from 1937 through 1999.

Table 3.3. Locations and descriptions of the disturbance map units at the Lacassine National Wildlife Refuge. These disturbance map units were used to spatially organize disturbances that occurred on the refuge between 1937 and 1999. This table is to accompany the map shown as Figure 3.3.

Disturbance Map Unit	Location	Description
1	East Lacassine Pool	impounded emergent and floating marsh, shallow ponds occupied by submerged and floating aquatic species
2	West Lacassine Pool	same as Disturbance Map Unit 1
3	Marsh east of Lacassine Pool	dense stands of *Panicum hemitomon*, shallow ponds occupied by submerged and floating aquatic species
4	Marsh west of Bayou Lacassine	thin floating mat composed of *Alternanthera philoxeroides*,
5	Marsh east of Bayou Lacassine	thin floating mat composed of *Alternanthera philoxeroides*
6	Lakeside Oil and Gas Field	dense stands of *Panicum hemitomon,* thin floating mats along canals edges and in marsh interior, shrub-scrub habitat on spoil banks and along canals
7	Marsh designated as a Wilderness Area south of GIWW	shrub-scrub habitat on and adjacent to spoil bank, dense stand of *Panicum hemitomon* in marsh interior, forested wetland along lake shoreline
8	Agricultural Units	agricultural crops
9	North spoil bank of GIWW	forested, shrub/scrub
10	South spoil bank of GIWW	forested, shrub/scrub
11	Canals and levees	open water, shrub/scrub

Water Level Manipulation

History of Events

The primary reason for founding the LNWR was to provide winter habitat for migratory waterfowl. To improve the waterfowl habitat at the LNWR, the USFWS began constructing the levees around a portion of the LNWR in 1939 to create a 6,475-ha

Table 3.4. A timeline of selected disturbances at the Lacassine National Wildlife Refuge (LNWR) from 1939 through 1999. Frequencies of disturbances including fires, dredging and seismic surveys are quantified for the disturbance mapping units (DMUs) affected. These DMUs are defined in Table 3.3 and shown on a map in Figure 3.3. The frequencies of the disturbances within the DMUs are indicated in parentheses [e.g. DMU-2 (6)]. Animal Use Months (AUMs), a measure of grazing intensity is given for cattle grazing. Total nutria harvested by trappers is used as an indicator of the nutria population dynamics at the LNWR. (Note: "NR" indicates no records of trapping. "NL" indicates that no location was provided for a given disturbance event. A "-" indicates no recorded event or data. The number within the parentheses following "NL" indicates the frequency of that disturbance.)

Year	Fires	Cattle Grazing (Animal Use Months)	Total Nutria Harvested by Trappers	Dredging	Seismic Survey
1939	1, 2	-	NR	1, 2	-
1940	2	1800	NR	1, 2	-
1941	5, 9	2050	NR	1, 2 (2), 6 (2)	-
1942	-	3060	NR	1, 2	-
1943	-	2100	NR	1, 2	1
1944	4, 8	600	3	1, 2, 6	-
1945	10	-	1	-	-
1946	1, 2 (2), 3, 4, 5	-	9	-	-
1947	9	-	443	-	-
1948	NL	2664	1522	-	-
1949	9	2388	543	-	-
1950	7, 8	2399	720	3	-
1951	7, 8, 9, 11	3526	1552	-	-
1952	8	2590	2505	3	-
1953	11	-	1914	3	-
1954	-	-	2457	-	-
1955	-	-	5510	-	-
1956	-	-	6498	6, 8	-
1957	-	3797	6550	-	2
1958	-	2844	11594	1	-
1959	-	2340	6815	9, 10	1, 2
1960	12	2340	2560	1, 2	1, 6
1961	-	2340	7072	-	-
1962	-	1860	7253	5	-
1963	-	1420	7123	3, 4, 5 (2), 6	-
1964	-	2015	4657	2 (2), 6	4
1965	-	2200	6304	6 (4)	1
1966	-	2420	5669	-	-
1967	-	3170	5791	-	1, 2, 7
1968	-	3170	5628	-	1, 2
1969	-	3170	5333	1, 2 (2)	1, 2
1970	-	2400	5095	-	2
1971	2 (2), 4, 8 (2)	2870	6355	5	-
1972	-	2870	6365	-	-

Table 3.4 continued.

Year	Fires	Cattle Grazing (Animal Use Months)	Total Nutria Harvested by Trappers	Dredging	Geophysical Survey
1973	-	2870	-	-	-
1974	-	2870	6608	-	-
1975	2	2870	4954	-	3 (2)
1976	1, 2	1270	-	-	-
1977	-	1670	-	-	-
1978	-	1270	-	-	-
1979	-	-	-	-	NL
1980	-	-	4751	-	NL (3)
1981	-	1260	4553	-	4
1982	-	-	3495	-	-
1983	-	-	2518	-	-
1984	-	720	896	-	NL (2)
1985	-	720	2727	-	-
1986	-	-	1822	-	-
1987	-	-	2025	-	-
1988	-	-	915	6 (4)	1 (3), 2 (3)
1989	-	-	-	1	
1990	1 (2), 2, 8	-	-	1	NL (2)
1991	1 (5), 2 (2), 3, 4, 6, 8 11	-	-	1,2, 8	NL (2)
1992	1 (2), 2 (2), 3, 8 (2), 11 (2), 6, 5	-	-	-	4, 5
1993	8, 6	-	-	-	4, 5, 6
1994	1 (2), 2, 6, 8 (2),10	-	-	-	1, 2, 8
1995	11, 4 (2), 8 (2), 5, 7	-	-	6	-
1996	11, 8 (2), 3, 5, 2, 1, 7	-	-	-	1, 2, 3
1997	2, 8, 6, 10	-	-	-	-
1998	11, 8 (2), 6, 13, 1	-	-	-	-
1999	11, 8 (2), 2 (2), 10, 5, 7	-	-	-	-

freshwater impoundment where water levels could be managed. This impoundment is referred to as the “Pool.” Figure 3.5 is a 1940 photograph of a newly constructed levee around the Pool. The Pool and borrow ditch created by the dredging of material to create the levee are visible on the left side of the photograph. Figure 3.6 is a photograph of a levee refurbished by the U.S. Department of Agriculture, Soil Conservation Service, on the

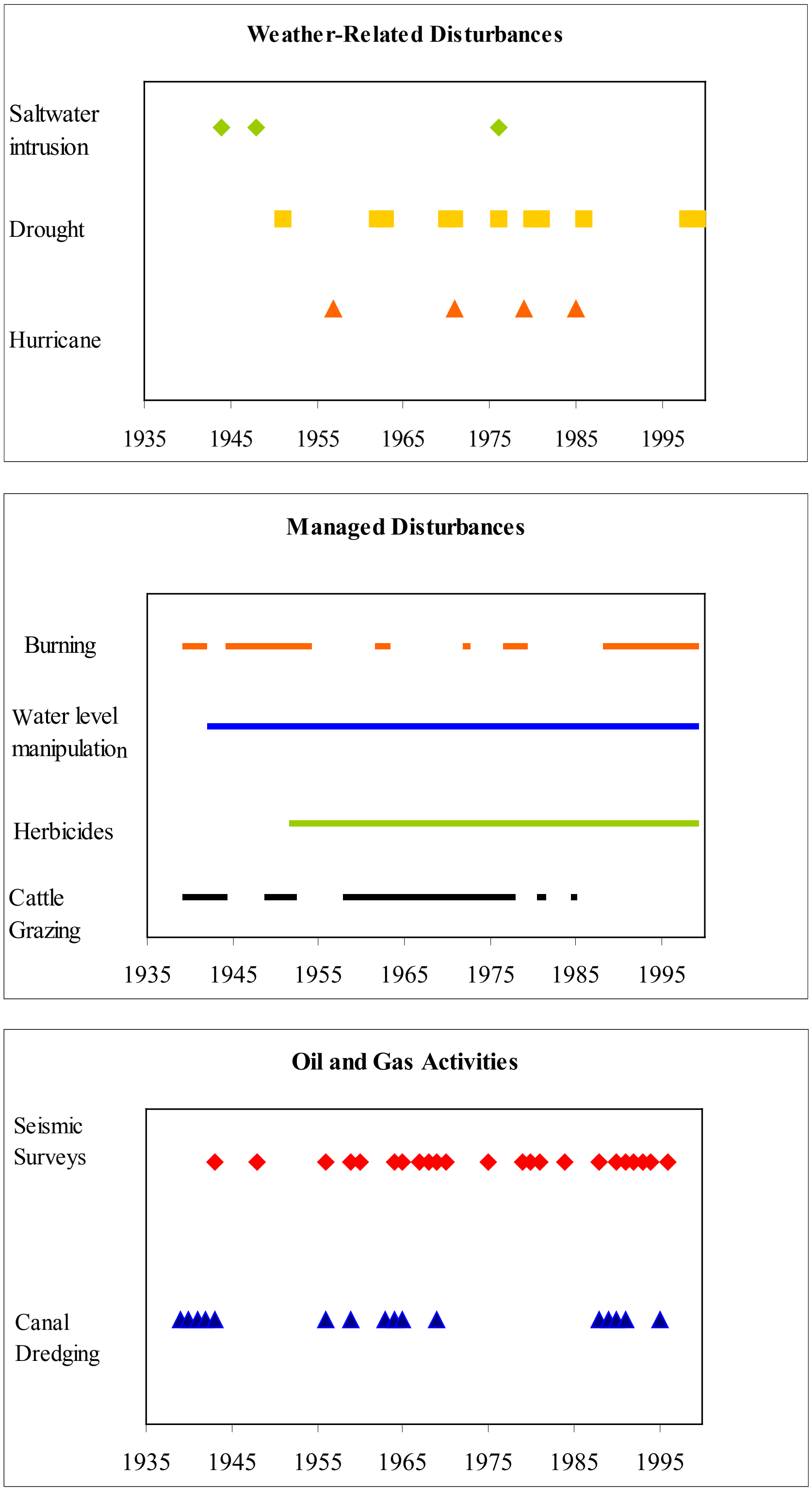


Figure 3.4. Timelines showing the frequency and duration of weather-related disturbances, oil and gas activities, and managed disturbances at the Lacassine National Wildlife Refuge. These data were obtained from a series of Narrative Reports for 1937 through 1999. These Narrative Reports are maintained at the refuge headquarters in Lake Arthur, LA.

Figure 3.5. Photograph of a portion of the levee around the Lacassine Pool in 1940. The photograph was taken approximately one year after the levee was completed. The Pool is shown to the left (U.S. Fish and Wildlife Service 1940).

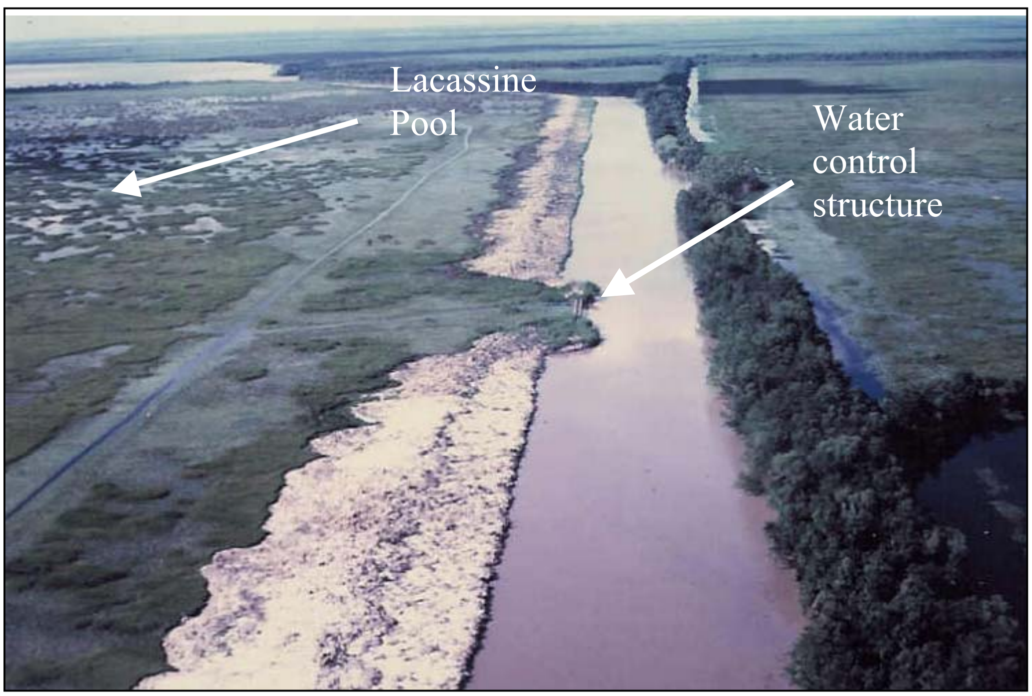


Figure 3.6. Photograph (facing south) of the Bell City Ditch and the levee along the western edge of of the Lacassine Pool. The Pool is shown to the left of the levee. A water control structure used to manage water levels in the southwestern portion of the Pool is visible near the center of the photograph (U.S. Fish and Wildlife Service 1985).

western boundary of the Pool taken from an airplane in 1985. The southwest Pool water control structure is also shown on the left side of the canal near the center of the photograph.

The primary objective of water level management since the completion of the levee system and installation of the water control structures in 1944 has been to raise water levels to reduce the coverage of emergent plant species, specifically *Panicum hemitomon* and *Sagittaria lancifolia*, and to increase the coverage of floating-leaved and submerged aquatic species such as *Brasenia schreberi, Eleocharis equisetoides*, and *Orontium aquaticum*. The Pool was initially designed to maintain water levels from 0 to 1.2 meters above mean sea level (U.S. Fish and Wildlife Service 1942). New water control structures were installed in 1992 to raise water levels an additional 2.4 to 4.8 centimeters (cm) during the growing season. This was done as an experiment to increase the area of open water in the Pool by increasing the level of flooding stress on the emergent vegetation.

Figure 3.7 shows the mean monthly high and low water stages in the Pool with respect to the nearby Mermentau River from 1945 to 1972. The mean monthly high and low water stages from 1945 to 1972 were approximately 0.4 meters higher in the Pool than in the nearby Mermentau River. The water stage fluctuation (difference between mean high and mean low stage) was also much less in the Pool.

<u>Flooding Impacts</u>

The most significant shifts in species composition in the Pool occurred between 1937 and 1950. This shift was from a community dominated by *Panicum hemitomon* and *Cladium jamaicense* to a floating aquatic community dominated by *Brasenia schreberi*, *Eleocharis equisetoides*, and *Orontium aquaticum*. Flooded conditions provided favorable conditions for the spread of floating aquatic species. However, the spread of these species

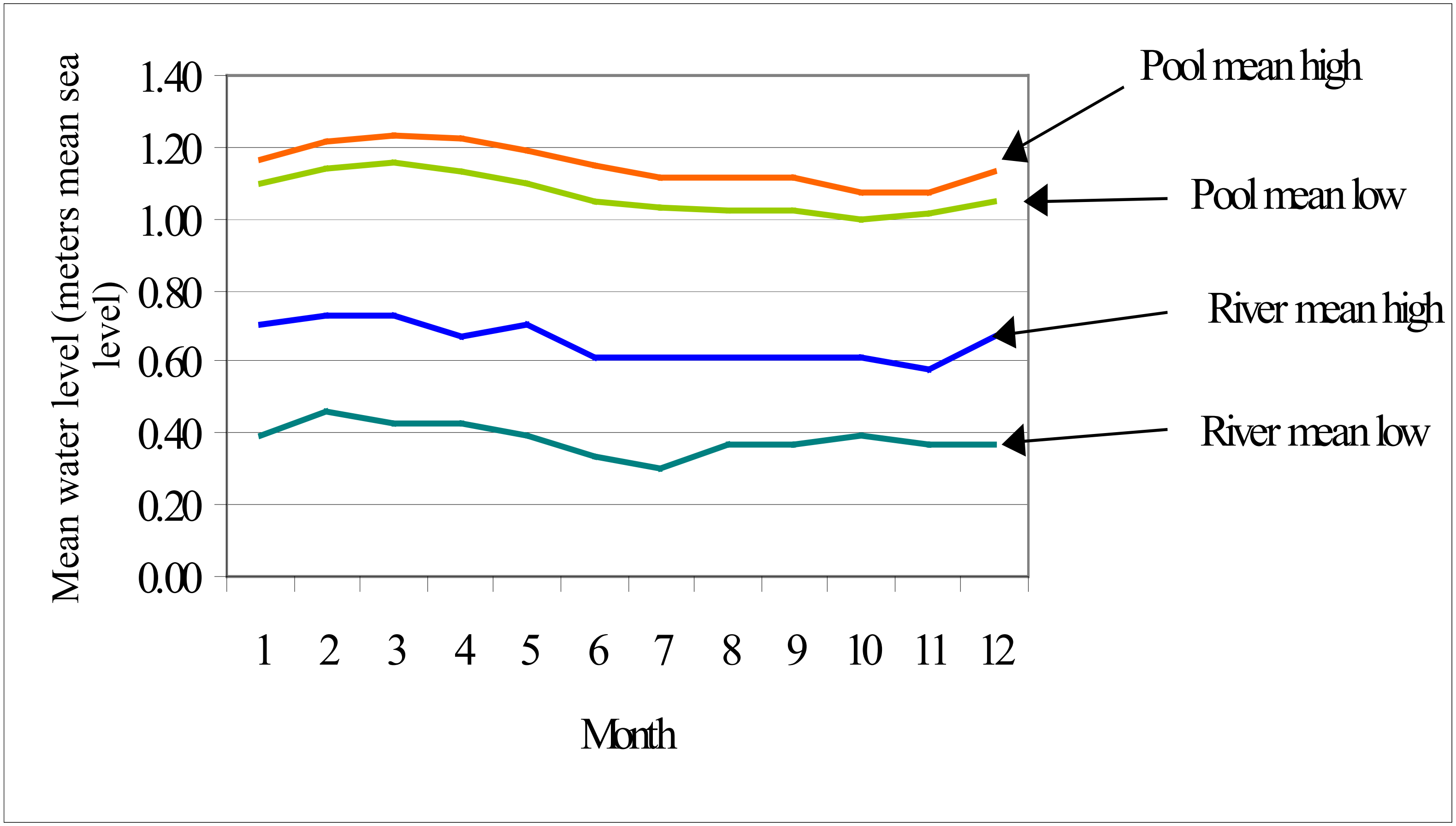


Figure 3.7. Mean monthly high and low water stages at the Lacassine Pool and the Mermentau River from 1945 to 1972. Data is shown in meters mean sea level. This water level data was obtained from the Narrative Reports maintained at the Lacassine National Wildlife Refuge in Lake Arthur, LA (U.S. Fish and Wildlife Service 1945 through 1972

was primarily into open water areas created artificially using herbicides, an underwater weed-cutter, or into "eat-outs" created by nutria. The LNWR's goal of reducing coverage of emergent marsh was hampered by its inability to maintain desired water levels during periodic dry events, the buildup of organic matter and formation of floating mats, and by the adaptive response of the emergent species. Significant species composition shifts, as a result of flooding, did not appear to occur between 1950 and 1990. *Cladium jamaicense* abundance decreased as a result of initial flooding; however, *Sagittaria lancifolia* was not adversely affected and *Panicum hemitomon* has adapted to prolonged flooding by growing on mats of floating organic matter.

The effects of flooding described in the narrative reports were generally consistent with those found in the literature (Kirkman and Sharitz 1993; Baldwin et al. 1998; Kuhn et al.1999; Baldwin et al. 2001). Plant community structure change in response to flooding and in the absence of disturbance was gradual, because the perennial species that typically dominate marshes are tolerant to a wide range of water levels (Chabreck 1972; Sasser 1977). Baldwin and Mendelssohn (1998) found that flooding has a greater effect on community structure when coupled with a disturbance. In the absence of disturbance, they found no effects on species richness and an increase in *Sagittaria lancifolia* biomass. *Spartina patens*, a flood-tolerant species, was nearly eradicated by the combination of flooding and disturbance. Similarly, Kirkman and Sharitz (1993) found that *Panicum hemitomon* favored flooded conditions over moist soil conditions, and responded to flooding by increasing stem growth. However, the interaction of fire and flooding adversely affected the growth of *Panicum hemitomon* stems. Table 3.5 provides a summary of the expected effects of water level manipulation on the primary habitats at the LNWR based on the literature review, on the review of the NRs, and on personal experience.

Table 3.5. Expected effects of water level manipulation on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities based on a literature review and personal experience.

Disturbance	**Expected Effects**		
	Emergent Marsh	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
Flooding	decreased primary productivity, decreased richness, decreased cover, altered species composition, decreased organic matter accumulation	increased overall coverage	increased cover
Drying	increased subsidence due to oxidation of soils, increased species richness (annual species) increased coverage of *Panicum hemitomon*	temporary decrease in coverage	overall increase in cover due to subsidence and pond formation, decreased cover of existing submerged aquatic species due to mortality

<u>Prescribed Burning</u>

History of Events

Prescribed burning has been used as a management practice at the LNWR since 1939. The narrative reports describe how burning was used in conjunction with flooding to change the species composition of the Pool from an emergent plant community to a floating/submerged aquatic community in the 1940s and 1950s. More recently, burning has been used to slow vegetative succession in the Pool and to control the spread of *Panicum hemitomon* and *Sapium sebiferum* (Chinese tallow-tree). The 1980 NR notes the alarming rate at which *Sapium sebiferum* spread throughout the marsh during dry conditions and concluded that the only way to manage it was through burning. The LNWR has maintained accurate records on prescribed burns since 1937. However, some of the data presented in the following section may be understated due to underreporting in the NRs.

Figure 3.8 shows the area burned during different time intervals from 1937 to 1999. There was an obvious shift away from prescribed burning from the 1950s to the 1990s. From 1937 to 1950 14,504 ha were burned. The area burned decreased significantly from 1961 to 1990. From 1990 to 1999, a new burning program was established and 14,300 ha were burned cumulatively.

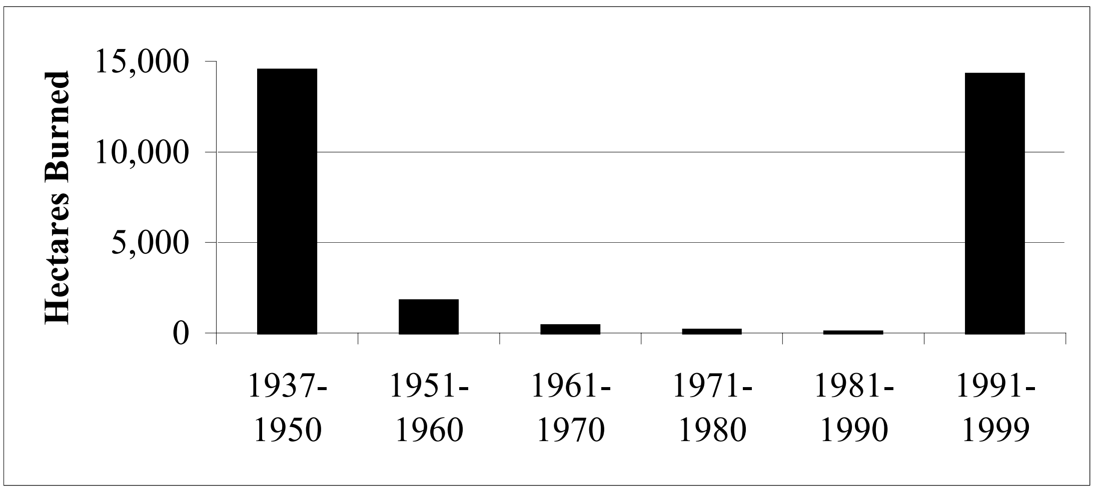


Figure 3.8. Area (ha) burned at the Lacassine National Wildlife Refuge from 1937 through 1999. This graph illustrates the temporal trends in prescribed burning as a management practice. This data was obtained from the Narrative Reports maintained at the Lacassine National Wildlife Refuge in Lake Arthur, LA (U.S. Fish and Wildlife Service 1937 through 1999).

The Pool was the most frequently burned area at the LNWR from 1939 to 1999 (Table 3.6). Nineteen fires occurred on the western portion of the Pool (DMU-2) and sixteen fires occurred on the eastern portion (DMU-1) (Figure 3.3). Six fires occurred in the marsh on the east and west sides of Bayou Lacassine and in the Streeter Canal area (DMUs 4 & 5). The marsh adjacent to the east Pool levee (DMU-3) was burned on four occasions and the Wilderness Area (DMU-7) was burned three times. In addition to these prescribed burns, the majority of the LNWR was burned as a result of lightning in 1954. Figure 3.9 is a photograph of a typical marsh burn in the Pool.

Table 3.6. Burn frequencies at Lacassine National Wildlife Refuge from 1939 to 1999 for individual disturbance units.

Disturbance Map Unit	**Burn Frequency**
East Pool (1)	16
West Pool (2)	19
Marsh east of Pool (3)	4
Bayou Lacassine West (4)	6
Bayou Lacassine East (5)	6
Lakeside Oil and Gas Field (6)	4
Wilderness Area (7)	3

Figure 3.9. Photograph of a marsh fire in a fresh marsh dominated by *Panicum hemitomon* and *Sagittaria lancifolia* in the Lacassine Pool at the Lacassine National Wildlife Refuge in 1975 (U.S. Fish and Wildlife Service 1976).

Assessment of Burning Impacts

Burning was effectively used at LNWR to reduce emergent marsh habitat dominated by *Panicum hemitomon* and *Cladium jamaicense* in favor of submerged and floating aquatic habitat and to slow the spread of exotic species. Table 3.7 summarizes the expected impacts associated with prescribed burning. The primary factors that determine the effect of fires include water level, timing, rainfall, and tidal inundation following the fire (Hoffpauer 1968). Long-term habitat changes typically occur when burns are conducted when water levels are below the root zone or when the organic soil is ignited.

These burns may cause damage to the root system or removal of peat, leaving a depression. Such severe burns may have been conducted from 1937 to 1950 which could have led to the significant changes described in the narrative reports. However, recent practices at LNWR have been to conduct prescribed burns when conditions favor cover burns and to avoid root and peat burns.

Much of the open water present in the Pool could have resulted from a combination of burning and flooding. The interactive effect of multiple disturbances on community shifts is widely supported in the literature. A combination of fire and draining reduced *Typha sp.* dominance in a fresh marsh near the Bay of Fundy. However, coverage increased following a treatment of flooding and fire (Mallik and Wein 1985). Schmalzer et al. (1991) reported temporary changes in community composition and diversity in a *Juncus romerianus* and *Spartina baker*i marsh in Florida following burning during flooded conditions. They concluded that both marshes were recovering to their original condition after one year. Research in the Florida Everglades attributed the conversion of *Cladium sp*. communities to slough communities to peat fires that reduced soil elevations and increased flooding.

Table 3.7. Expected effects of prescribed burns on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities based on a literature review and personal experience.

Disturbance	**Expected Effects**		
	Emergent Marsh	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
Burning	removal of biomass, release of “locked-up” nutrients in standing crop, increased primary production, short-term increased species richness, reduced dominance by *Panicum hemitomon*	same as emergent marsh	no impact

<u>Cattle Grazing Events</u>

Cattle grazing occurred on portions of the LNWR from 1942 to 1986. The narrative reports indicate that grazing was used in conjunction with burning to manage woody vegetation on the levees, spoil banks, and uplands in an effort to improve wildlife habitat. Cattle were also permitted to graze in the surrounding marsh, with access being determined by water levels. Dry conditions permitted cattle to move away from the spoil banks and uplands further into the marsh (U.S. Fish and Wildlife Service 1960).

The LNWR was divided into ten grazing units by 1956. These grazing units are separate and distinct from the DMUs established for this study. Three grazing units were located on Brown’s Island (Units 2, 9, and 10). Brown’s Island appears on Figure 3.2 as a small island where the Mermentau River enters Grand Lake. Figure 3.10 is a photograph of cattle being loaded onto a barge at Brown’s Island. Grazing Unit 4 was located on the west side of the Pool along the Bell City Canal. Unit 8 was south of the Pool levee along the

GIWW. These descriptions given in the narrative reports indicate that Units 5 and 7 were in grasslands and fresh marsh.

Figure 3.10. Photograph of cowboys removing cattle from Brown's Island by barge at the Lacassine National Wildlife Refuge in 1967 (U.S. Fish and Wildlife Service 1967).

The precise locations of these units were not available. The locations of Units 1, 3, and 6 could not be obtained through descriptions given in the narrative reports, research of historic maps, nor interviews with current LNWR personnel. An interesting finding was that anecdotal evidence throughout the narrative report review indicated that most of the area grazed was marsh. "Grazing is allowed on 1,300 acres (526 ha) of wet meadow and marsh" (U.S. Fish and Wildlife Service 1974). Grazing in the marsh areas increased during dry periods. "Low water levels during the summer provided much additional grazing in the shallow marshes" (U.S. Fish and Wildlife Service 1960).

One significant reference was made in a narrative report to plant species composition change caused by cattle grazing. The 1942 narrative report stated that the northern portion of

the LNWR had been *Spartina patens* (wiregrass) prior to being grazed by cattle. This is a significant finding because *Spartina patens* is commonly found in brackish marshes. There were no other references in the narrative reports of brackish marsh in the vicinity of the LNWR.

The LNWR allowed year-round grazing from 1948 to 1981. Grazing intensity was measured by *Animal Use Months* (AUMs). The grazing units supported from 1,270 to 3,797 AUMs depending upon the number of permits issued, and the grazing units utilized. The same grazing policy was in effect on the LNWR from 1948 to 1976. An internal review of the LNWR grazing program was conducted in 1976 by USFWS biologists. It was determined that waterfowl habitat was not being enhanced by grazing and that some upland areas near the Gulf Intracoastal Waterway (GIWW) were being degraded (U.S. Fish and Wildlife Service 1976). The two grazing units along the GIWW contained 216 ha of primarily upland habitat that graded down to fresh marsh habitat (U.S. Fish and Wildlife Service 1976). There was no indication in the NRs of fences along the levees to prohibit the cattle from grazing in the natural marshes or in the Pool. Therefore, it can be assumed that the cattle had access to the Pool and natural marshes during low water conditions. Major revisions to the program were recommended as a result of the review. These changes included: (1) eliminating grazing along the GIWW, (2) restricting grazing to winter-only, and (3) increases in grazing fees. Grazing was still allowed in 1976 in the marsh north of the Pool. The rate increase was enacted in 1976 and cattle were removed from the area south of the GIWW in 1977. However, immediate changes to the grazing period restriction were prohibited due to the deteriorated condition of the LNWR fences, lack of funds to repair the fences, and Cameron Parish's free range law (U.S. Fish and Wildlife Service

1976). The LNWR hoped that winter-only grazing would result in the re-growth of natural prairie plant species.

The 1977 narrative report indicated that only a portion of the grazed area was grassland and that most was marsh (U.S. Fish and Wildlife Service 1977). The fences were eventually repaired in 1981 and the winter-only policy was implemented in 1982 (U.S. Fish and Wildlife Service 1982). Two years before grazing was ceased on the LNWR, the 1984 narrative report declared "there are no specific objectives of grazing and that it neither helps nor hurts wildlife habitat" (US Fish and Wildlife Service 1984).

<u>Assessment of Cattle Grazing Impacts</u>

The physical effects of livestock grazing on marshes include vegetation trampling, creation of gaps, increased nutrients, removal of biomass, reduced cover, and soil compaction. (Table 3.8) (Ungar and Woodell 1996). The community level effect of grazing is highly dependent on grazing intensity. For instance, low intensity grazing has been shown to create community structure gradients in marshes and typically results in higher species richness than in ungrazed and heavily grazed marshes (Andresen et al. 1990, Ungar and Woodell 1996). Grazing has also been shown to favor annual species over perennial species, as indicated by vegetative cover and seed bank data described by Ungar and Woodell (1996).

A detailed assessment of the effects of grazing on the marsh vegetation was limited by the level of reporting provided in the NRs Descriptive accounts of wetland plant community response were generally lacking, and maps delineating the boundaries of each grazing unit, especially those with access to the marsh, were not available. It is plausible to conclude that the effects of cattle grazing were similar to those of small-scale prescribed burns, which are currently being used to replace grazing as a management tool.

Table 3.8. Expected effects of cattle grazing on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities based on a literature review in and personal experience.

Disturbance	Expected Effects		
	Emergent Marsh	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
Cattle Grazing	removal of old growth biomass, increased insolation, depressed *Panicum* hemitomon growth, increased annual plant abundance, release of "locked-up" nutrients in standing crop	not accessible to cattle	not accessible to cattle

Herbicide Application

The history of herbicide application at the LNWR is variable. The LNWR began using herbicides to kill undesirable species such as *Nelumbo lutea* (American lotus) in the 1940s. In 1962, managers sprayed 243 ha of *Nelumbo lutea* and 41 ha of *Sagittaria lancifolia* with herbicide mixed with diesel fuel to create open water areas in the Pool. Figure 3.11 shows the before and after photographs of this area in the Pool. *Nelumbo lutea* was almost completely eradicated two months after the herbicide was applied. Beginning in the mid-1960s, herbicides were primarily used to control the spread of *Eichhornia crassipes* (water hyacinth).

In 1987, the USFWS provided special funding to purchase herbicides to combat the spread of *Sapium sebiferum* (Chinese tallow-tree) across the LNWR. Because of the limited success in controlling the spread of the Chinese tallow-trees, the LNWR discontinued its efforts to eradicate this species with herbicides and focused on controlling the spread of *Salvinia spp.* and *Eichhornia crassipes*.

Figure 3.11. Photographs of *Nelumbo lutea* in the Pool three days (upper photograph) and then two months after being sprayed with 2-4-D herbicide (lower photograph). Photographs compliments of the Lacassine National Wildlife Refuge.

Ditches and Boat Trails

Ditches were constructed throughout the Pool to facilitate travel by hunters, trappers, and fishers. Figure 3.12 is a series of photographs showing the construction of a ditch in the Pool intended for boat travel. These ditches re-vegetate with submerged and floating aquatic vegetation and have no significant effects on the marsh hydrology because water levels are maintained at constant levels within the Pool.

Boat trails made by hunters in the Wilderness Area south of the GIWW, however, did have a significant effect on the hydrology of the marsh. These boat trails increased the drainage of the marsh north of Grand Lake. The drainage reduced water level and resulted in drier conditions in the marsh. These drier conditions led to the invasion by *Sapium sebiferum* into that area (U.S. Fish and Wildlife Service 1983). Outboard motors were banned from the marsh to alleviate the drainage problems. Figure 3.13 is a photograph taken in 1983 of one of the boat trails in the Wilderness Area caused by outboard motors.

Dredging

Oil and gas activities have had a pronounced impact on the LNWR since the 1940s. The primary disturbances have been dredging for access canals, roads, and well pads. Approximately 152 ha of marsh were converted to open water and spoil banks in the Lakeside Oil and Gas Field in the northeastern portion of the LNWR in the 1960s. Figure 3.14 is a photograph of a dredge boat building a canal in the Pool in 1940. The spoil deposition area (spoil bank) is visible parallel to the canal.

Twelve kilometers of roads and well pads were also constructed in the Pool between 1978 and 1988. Figure 3.15 shows photographs of a road and a well pad constructed in the Pool in 1958. These roads and well pads have become permanent features at LNWR and are also shown on Figure 3.1. Additionally, a pipeline (canal) was constructed between 1956 and

1978 from the Lakeside Oil and Gas Field, across the GIWW, and through the Wilderness Area. Figure 3.16 is a photograph of a small pipeline (often referred to as flowline) under construction in the Pool in 1979. The dredged material is visible adjacent to the pipeline ditch in the marsh. Fresh marsh soils are typically high in organic matter and rapidly oxidize if left exposed for a prolonged period. The locations of oil and gas canals, roads, well pads, and the pipeline are shown on Figure 3.1.

Figure 3.12. Series of photographs showing a marsh-ditching machine (upper left), a marsh before ditch construction(upper right), the ditcher in action (bottom left), and the marsh after ditch is complete (U.S. Fish and Wildlife Service 1955).

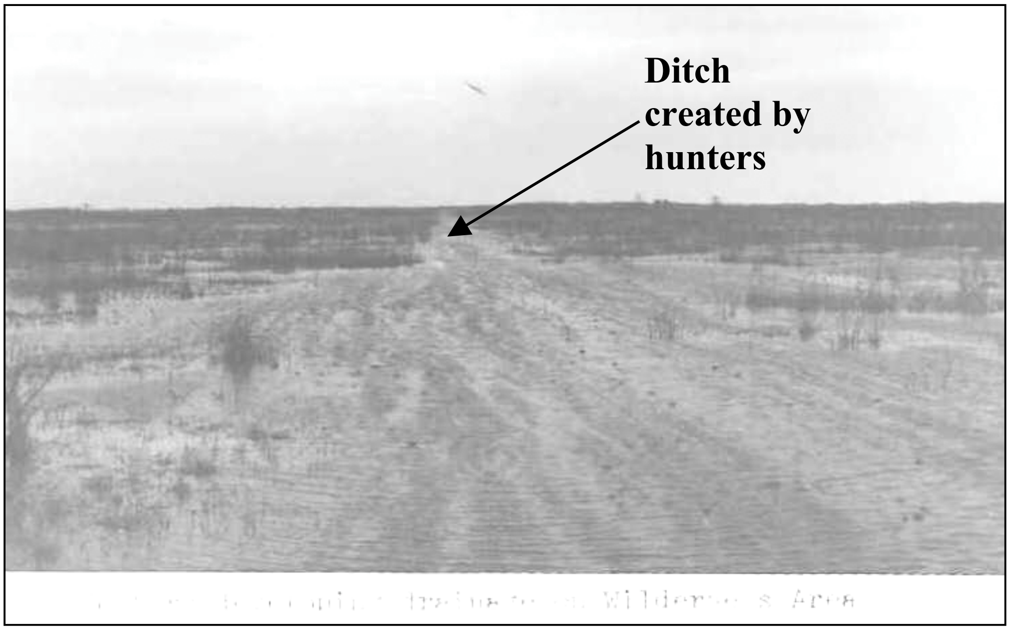


Figure 3.13. Photograph of a manmade drainage system in the Wilderness Area caused by outboard motors used by duck hunters to access hunting areas (U.S. Fish and Wildlife Service 1983).

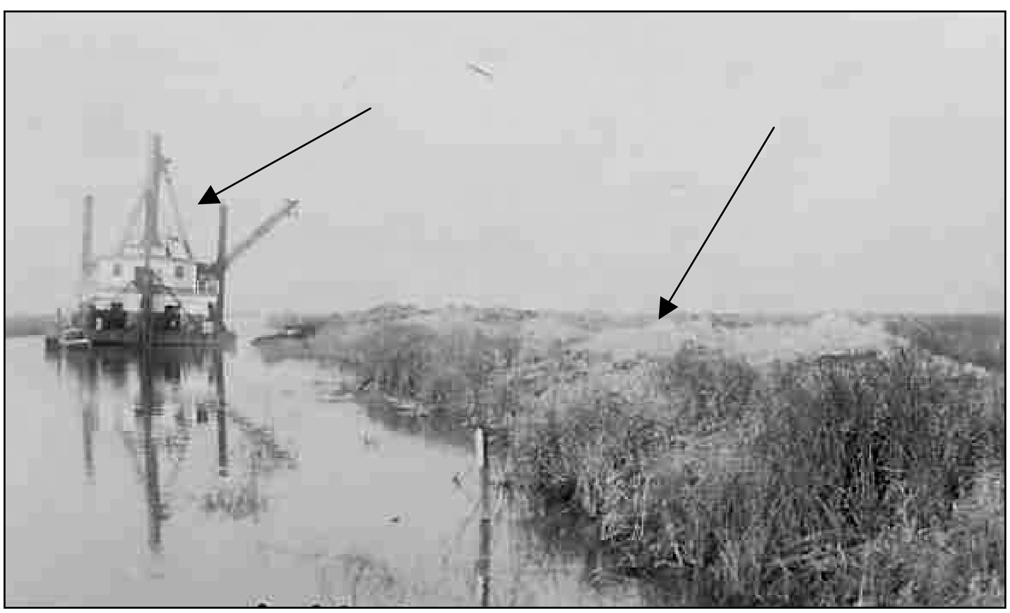


Figure 3.14. Photograph of Shell Oil Company dredging a canal in the Pool in 1940 (U.S. Fish and Wildlife Service 1940).

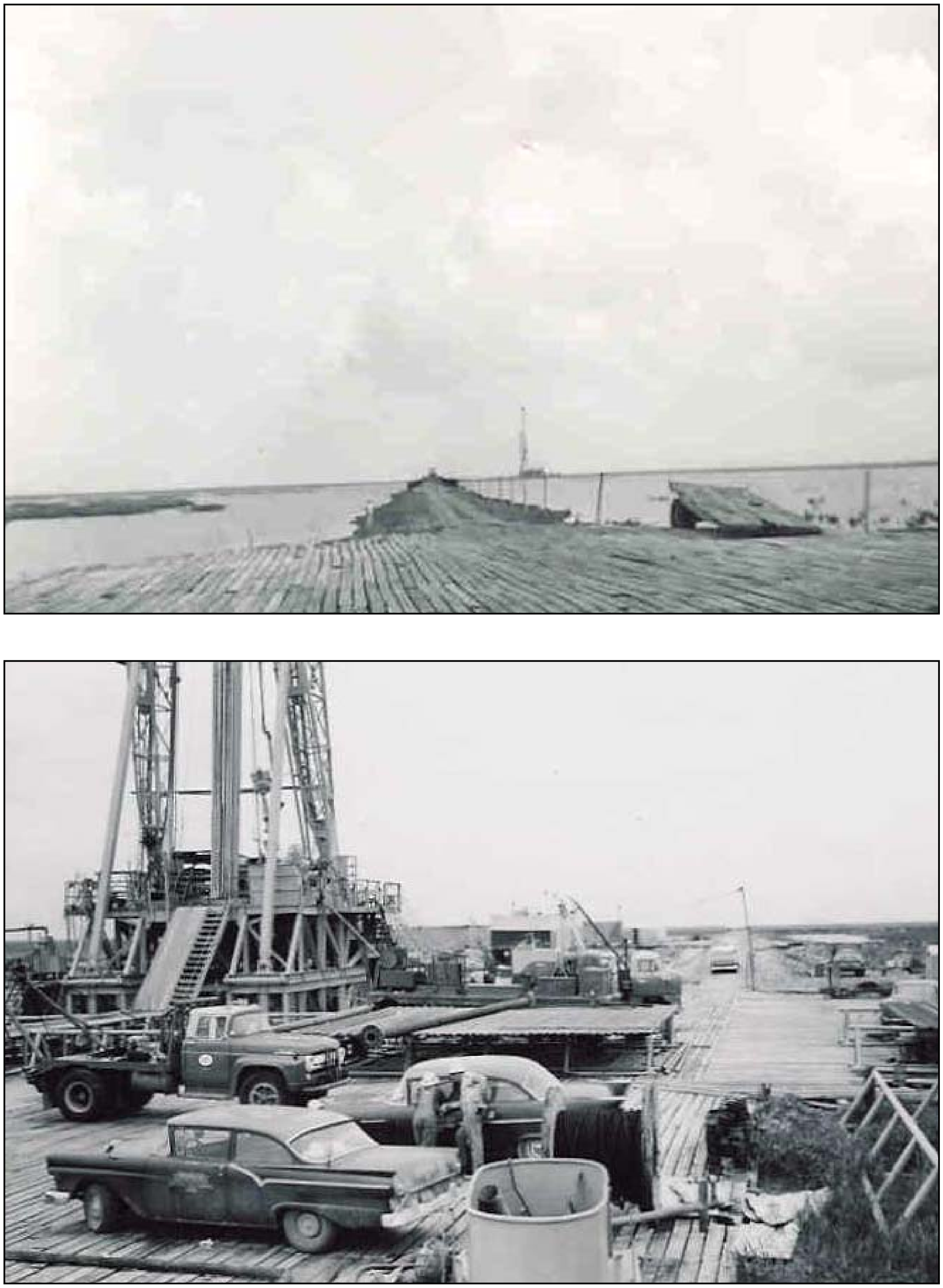


Figure 3.15. Photographs of a drilling rig and board road in the Lacassine Pool in 1958 (U.S. Fish and Wildlife Service 1958).

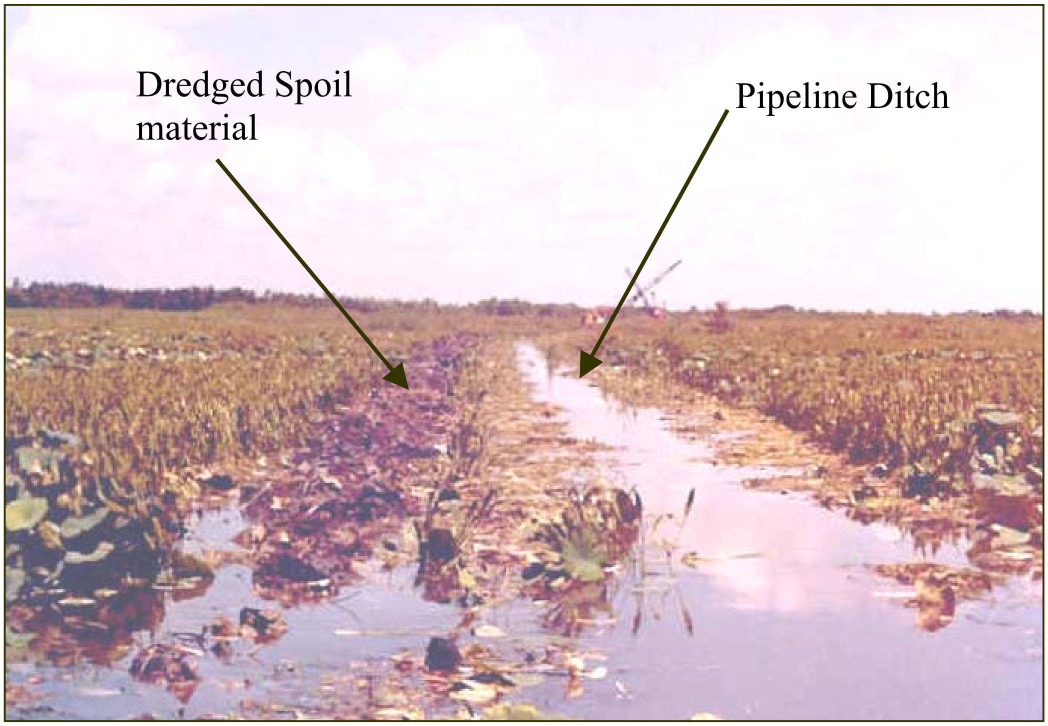


Figure 3.16. Photograph of a flowline ditch on the eastern half of the Lacassine National Wildlife Refuge. The flowline was 1,720 meters in length (5,676 feet). Flowlines are small pipelines that transport oil or gas from producing wells to storage tanks that are centrally-located within the field (U.S. Fish and Wildlife Service 1979).

Dredging Impacts

The primary disturbance associated with dredging at LNWR was the direct conversion of emergent marsh to open water and spoil bank habitats. Canals and associated spoil banks have been linked to wetland loss in coastal Louisiana by numerous researchers (Scaife et al. 1983; Turner and Cahoon 1987; Baumann and Turner 1990; Turner and Rao 1990; Britch and Dunbar 1993; Bass and Turner 1997). Baumann and Turner (1990) estimated that approximately 16.1 percent of the wetland loss in coastal Louisiana from 1955/6 to 1978 was fro.m the combined direct effects of canals and spoil banks. Britsch and Dunbar (1993) estimated that canals dredged from the 1930s to 1990 accounted for approximately 12 percent of the total land loss. Similarly, Scaife et al. (1983) concluded that from 1955 to 1978 canal surface area accounted for approximately eight percent of the total land loss.

The causal factors linking canals to wetland losses are a result of the altered natural hydrology and sedimentation patterns. Spoil banks have been shown to hydrologically isolate areas which affects the frequency and duration of tidal events, which in turn affects plant life and sedimentation patterns. Canals and spoil banks also provide conduits for introduced plant species such as *Eichhornia crassipes* (water hyacinth) and *Sapium sebiferum* (Chinese Tallow-trees) to spread into the marsh interior. Figure 3.17 is a photograph of a spoil bank immediately after spoil deposition and then a photograph of the same spoil bank approximately six months later. The spoil material did not subside as expected, and brush is shown colonizing the site. A summary of expected dredging impacts is found in Table 3.9.

Seismic Surveys

Thirty-eight seismic surveys were documented on the LNWR between 1943 and 1999. Eighteen surveys were conducted in the Pool (DMU-1 and DMU-2), four in DMU-4, three each in DMU-2, DMU-3, and DMU-5, two in DMU-6, and one each in DMU-7 and DMU-8. The DMUs are shown in (Figure 3.3). The locations of the remaining surveys could not be determined from the NRs.

Anecdotal evidence throughout the history of the LNWR has documented damages caused by equipment used to conduct the seismic surveys. As early as 1943, refuge personnel documented disturbances associated with marsh buggy use. The LNWR biologists noted that marsh buggies and mudboats (boats capable of travelling in shallow water or mud) "broke up" areas of marsh dominated by *Cladium jamaicense* (U.S. Fish and Wildlife Service 1943).

Figure 3.17. Photographs of spoil material from dredged canal that was spread out at the request of the Lacassine National Wildlife Refuge in an attempt to eliminate spoil banks, which promote the growth of brush and trees (upper photograph). The lower photograph shows the same spoil deposition site six months later. The spoil material did not subside as expected and brush is shown in the upper left-hand corner colonizing the spoil bank (U.S. Fish and Wildlife Service 1978).

Table 3.9. Expected effects of dredging on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities based on a literature review and personal experience.

Disturbance	Expected Effects		
	Emergent Marsh	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
Dredging	Direct wetland loss, altered local hydrology, increased drainage and flooding during storm events, periodic increased salinity, shoreline erosion, increased subsidence adjacent to spoil banks, facilitate spread of noxious species	Direct wetland loss, increased susceptibility to damages by storms due to storm surges and scouring	Bottom disturbance, decreased cover of floating species limited by water depth, increased turbidity in natural waterbodies

In 1951, the LNWR biologists noted that the continuous activity of the shooting crews and the trampling caused by marsh buggies caused nesting birds to leave the Pool. Figure 3.18 is a photograph of a marsh buggy trail at the LNWR taken two months after the disturbance. The photograph shows a trail approximately 24 meters wide through fresh marsh. A survey conducted in 1955 experimented with the use of helicopters to transport equipment and personnel along a seismic survey line in the marsh at the LNWR. Figure 3.19 is a photograph that shows the seismic survey crew working out of the aluminum tubs transported by the helicopter. Marsh buggies were later outlawed in the Pool in 1957.
The renewal of the oil boom in the late 1970s and 1980s led to numerous requests by oil companies and speculators to conduct seismic surveys on the LNWR. Many of the requests were about speculative surveys in which seismic companies conducted surveys and sold the data to anyone interested in purchasing it.

Figure 3.18. Photograph of a 1954 marsh buggy trail at the Lacassine National Wildlife Refuge taken two months after initial disturbance of a seismic survey. The trail is approximately 24 meters (80 feet) wide (U.S. Fish and Wildlife Service 1954).

The 1978 NR stated that marsh buggies left tracks through the marsh that were visible for several years. It also noted that "recent use" of a marsh buggy in open water caused organic matter on the bottom to break loose and float to the surface (pop-ups), and that most of the emergent vegetation growing in the Pool was growing on these pop-ups (Figure 3.20) (U.S. Fish and Wildlife Service 1978). Figure 3.20 is a recent photograph of a pop-up taken in 1996 in the Pool following a 3-D seismic survey. *Eleocharis spp.* is visible colonizing the newly-formed organic mat. The 1980 NR also noted that seismic surveys can be extremely damaging to the marsh. For example, "What this (speculative seismic surveys) is leading to is the LNWR marsh being completely chewed up by seismic survey equipment over a period of a few years" (U.S. Fish and Wildlife Service 1980). In an effort to eliminate some of the seismic surveys, the LNWR began requiring mineral owners make a written request to the LNWR that the seismic company be issued a permit.

Figure 3.19. Photograph of a 1955 seismographic crew working out of aluminum tubs in the Lacassine National Wildlife Refuge. Aluminum tubs were transported along the seismic survey line by a helicopter as part of an experiment to reduce damages caused by marsh buggy traffic. Marsh buggies were later banned from the Lacassine National Wildlife Refuge. Tubs were transported by helicopter from location to location to avoid excessive disturbance caused by marsh buggies (U.S. Fish and Wildlife Service 1955).

Biologists in 1981 also recognized that marsh buggies transported and facilitated the spread of pest plants and that the tracks affected drainage (U.S. Fish and Wildlife Service 1981). To combat the spread to pest species in 1981, the LNWR required seismic operators to steam clean the machinery before it was taken onto the LNWR.

In 1983, the most dramatic disturbance associated with marsh buggy traffic was documented when 81 ha of floating marsh were destroyed on the east and west sides of Lacassine Bayou as a result of seismic crews tracking through this sensitive area. "The marsh buggies cut through the floating mat and contributed to large chunks of it floating away" (U.S. Fish and Wildlife Service 1983). Figure 3.1 shows the location of the sensitive floating mat that was impacted at the LNWR.

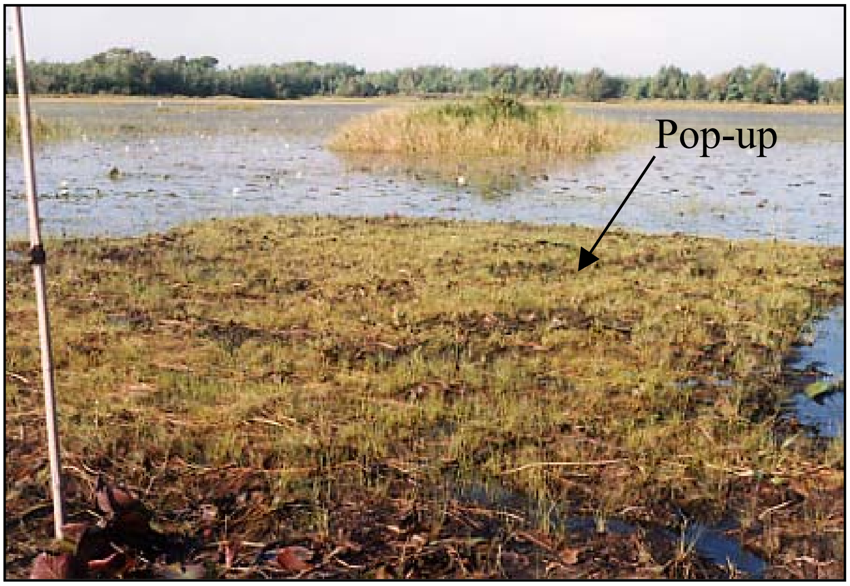


Figure 3.20. A small floating island (pop-up) that formed when a marsh buggy caused organic matter on the bottom to break loose and float to the surface. *Eleocharis spp.* is typically one of the first species to colonize these pop-ups. Refuge personnel took this photograph in 1996 following a 3-D seismic survey (Fuhrmann 1996).

Technological advancements in the seismic industry resulted in shifts from the conventional two-dimensional (2-D) surveys to three-dimensional (3-D) surveys in the 1980s. Surveys conducted on the LNWR between 1943 and 1993 were 2-D. The Las Colinas Energy Corporation conducted the first 3-D survey on the LNWR in 1994, followed by Flores and Rucks, Inc. in 1996, and Shell Western Exploration and Production Company in 1997. The 2-year monitoring program described in Chapter 3 was established to investigate disturbances associated with the former 3-D survey.

All seismic surveys consist of a surveying phase, a drilling phase, and a recording phase. During the surveying phase, standard surveying equipment is used to establish the locations of shot points and receivers. The drilling phase involves the installation of an energy source. Shot holes are typically approximately 15 meters deep. The recording phase involves laying out recording equipment, discharging the source, recording the reflected

energy, and retrieving the recording equipment. Figure 3.21 shows a typical airboat drilling rig used to conduct seismic surveys at the LNWR.

Figure 3.21. Photograph of an airboat-mounted drill rig used to drill seismic shot holes in areas with standing water at the Lacassine National Wildlife Refuge. Seismic companies began using airboats after marsh buggies were banned in the Pool for the second time in 1988 (U.S. Fish and Wildlife Service 1988).

Two-dimensional surveys are conducted along a single line. A 3-D pattern resembles a checkerboard and consists of many shot and receiver lines. Disturbance associated with 2-D surveys is confined to a single line, whereas 3-D surveys may disturb hundreds of square miles.

The locations of the three recent 3-D seismic surveys at the LNWR are shown on Figure 3.22. The Las Colinas Energy Corporation survey was conducted in the northern portion of the Pool. The Flores and Rucks survey covered 4,662 ha in the western portion of the Pool and in the marsh east of the Pool. The Shell Onshore Ventures, Inc. survey covered 5,439 ha on the eastern half of the LNWR.

Summary of Seismic Survey Impacts

Data from several recent field studies conducted in similar marsh habitats indicate that vehicle traffic by marsh buggies and airboats can reduce vegetation cover and dominance of certain species, increase species richness, and cause minor shifts in species composition (Nidecker et al. 1993; Wilson et al. 1998). Bass (1997) reported significantly lower vegetation height and cover in study plots at the LNWR following the Flores and Rucks 3-D survey in 1996. Repeated airboat traffic along trails in a floating marsh in Alaska resulted in significantly lower plant cover compared to areas with less intense traffic (Racine et al. 1998). Schemnitz and Schortemeyer (1973) reported similar results on controlled vehicle treatment plots in the Big Cypress Preserve in south Florida. Whitehurst et al. (1977) documented the successive stages of marsh deterioration and eventual land loss along marsh buggy trails in a salt marsh near Leeville, Louisiana. Harris and Chabreck (1958) also documented permanent habitat loss following Hurricane Audrey on Marsh Island, Louisiana where marsh buggies weakened the marsh turf and substrate resulting in open water areas. Table 3.10 includes a summary of impacts associated with vehicle traffic during seismic surveys.

<u>Hurricanes</u>

Three hurricanes affected the LNWR between 1937 and 1999. Hurricane Audrey (June 27, 1957) created significant changes in species composition in the southern portion of the LNWR. High water associated with the storm drowned all species except *Sagittaria lancifolia*, and *Scirpus californicus*. The large stands of *Cladium jamaicense* south of the GIWW were killed and replaced with *Sagittaria lancifolia.* The stress associated with Hurricane Audrey combined with intensive grazing by nutria resulted in ponds forming in the marsh in the southern portion of the Pool. These ponds proliferated the spread of

Figure 3.22. Map showing the locations of 3-D seismic surveys at the LNWR.

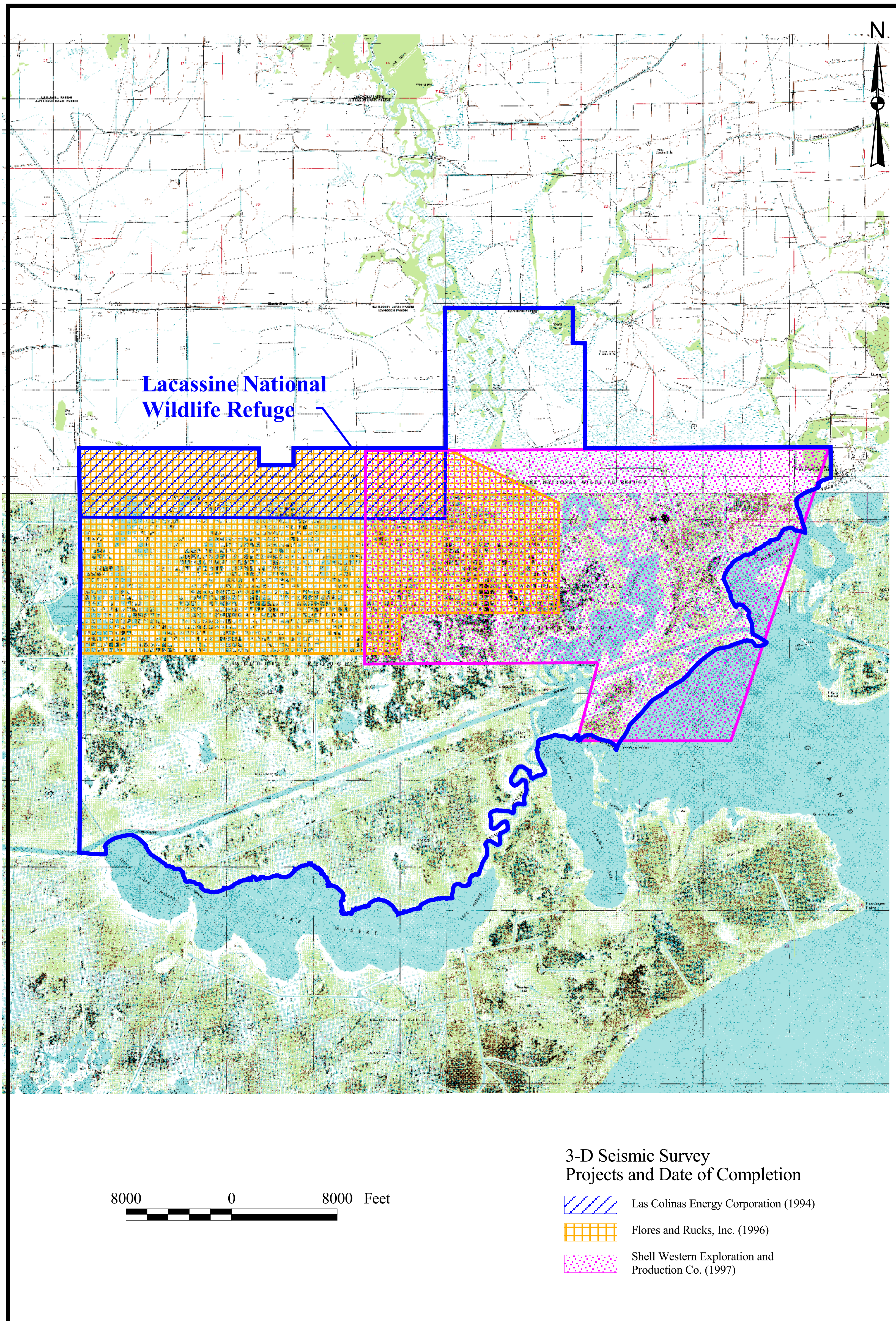


Figure 3.22. Map showing the areas covered by the 3-D seismic surveys at the Lacassine National Wildlife Refuge in southwest Louisiana.

Table 3.10. Expected effects of vehicle traffic during seismic surveys on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities. These expected effects were based on a literature review, descriptions provided in the U.S. Fish and Wildlife Service narrative reports, and personal experience.

Disturbance	**Expected Effects**		
Seismic Surveys	**Emergent Marsh**	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
	local plant mortality, surface compaction, increased insolaton, temporary increased species richness, direct habitat loss, altered local hydrology by rutting, facilitate spread of noxious species	local plant mortality, severed root mat, increased habitat due to floating organic mat formation, increased susceptibility to damages by storms	temporary increased turbidity, local disturbance to waterbottom, severed roots, local plant mortality

Brasenia schreberi. In 1971, Hurricane Edith raised the water levels in the natural marsh and overflowed the Pool levees. *Eichhornia crassipes*, present in the natural marsh and in isolated portions of the Pool near the levees, was carried into the interior portion of the Pool where it previously had not existed. Hurricane Juan caused record high water levels in 1985, but did not cause any significant habitat changes. The NRs indicated no other significant disturbances caused by hurricanes during the study period.

Summary of Hurricane Impacts

Hurricanes are a significant source of large-scale disturbance in coastal marshes (Table 3.11). Numerous researchers have provided descriptive reviews of marsh impacts following many of the early severe hurricanes along the Louisiana coast (O'Neil 1949; Ensminger and Nichols 1957; Harris and Chabreck 1958; Morgan 1959; Chamberlain 1959; Wright et al. 1970). The most severe of these impacts resulted from saltwater trapped within impounded marshes and damages to marshes previously impacted by marsh buggies (O'Neil

1949; Ensminger and Nichols 1957; Chabreck and Palmisano 1973). O'Neil (1949) noted that the interacting effects of burning prior to a hurricane event could also result in large-scale plant community changes throughout Louisiana's coastal marshes.

Table 3.11. Expected effects of hurricanes on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities. These expected effects were based on a literature review, descriptions provided in the U.S. Fish and Wildlife Service narrative reports, and personal experience.

Disturbance	**Expected Effects**		
Hurricanes	**Emergent Marsh**	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
	physical damage to vegetation, facilitated spread of exotic species into marsh interior, deposited wrack, compressed marsh surface, local scouring, temporary increased salinity, increased sedimentation, temporary increased annual species abundance, reduced plant cover	Same as emergent marsh	facilitated spread of exotic species, physical damage to vegetation, local scouring, increased turbidity

<u>Droughts</u>

Extended periods with below-average rainfall, typically on the order of six to twelve months occurred throughout the study period and were a recurring topic of discussion in the narrative reports. These droughts resulted in temporary shifts in plant species composition from floating and submerged aquatic species such as: *Brasenia schreberi*, *Nymphaea odorata*, and *Nymphoides aquatica*, to emergent species such: *Panicum hemitomon*, *Sagittaria lancifolia*, *Scirpus californicus*, *Pontederia cordata*, *Cladium jamaicense*, *Eleocharis spp.* and other annual grasses.

Droughts have had some positive influences on the LNWR. The dry conditions in 1960 promoted the growth of vegetation in areas that were left barren following Hurricane Audrey in 1957. Dry conditions on the LNWR have also promoted the growth of species

such as annual grasses, which are favored as food by wintering waterfowl. However, the management goals at the LNWR since the construction of the levees around the Pool in the late 1930s have been to increase the area of open water and reduce coverage of emergent species such as *Panicum hemitomon* and *Cladium jamaicense*. The Pool is especially susceptible to droughts because the only source of freshwater into the impoundment is through precipitation and runoff from the levees. Periods of low rainfall have hampered the LNWR's attempts at halting the spread of *Panicum hemitomon* and other emergent species throughout the Pool. The drought in 1970 allowed *Panicum hemitomon* and *Sagittaria lancifolia* to grow towards the center of the Pool into areas that were previously open water. Figure 3.23 is a photograph of a dry mudflat in the Pool during the drought of 1970. *Ludwigia spp.* and *Eleocharis spp.* are typical species that colonized these mudflats. The LNWR estimated that the area of open water in the Pool was reduced to 10%. This species composition shift also resulted in nutria expanding their range into the interior of the Pool where they previously had not existed.

Summary of Drought Impacts

The study of hydrologic drawdowns in managed marshes provides a parallel for comparing the effects of droughts on the marsh in Lacassine Pool and in the shallow ponds scattered about the remainder of LNWR. The organic substrate present throughout LNWR quickly dries and oxidizes when exposed. Consequently, the relative elevation of the marsh or pond surface is reduced. In the short term, annual species represented in the seed bank thrive on the mudflats and provide a temporary increase in species diversity. These periodic droughts are described throughout the history of LNWR and appear to have no significant effect on the dominant plant communities, except, possibly, to promote the incremental

increase in coverage of *Panicum hemitomon* at the expense of open water habitat. Table 3.12 presents a summary of impacts caused by droughts.

Table 3.12. Expected effects of droughts on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities. These expected effects were based on a literature review, descriptions provided in the U.S. Fish and Wildlife Service narrative reports, and personal experience.

Disturbance	**Expected Effects**		
Droughts	**Emergent Marsh**	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
	Increased overall emergent marsh habitat, soil oxidation and subsidence, increased coverage of *Panicum hemitomon*, expanded the range of cattle grazing	Decreased overall floating marsh habitat, soil oxidation and subsidence, increased coverage of *Panicum hemitomon*	Soil oxidation and subsidence, temporary decreased overall habitat, shift in species composition to sedge/spikerush community

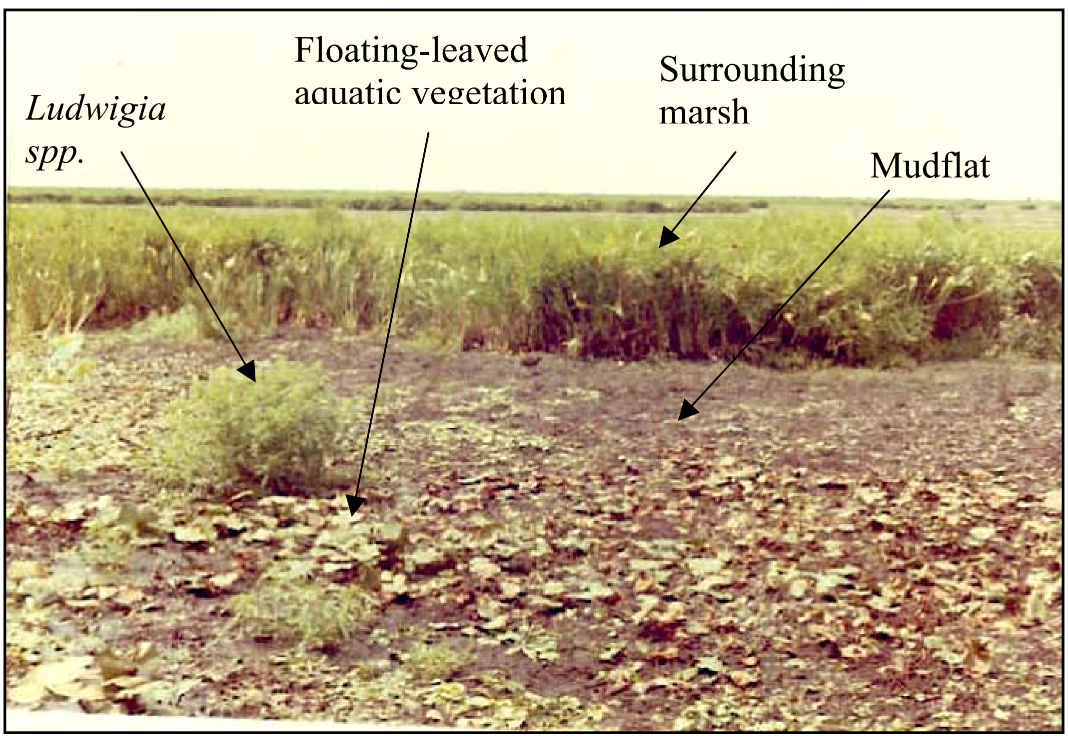


Figure 3.23. Photograph of dry mudflats in the Lacassine Pool during the drought of 1970 (U.S. Fish and Wildlife Service 1970).

Grazing by Nutria

Nutria were first noticed on the LNWR in 1943 (U.S. Fish and Wildlife Service 1943). There were 4,500 nutria in the Pool in 1945 (U.S. Fish and Wildlife Service 1946). Biologists noted in 1947 that the population was increasing rapidly and that 80 percent of the nutria trapped in the LNWR came from the Pool (U.S. Fish and Wildlife Service 1947). Results from a study completed in 1947 indicated that optimal nutria habitat consisted of *Scirpus californicus*, *Sagittaria lancifolia*, *Cladium jamaicense*, *Pontederia cordata*, and *Typha sp*. (U.S. Fish and Wildlife Service 1947). The LNWR biologists observed severe reduction in stem counts of emergent vegetation in the Pool associated with nutria grazing. Because of these large "eat-outs," they predicted that the nutria would do more to reduce emergent vegetation in the Pool than high water levels (U.S. Fish and Wildlife Service 1946). Biologists observed an increase in the nutria population in 1957 when Hurricane Audrey apparently washed them up from marshes south of the LNWR (U.S. Fish and Wildlife Service 1957). The apparent increase in the nutria population, combined with the loss of emergent vegetation caused by Hurricane Audrey, resulted in an overpopulation of nutria (U.S. Fish and Wildlife Service 1957). In the following year, biologists noted very little vegetative cover on the LNWR due to grazing by nutria on emergent species combined with the loss of those species by the storm (U.S. Fish and Wildlife Service 1958). This resulted in an apparent nutria die-off in 1957 and 1958 (U.S. Fish and Wildlife Service 1960). The 1961 NR indicated that the nutria population began to increase gradually on the refuge and surrounding marshes due their high reproductive rates and insufficient trapping pressure (U.S. Fish and Wildlife Service 1961).

The first nutria was trapped on the LNWR in 1944 (U.S. Fish and Wildlife Service 1944). Trapping continued until 1988 when low fur prices made it uneconomical. Nutria

harvest data were obtained for each year from 1939 through 1999. The peak in nutria harvest occurred in 1958 with 11,594 nutria harvested. Averages of 3,536 nutria were harvested annually from 1939 to 1988. These data can be used as an indicator of nutria population trends and grazing pressure. However, fluctuating fur prices also affected the levels of the trapping effort during this period.

Summary of Nutria Impacts

Nutria caused dramatic shifts in species composition from 1943 through 1957, especially when combined with the effects of Hurricane Audrey. The effect of nutria grazing on the plant communities at the LNWR after this period was not well documented. Large "eat-outs" frequently observed in other areas along the Louisiana coast were not observed by the author at the LNWR. *Panicum hemitomon* is not a preferred food of this mammal. However, nutria grazing has likely affected community development on the pop-ups and on mudflats during droughts because nutria frequently feed on the herbaceous species that colonize these areas. Table 3.13 lists some of the expected effects of nutria herbivory at the LNWR based a literature review, descriptions provided in the U.S. Fish and Wildlife Service narrative reports, and personal experience.

DISTURBANCE INITIATED PLANT COMMUNITY DYNAMICS

The previous section identified the prominent disturbance agents at the LNWR. This section highlights significant community changes and provides linkages to interacting disturbance agents.

<u>Lacassine Pool Species Composition Shift (1944 through 1947)</u>

The dominant plant species present when the LNWR was established were *Cladium jamaicense*, *Phragmites communis*, and *Panicum hemitomon* (U.S. Fish and Wildlife Service 1940). To improve habitat for waterfowl, the U.S. Fish and Wildlife Service

Table 3.13. Expected effects of nutria grazing on emergent marsh, floating marsh, and floating-leaved and submerged aquatic plant communities. These expected effects were based on a literature review, descriptions provided in the U.S. Fish and Wildlife Service narrative reports, and personal experience.

Disturbance	**Expected Effects**		
Nutria Grazing	**Emergent Marsh**	**Floating Marsh**	**Floating Leafed/Submerged Aquatic**
	reduced cover, created bare areas known as "eat-outs," species caused composition shifts, interacted with flooding to change habitat to open water	same as emergent marsh	increased habitat

instituted management practices to reduce the coverage of these species in favor of submerged and floating aquatic species, namely, *Brasenia schreberi*, *Eleocharis spp.*, *Utricularia sp*., and *Nymphaea odorata.* Raising water level was the primary tool used by the refuge to reduce competition from the emergent species in the Pool. In conjunction with the stresses caused by flooding, other disturbance agents contributed to the spread of the desired species. Nutria created open water patches while feeding on *Sagittaria lancifolia* and *Scirpus californicus*. An underwater weed cutter and boat trails were used to breakup patches of *Cladium jamaicense*, *Panicum hemitomon,* and *Sagittaria lancifolia*. Fire was also used to clear patches of *Cladium jamaicense* exceeding 400 ha. Additionally, herbicides were used to kill unwanted floating aquatic species, and *Brasenia schreberi* was transplanted into the patches created by these disturbances. The species composition shift from a predominantly emergent plant community to a mixture of emergent, floating-leaved, and submerged aquatic plant communities during this period resulted from the interactions of multiple disturbance agents including fire, mechanical clearing, nutria herbivory, vegetative transplants, and herbicides. By 1946, the utility of flooding to control the growth of *Panicum*

hemitomon was first questioned when that species demonstrated an adaptation to flooding by growing in floating mats.

<u>The *Cladium jamaicense* Kill (1957)</u>

Hurricane Audrey (June 27, 1957) caused flooding that killed all emergent species outside of the Pool except *Sagittaria lancifolia* and *Scirpus californicus*. The *Cladium jamaicense*-dominated marsh south of the Pool was replaced with a *Sagittaria lancifolia*-dominated community. High water levels in the years following Hurricane Audrey prevented the germination of *Cladium jamaicense* and favored the increased abundance of *Sagittaria falcatta*, *Najas quadalupensis*, and *Utricularia spp*., and *Eleocharis equisetoides*.

<u>Emergent Marsh Expansion (1971 through 1979)</u>

Unusually dry conditions during the summer of 1971 resulted in the expansion of *Panicum hemitomon*, *Sagittaria lancifolia*, and *Pontederia cordata* toward the center of the Pool, reducing open water habitat to approximately 10 percent and resulted in nutria also expanding their range as a response to the new vegetation growth. By 1974, it became evident that organic matter deposition in the Pool was resulting in a shallower marsh, which further promoted the growth of these undesirable species. The disturbed hydrologic regime, which had created a sink for organic matter in the Pool, supported this positive feedback between organic matter deposition and emergent marsh expansion, and continues to be a management obstacle at the LNWR today.

<u>Floating Mat Formation (1977 through 1979)</u>

Plant community changes in the Pool also resulted from the formation of floating marsh islands (pop-ups) originating from organic mats of decaying matter. The U.S. Fish and Wildlife Service (1979) provides the following account of the perceived process of floating marsh formation and its eventual impact on the refuge:

> *Through the course of natural succession the marsh is gradually filling up with decaying vegetation. As the plants decompose on the marsh bottom, they form gasses that lift large mats of this decayed plant matter to the water surface. Plants become established on the decayed material forming large islands of floating vegetation. If left unchecked, the Pool would completely fill up, and the marsh would be lost. Succession is progressing at a slower pace in the areas outside the Pool. Water movement out of the marsh is very pronounced here, causing dead plant material to be flushed out instead of allowed to accumulate* (U.S. Fish and Wildlife Service 1979, p. 7).

This phenomenon appeared to have been triggered, at least in part, by a physical disturbance that severed the root mat binding the organic matter to the marsh bottom. Floating islands that resulted from marsh buggy disturbance were described and photographed by refuge biologists (U.S. Fish and Wildlife Service 1978). I also observed the formation of these floating organic mats during the field component of this project.

<u>Proliferation of *Sapium sebiferum* (1980)</u>

Dry conditions coupled with human disturbance led to the spread of *Sapium sebiferum* on the refuge beginning in the early 1980s. Ditches cut by hunters using outboard motors and inboard mud boats reduced marsh water levels in the Wilderness Area and promoted the invasion of brush, including *Sapium sebiferum*. Spoil banks along oil and gas and pipeline canals provided an artificial habitat for this species to spread into the interior marsh. Prescribed burning was used in an attempt to control the spread of this species and outboard motors have been banned from the Wilderness Area.

<u>Floating Marsh Loss Along Bayou Lacassine (1983)</u>

Large portions of marsh located along Lacassine Bayou north of the GIWW have been lost due to a combination of disturbances. This marsh is composed primarily of *Alternanthera philoxeroides* which forms large mats that are in a semi-floating state. These mats vary in width from a few to several hundred meters and are susceptible to wind and damage by high water. Several hundred ha were lost in one night when high water washed

away large portions of the floating mat that had previously been cut by marsh buggies during a seismic survey.

CONCLUSIONS

The dominant force of vegetation change at the LNWR has been flooding caused by hurricanes and water level fluctuation of in the 6,475-ha marsh impoundment (U.S. Fish and Wildlife Service 1980). Superimposed on the landscape-level changes initiated by these large-scale disturbances are smaller-scale mechanical disturbances caused by oil and gas activities, dredging, vegetation clearing, and herbicides.

A disturbance frequency gradient may be used to explain the differences in species composition and community structure in the Pool and other portions of the refuge. The patchy community structure of the Pool consists of a mosaic of emergent and floating marsh vegetation and shallow water ponds with numerous boat trails and oil and gas access roads. Extended periods of flooding have slowed the expansion of the emergent perennial species, while periodic drawdowns maintain pond depth somewhat, by allowing the organic soils to oxidize.

Other parts of the refuge, most notably DMU-3 (marsh east of the Pool) and DMU-7 (Wilderness Area), are relatively homogenous in terms of species composition and structure. These marshes are characterized by dense stands of *Panicum hemitomon* with scattered shallow water ponds, intermittent flooding, and infrequent burning. The historical disturbance regime that shaped the community structure in these areas differs significantly from the Pool. Infrequent disturbances, the twelve month growing season, and the high biomass production of *Panicum hemitomon*, have limited the space and opportunities for other species to coexist. In the absence of fire, dense mats of dead plant matter have accumulated in these marshes. These dense mats limit the coexistence of shade-intolerant

species. An artificial ridge adjacent to the pipeline canal facilitates invasion of exotic species in DMU-7. This artificial ridge provides upland habitat and a conduit for exotic species to invade the marsh interior during dry periods. The network of oil and gas canals provides the primary source of disturbance in DMU-6. Spoil banks partially impound portions of this marsh and the canals provide a direct hydrologic link to Bayou Lacassine and the Mermentau River, resulting in frequent flooding, especially during periods of strong southerly winds. The effects of the canals on the plant communities in this area cannot be determined from available information; however, significant portions of the interior marsh are floating, which may be a result of frequent water level fluctuations.

This disturbance history can be used to explain the current landscape at the LNWR and to make mechanistic predictions about the effects of future natural and human disturbances on plant communities on the refuge. In emphasizing the importance of disturbance, Picket and White (1985), point out two kinds of frequent misinterpretations made in field ecology: (1) extrapolation of events measured during disturbance-free years to predict future system states, and (2) integrating different kinds of patches into a single experimental plot. These misinterpretations can be avoided with knowledge of historical disturbance regimes of a given area.

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CHAPTER 4

EFFECTS OF 3-D SEISMIC EXPLORATION ON THE PLANT COMMUNITIES AT LACASSINE NATIONAL WIL DLIFE REFUGE: A TWO-YEAR FIELD STUDY

INTRODUCTION

Louisiana's wetlands account for 41% of the United States' coastal wetlands (Turner and Gosselink 1975) and 80% of nation's total wetland losses (Dahl 1990). These wetlands are important as a fisheries habitat (twenty-seven percent of commercial fisheries catch by weight in the contiguous U.S.), are the location of the largest concentration of over-wintering waterfowl in the U.S., and are a buffer from storm damage for 2 million inhabitants (Louisiana Department of Natural Resources 2003). Louisiana also ranks first in crude oil production and second in natural gas production nationally (Louisiana Department of Natural Resources 2003). Much of this production originates in, or is transported through, Louisiana's offshore and coastal waters and wetlands.

This investigation explores how one aspect of oil and gas production affects the emergent wetland vegetation at a national wildlife refuge. Activities associated with oil and gas exploration and production include seismic surveys, dredging (access canals, pipelines, and navigation channels), and well-site construction. The direct and indirect wetland loss caused by dredging canals and navigation channels has been estimated to account for 30% to 59% of the wetland losses between 1955 and 1978 (Boesch et al. 1994). The effects from other development activities, such as off-road vehicles used during seismic surveys, pipeline construction, and spill clean-ups, also pose a significant threat if not managed properly. Concern over the possible adverse effect of off-road vehicles to coastal wetlands began to develop prior to the 1950s when trappers reported damage to their leases (Detro 1977). In an effort to minimize the damages, trappers insisted that the marsh buggy operators utilize the same path repeatedly. This practice resulted in soil rutting, erosion, salinity changes,

and plant species composition changes. Over time, some marsh buggy trails became canals (Detro 1977).

A number of researchers attempted to quantify the effects of vehicular traffic on wetland vegetation (Harris and Chabreck 1958; Schemnitz and Schortemeyer 1973; Detro 1977; Whitehurst et al. 1977; Sikora et al. 1983; Duever et al. 1986; Sikora et al. 1988; Nidecker et al. 1993; Ensminger 1995; Kevan et al. 1995; Bass 1997; Ensminger et al. 1997; Racine et al., 1998; Hess et al. 1998; Wilson et al. 1998). Whitehurst et al. (1977) used aerial photography to document several stages of marsh destruction caused by marsh buggies in a saline marsh near Leeville, Louisiana. Harris and Chabreck (1958) attributed increased marsh damages associated with Hurricane Audrey to marsh buggy trails. Deuver et al. (1981) investigated the effects of airboats and all-terrain tracked vehicles on south Florida wetland habitats. They found that after one year, vegetation height was the most impacted parameter, biomass was moderately impacted, and percent cover was the least impacted. Schemnitz et al. (1973) investigated the short-term effects of airboat and tracked vehicles in the Florida Everglades. They found that the vegetative biomass at the airboat treatment sites did not differ significantly from that at control sites, except for a five-run treatment site. However, they reported statistically significantly lower biomass at one tracked vehicle treatment site compared to control sites. Racine et al. (1998) described the nature, magnitude, and distribution of disturbances caused by airboat trails over a floating mat fen wetland near Fairbanks, Alaska. They documented over 100 km of airboat trails on which all of the emergent floating marsh vegetation and approximately 50% of the floating mat had been destroyed (Racine et al. 1998). Chabreck (1994) assessed a seismic program at Sabine National Wildlife Refuge in Cameron Parish, Louisiana, and found that marsh buggies caused rutting in four of the twenty-one sites inspected, but that plant re-growth did

not appear to be affected (Chabreck 1994). Evidence of rutting by airboats was not reported and long-term impacts were not expected. Nidecker et al. (1993) developed a monitoring program to assess the impacts of 3-D seismic activity on wildlife and wetlands at Sabine National Wildlife Refuge. They concluded that vegetation quickly recovered on airboat and marsh buggy trails where compaction did not occur. Plant species dominance was not affected. Wilson et al. (1998) found that seismic activity had no significant effect on total emergent vegetation cover, but caused a minor, short-term species composition change in an intermediate marsh at Rockefeller Refuge in Cameron Parish, Louisiana. Hess et al. (1998) evaluated soil impacts associated with the same 3-D survey and found no significant elevation differences on treatment and control transects. Of these studies, which document the effect of vehicle traffic on fresh marsh vegetation, none have been conducted in Louisiana where these vehicles are used extensively, especially during 3-D seismic surveys.

The potential for large-scale wetland damages exists if seismic surveys are not managed properly. According to the South Louisiana Oil Scouts Association (2002), 286 seismic surveys were conducted in south Louisiana from 1997 to 2002 (South Louisiana Oil Scouts Association 2002) (Figure 4.1). The area surveyed in parishes included within the official Louisiana Coastal Zone was 43,924 km^2 (16,959 mi^2) (Louisiana Department of Natural Resources 2002). This area does not include surveys conducted in offshore state waters. There are approximately 13,759 km^2 (1,375,931 ha) of wetlands in coastal Louisiana. Based on a conservative estimate that 80% of these seismic surveys were in coastal wetlands, then an area approximately 2.6 times the size of all Louisiana's coastal wetlands were covered by 3-D seismic surveys (Finley-Warner 2003). This area includes overlapping coverage of 3-D surveys (See Figure 4.1). If one assumes that the survey lines are 4 m wide and 500 m apart, then 0.024 km^2 of trails are created for every 1 km^2 surveyed.

If 80% of the area surveyed was coastal marsh, and there was 60% vegetative recovery after one growing season (estimates based on best professional judgment of the author and Finley-Warner (2003), then a total 337 km^2 wetland damage may be attributable to 3-D seismic surveys between 1994 and 1999. If this vegetative damage resulted in permanent wetland loss, then 22.5 km^2 of wetland loss per year may be attributable to 3-D seismic survey traffic. This loss rate is approximately 36% of the annual wetland loss based on an estimated annual wetland loss rate of 62 km^2/year (Louisiana Department of Natural Resources 2003).

The purpose of this study was to conduct a "before and after" investigation of those mechanical disturbances in a Louisiana fresh marsh. In 1997 Shell Onshore Ventures, Inc. (Shell) proposed, and subsequently conducted, a three-dimensional (3-D) seismic survey for petroleum reserves at Lacassine National Wildlife Refuge (LNWR) in Cameron Parish, Louisiana. I formulated a sampling design to determine how effectively new seismic data-gathering technology, vehicle design, and management techniques could be used to reduce the overall impacts to vegetation on the refuge. The program included baseline and annual post-disturbance sampling for two years following the 3-D survey. This monitoring data provided an ideal opportunity to test various hypotheses about ecological disturbance under a semi-controlled field environment and in an applied research setting.

The objectives of this investigation were to: (1) determine whether vehicle traffic causes changes in percent live cover, live biomass, and/or dead biomass, (2) compare the effects of different equipment types (marsh buggies and airboats) on these measures of marsh vegetation health, (3) assess the effectiveness of managing traffic levels in defined areas, (4) determine if spatial effects exist among areas of the refuge, and (5) assess the effects of vehicular disturbance on species composition and richness.

Study Area

The LNWR is comprised of 14,164 ha (35,000 acres) of freshwater marsh in Cameron Parish in southwest Louisiana (Figure 4.2) (U.S. Department of the Interior 1997). The National Wetland Inventory (NWI) maps classify this area primarily as impounded fresh marsh, impounded aquatic vegetation beds, and fresh marsh (U.S. Department of the Interior 1992).

The primary management goal of the refuge is to provide habitat for wintering waterfowl. A major feature within the refuge is the 6,475-ha (16,000-acre) Lacassine Pool (Figure 3.1). The Lacassine Pool is located where the Pleistocene coastal prairie borders the vast coastal fresh marshes (Fruge 1974). The Lacassine Pool and the surrounding marshes were previously part of an estuarine system associated with the Mermentau River. In 1944, the levee system surrounding Lacassine Pool was complete. Other changes to this area include the installation of Catfish Point Water Control Structure and the saltwater locks near Grand Lake, and the junction of the Calcasieu River and the Gulf Intracoastal Waterway (Louisiana Coastal Wetlands Conservation and Task Force 2002).

The primary surface soil present is poorly drained Allemands muck that is commonly found in fresh marshes (U.S. Department of Agriculture 1995). The natural ridges of the Lacassine Pool are composed of a very poorly drained mineral soil classified as as Ged mucky clay (U.S. Department of Agriculture 1995). The northern portion of the Lacassine Pool contains some clay soils near the surface; however, most of the impoundment contains soils with more than 50% organic matter (Fruge 1974).

Two dominant plant community types exist at the study site: an emergent community and a floating-leafed community. The most abundant species in the emergent community

Figure 4.1. Map showing 3-D seismic survey locations in south Louisiana from 1987 through 2002. Source: South Louisiana Oil Scouts Association 2002.

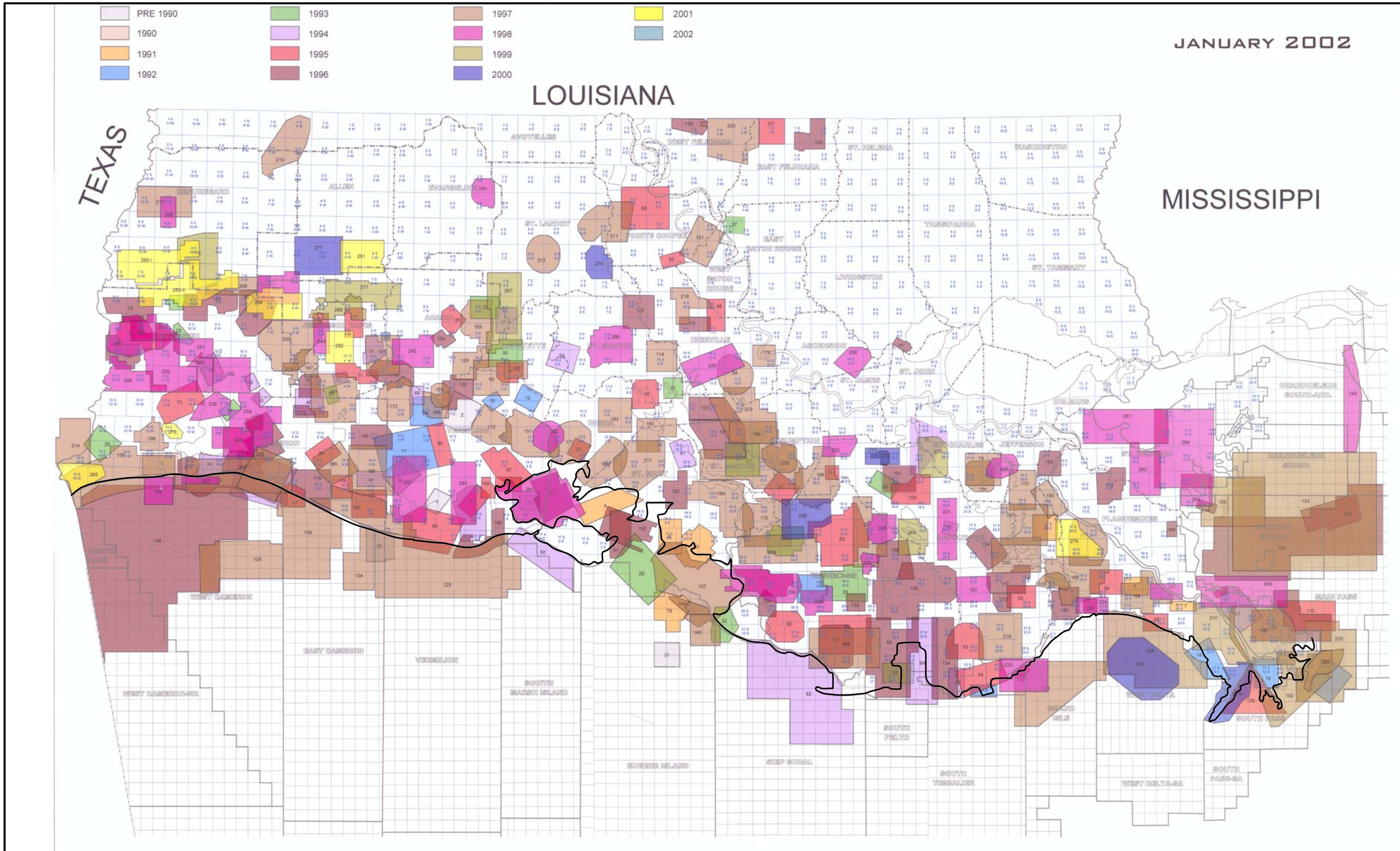


Figure 4.1. Map showing locations of 3-D seismic survey projects in South Louisiana from pre-1990 through 2002 (South Louisiana Oil Scouts Association 2002).

are *Sagittaria lancifolia* and *Panicum hemitomon*. The floating-leafed community is composed of *Brasenia schreberi* (water shield), *Nymphoides aquatic* and *Nymphaea odorata*. Common names for all species are included in tabular form in Table 4.1. A detailed history of the LNWR is in Chapter 3.

MATERIALS AND METHODS

Study Sites

The study area was divided into four units based on habitat and disturbance history. One study site was randomly selected from each unit. Figure 4.2 shows the portion of LNWR covered by the 3-D the seismic survey.

Site 1 (Pool) is located in the Lacassine Pool (a freshwater marsh impoundment constructed in 1951) (Figure 3.1). Habitat in the impoundment consists of a mixture of emergent floating and non-floating marsh, and shallow ponds occupied with floating-leaved and submerged aquatic vegetation. Human disturbances in the Lacassine Pool include flooding, prescribed marsh burning, road construction for oil and gas activities, disturbance associated with outboard motors, and previous seismic surveys.

Site 2 (Lacassine Bayou) is located in a homogeneous freshwater marsh east of Lacassine Pool and west of Bayou Lacassine (Figure 4.2). The habitat in this area consists primarily of emergent freshwater marsh with small intermittently flooded ponds. Dominant plant species include *Panicum hemitomon* and *Sagittaria lancifolia*. Previous human disturbances in the Lacassine Bayou study unit have included prescribed burning, cattle grazing, and seismic surveys.

Site 3 (Lakeside Oil Field) is situated west of the Mermentau River and north of the Gulf Intracoastal Waterway in the Lakeside oil and gas field (Lakeside) (Figure 3.1). Numerous oil and gas canals, spoil banks, pipelines, and levees have altered the natural

hydrology of the site. Previous seismic surveys have also been conducted at the Lakeside in the study unit, and prescribed burns have been conducted there since the early 1990s.

The site is characterized by floating and non-floating freshwater marsh, spoil banks, shallow ponds, and dense stands of *Cephalanthus occidentalis* and *Salix nigra*.

Site 4 (Grand Lake) is situated south of the Gulf Intracoastal Waterway on the northern shore of Grand Lake. A dredged oil and gas canal is located due north of the Grand Lake site, and a petroleum pipeline is located approximately one-half mile to the east. Portions of the Grand Lake study unit were burned in the early 1950s and again in the mid-1990s.

3-D Seismic Survey Activities

Three-dimensional surveys use reflective seismology to map geological features. The two primary elements of these surveys are an energy source (shot) and data receivers. The energy source, typically a form of dynamite, is placed in shot holes drilled approximately 15 meters below the marsh surface. The receivers record subsurface data, which is in the form of energy that is reflected off geological features. These data are processed to create a 3-D representation of the subsurface geology. Cross-array field designs resembling a checkerboard pattern are commonly used for land surveys. These patterns generally consist of a series of receiver stations forming transects oriented east/west (receiver lines) and a series of shot holes forming transects (shot lines) running north/south. I have described this in more detail in Bass (2001). Fenstermaker (1994) also provides additional information pertaining to 3-D survey project design.

Shell Western E&P, Inc. conducted the South Thornwell 3-D seismic survey at the LNWR from July through August 1997. The contract seismic operator was Veritas DGC Land and the contract surveyor was Survey Technologies, Inc. The coverage area of the

entire survey included Townships 11 and 12 South, Ranges 4 and 5 West, in Cameron and Jefferson Davis Parishes, Louisiana.

The total estimated seismic survey time was 11 weeks. The seismic survey was divided into three phases: (1) initial land surveying to locate shot hole and receiver stations, (2) drilling shot holes, and (3) seismic data acquisition.

The first two weeks of activity consisted of land survey crews in the field marking shot hole and receiver station locations with cane poles. The surveyors were equipped with GPS (Global Positioning System) technology and traveled around the refuge both in airboats and in a small Marsh Master® marsh buggy. They surveyed both shot and receiver lines, marking the shot hole and receiver locations with cane poles. Land surveying lasted approximately 8 weeks. The drilling of shot holes began in week 2 and lasted 8 weeks. The drill crews performed work from airboats when possible, and used a lightweight aluminum marsh buggy when necessary. The shot hole drilling was concentrated on portions of the project area. The majority of the project area would have no drilling activity for 6 of the 8-week drilling period.

The seismic data acquisition phase began at week 4 and lasted 7 weeks. This was the most concentrated period of activity. Geophones and recording boxes were placed and retrieved from receiver points by airboats or by walking. As with the drilling phase, the layout and pickup were continuously active on a small portion of the project area. The shooters (personnel who detonate explosives) also worked from airboats. Airboats were stationed along the lines to solve any problems that arose. As part of the Special Use Permit issued by the U.S. Fish and Wildlife Service (USFWS), helicopters were used to transport explosives, receivers, and other supplies in an effort to minimize airboat travel along lines.

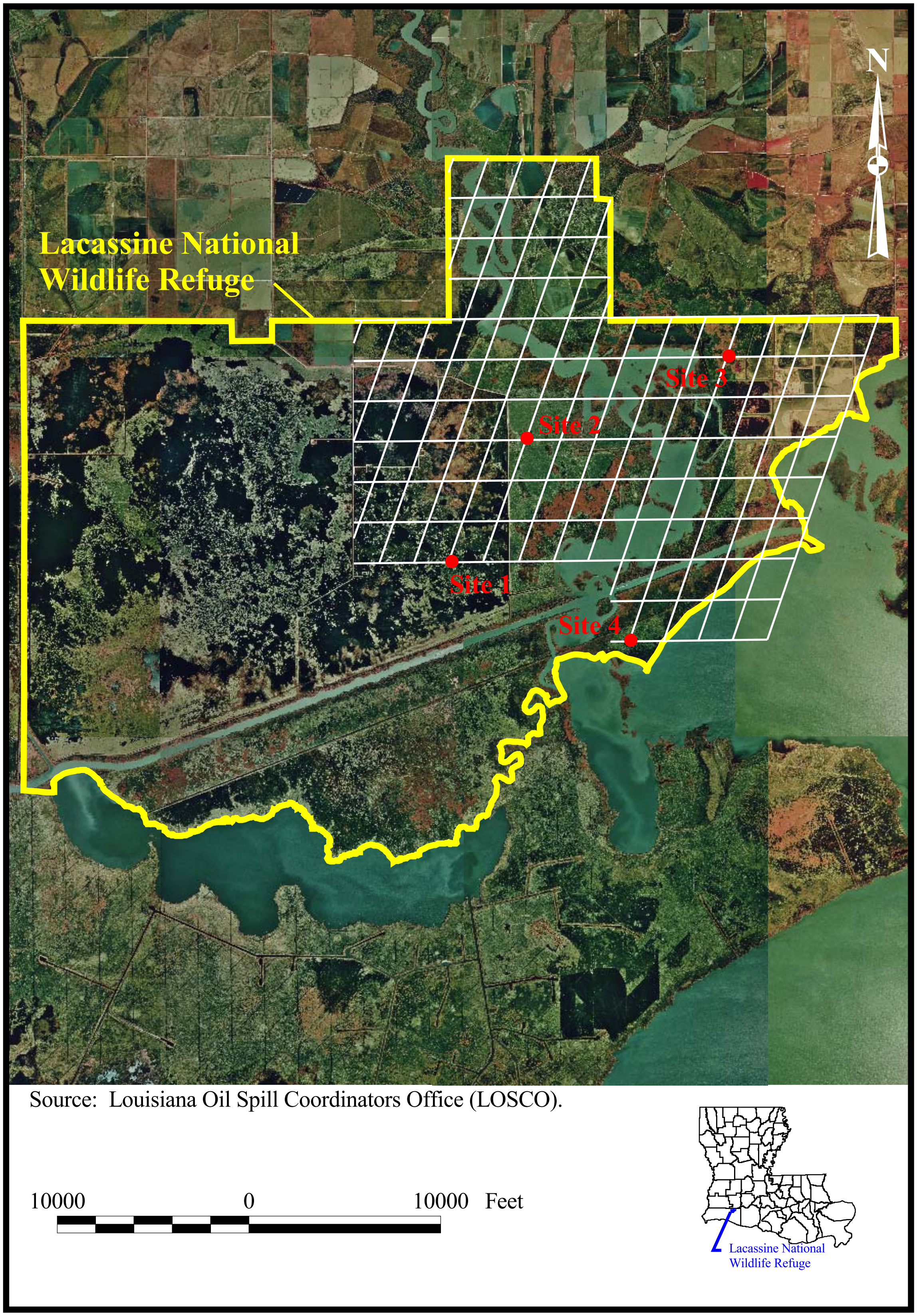
The four study sites were established during the survey phase of the 3-D program once the shot and receiver lines had been delineated with cane poles. Research goals were discussed with the seismic survey personnel. Signs were placed at each site indicating specific treatment protocols for the operators to follow. Coordination was maintained with the seismic operators throughout all phases of the 3-D program to ensure that the research objectives were met.

Oversight

Three biological monitors, with no financial relationship to the oil company, were selected by the Refuge Manager to supervise the field crews and enforce the operating restrictions established in the Special Use Permit issued by the USFWS. The refuge did not place limits on the number of vehicle passes allowed along newly-cut trails. However, the biological monitors were given the authority to manage access routes and trail use to minimize impacts. Helicopters were required to distribute equipment and supplies, and marsh buggy and airboat drill rigs were to be left in the marsh at the end of each day. A performance bond for $250,000 was also required prior to the seismic survey to guarantee that damage occurring on the refuge property would be properly corrected or repaired.

Sampling Design and Treatment Protocol

The sampling design incorporated a checkerboard grid pattern that was used in the 3-D geophysical survey. The general study site design consisted of a 1,677 m transect (oriented north-south along a shot line) and a 1,372 m transect (oriented east-west along a receiver line). Each transect was permanently marked with cane poles (Figure 4.3). Approximately 30 sampling points were spaced evenly along each transect. The north-south transects received both marsh buggy and airboat traffic. The east-west transects received



Source: Louisiana Oil Spill Coordinators Office (LOSCO).

Figure 4.2. 1998 Color infrared aerial orthophotograph of Lacassine National Wildlife Refuge showing locations of study sites and the portion of the refuge covered by the South Thornwell 3-D seismic survey project.

only airboat traffic. Each transect was then subdivided into two levels of traffic – single vehicle pass and multiple vehicle pass experimental lanes.

Adjustments to the Pool and Grand Lake sites were made in the field to fit the 3-D seismic pattern. This resulted in missing data cells on the southern shot line transect at the Pool. Additionally, Grand Lake had no eastern receiver or southern shot line transect to sample. Permanent control transects were established in Year 1 approximately 31 meters away from the experimental transects in undisturbed marsh. Each experimental transect was then sub-divided into single-pass or multiple-pass treatments. Figure 4.3 shows sampling diagrams for the four study sites.

Each study site was clearly marked in the field with signs designating single-pass and multiple-pass areas and on field maps used by the equipment operators. Equipment operators were given specific instructions to make multiple passes on the same trail while operating in the "multiple-pass areas" and to avoid making multiple passes on the same trail in the "single-pass" areas. Signs were clearly posted at the entrance of each experimental transect and corresponding instructions were provided on field maps used by the equipment operators. Additionally, specific operating instructions regarding travel protocol in experimental plots were given to all personnel involved in the survey during the initial meeting at the beginning of the project and at daily safety and planning meetings.

<u>Data Collection</u>

Baseline Data Collection

Baseline data were collected in July 1997 following the land survey of shot hole and receiver locations. I accessed the study sites using an airboat and sampled vegetative cover using the line-intercept method (Chabreck 1960). Approximately 30 treatment sample plots were evenly spaced along each transect. I estimated live percent cover (total and by species)

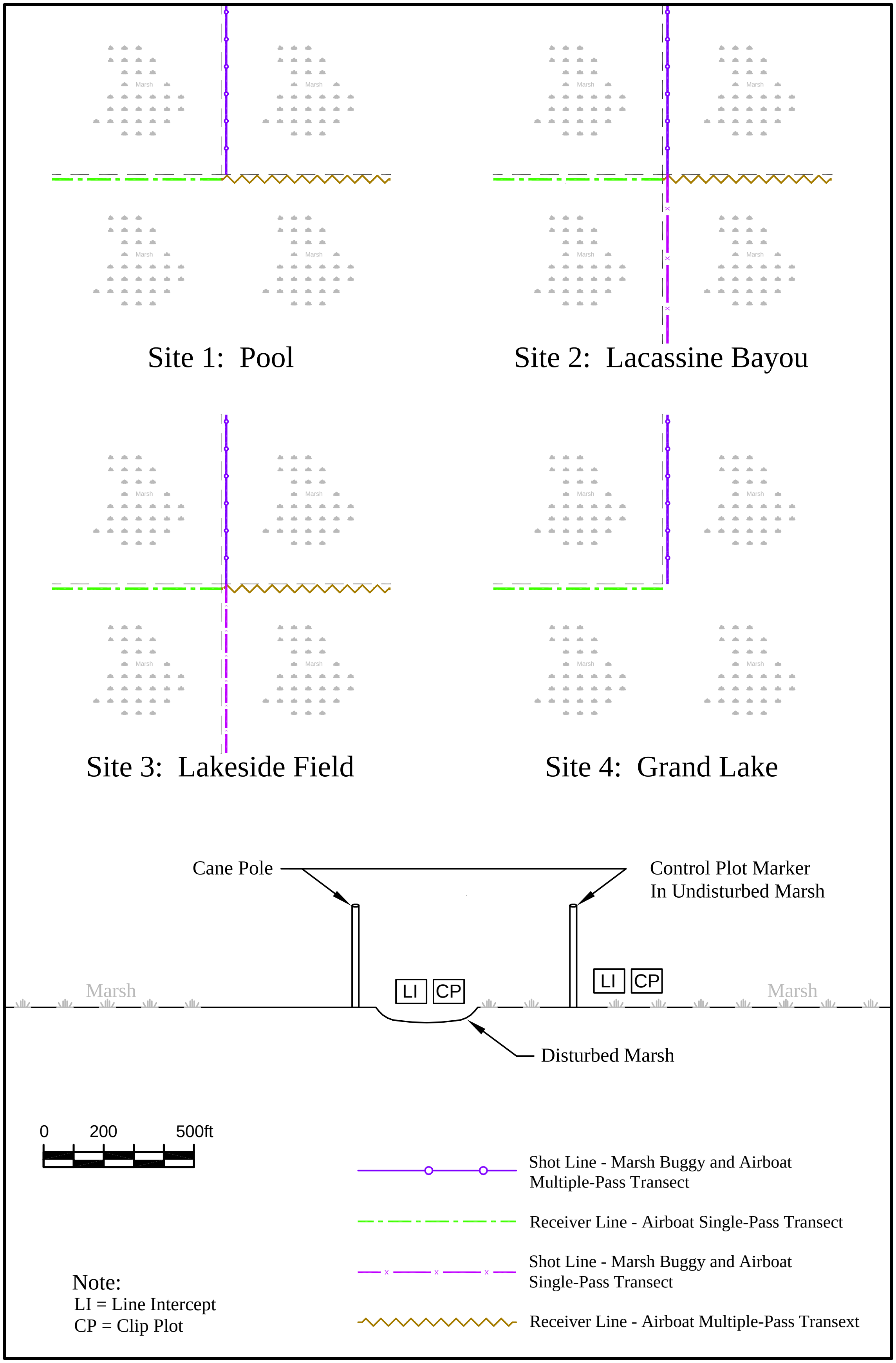


Figure 4.3. Study site sampling schematic.

without removal at each sample point and attempted to identify all vegetation down to the species level. Samples lacking distinguishing characteristics were identified to the family or genus level.

Post-disturbance Data Collection

I collected post-disturbance data at the end of each growing season in 1998 (Year 1) and 1999 (Year 2) using the same experimental study points sampled during the pre-disturbance vegetative survey. The permanent control points were marked with plastic pipe in undisturbed marsh. The control points were sampled in Years 1 and 2. In addition to percent cover, aboveground biomass was sampled using 0.25 m^2 clip plots. The clip plot samples were collected from within the vehicle path approximately 2 m from the permanent vegetative cover treatment plots. Care was taken to avoid disturbing the vegetation in the permanent treatment plots. In Year 2, clip plot samples were taken approximately 4 m from the permanent treatment plot in areas that were undisturbed by the previous sampling activities. All sample locations were accessed by foot in Years 1 and 2, when possible, to avoid/minimize disturbance to other sample locations. Each site had a total of 24 clip plot replicates. There were eight clip plots on each source and receiver line, and in the control plots. In sampling each clip plot, I removed all above-ground standing live and dead culms and litter, placed the plant material into plastic bags and brought back to the LSU Coastal Ecology Institute vegetation laboratory for processing. Samples were then sorted into live culms by species, dead culms, and litter. Plant material was dried at 60˚ C to a constant weight. Biomass weights were taken for total live, total dead, and total live by species. I attempted to identify all live vegetation at the species level. Samples were identified to the family or genus level when they lacked distinguishing characteristics.

Experimental Design

A split-plot statistical design was selected for the study (Freund and Wilson 1997). The four independent study sites served as the main plots, and equipment type as the sub-plot (marsh buggy and airboat traffic constituted one sub-plot and airboat traffic-only constituted the other sub-plot). Nested within these sub-plots were two levels of traffic (single-pass and multiple-pass).

A mixed linear model was used to test the means of the data as well as assess the effects of site differences, year/treatment, equipment type, traffic levels, and their interactions. Specific models for each parameter measured (percent live cover, live aboveground biomass, and dead aboveground biomass) are provided below.

The percent live cover (Cvr) was modeled as follows:

(Eq. 1) $$Cvr_{ijkl} = \mu_{Cvr} + \alpha_i + \beta_j + \gamma_{k(j)} + \delta_l + \alpha\beta_{ij} + \alpha\gamma_{ik(j)} + \alpha\delta_{il} + \varepsilon_{ijkl}$$

where Cvr_{ijkl}, is the estimated live vegetative cover, μ_{Cvr} is the overall mean, α_i is the site effect, β_j is the equipment effect, $\gamma_{k(j)}$ is the traffic effect nested within equipment effect, δ_l is the overall traffic effect, $\alpha\beta_{ij}$ is the interaction of site with equipment, $\alpha\gamma_{ik(j)}$ is the interaction of site with traffic nested within equipment, $\alpha\delta_{il}$ the interaction of site with traffic, and ε_{ijkl} is the error term associated with the observations. The sites are represented by the subscript i, equipment by j, traffic by k, and time and treatment by l. These variables are included to account for suspected spatial, equipment, traffic, and temporal variation believed to affect the vegetation parameters.

The site effect is incorporated into the model to account for possible spatial variation associated with different plant communities, soils, and disturbance histories. β_j is included in the model to account for the potential effects of the two types of equipment used. I

hypothesized that a combination of marsh buggy and airboats had a greater effect on Cvr_{ijkl} than airboats only. $\gamma_{k(j)}$ accounts for the two levels of traffic – single pass and multiple pass for each equipment type.

I hypothesized that multiple-pass traffic would have a greater negative effect on Cvr_{ijkl} than single-pass traffic. δ_l was incorporated into the model to account for overall traffic effects on Cvr_{ijkl}. $\alpha\gamma_{ik(j)}$ was incorporated to account for suspected different site effects associated with the two levels of traffic intensities and equipment types.

(Eq. 2) $Lbio_{ijkl} = \mu_{Lbio} + \alpha_i + \beta_j + \gamma_{k(j)} + \delta_l + \alpha\beta_{ij} + \alpha\gamma_{ik(j)} + \alpha\delta_{il} + \varepsilon_{ijkl}$

where $Lbio_{ijkl}$ represented live biomass. Similar patterns to the above were expected. The remaining variables were as previously defined.

(Eq. 3) $Dbio_{ijkl} = \mu_{Dbio} + \alpha_i + \beta_j + \gamma_{k(j)} + \delta_l + \alpha\beta_{ij} + \alpha\gamma_{ik(j)} + \alpha\delta_{il} + \varepsilon_{ijkl}$

where $Dbio_{ijkl}$ represents dead biomass. Here, I expected dead biomass to be significantly higher in treatment plots because of the trampling effect by the vehicles on the vegetation.

Statistical Analysis

Vegetative cover data was analyzed with SAS (SAS Institute Inc. 2001) using the PROC MIXED procedure (Singer 1998, SAS Institute Inc. 2000). Interactions between the main effects were tested. When a factor was significant, post hoc pairwise comparisons of means were made. An alpha of 0.05 was used to determine significance. The following hypotheses were tested:

H_1: Vegetative live cover and live biomass will be significantly reduced by equipment traffic.

H_2: The effects on live cover and live biomass will vary significantly among sites.

H_3: Dead biomass will be significantly higher in treatment plot in both years.

H_4: There will be a significant overall traffic effect. Single-pass

treatments will create less disturbance and have greater live cover and live biomass than
multiple-pass treatments.

H_5: Marsh buggy + airboat treatments will have a greater negative effect on live biomass and cover than the airboat-only treatment.

Species Composition and Richness

Sorenson's Community Similarity Index (Magurran 1988) was used to compare baseline species composition with species composition in treatment plots for years 1 and 2. Comparisons were also made between treatment and control plots for both years. Calculations were based on all sites combined.

This index is based on presence/absence of species that are shared between samples of vegetation and species that are unique to each sample and is calculated as:

$$2c / (s1 + s2)$$

where *c* is the number of species treatment and control sites have in common, and *s1* and *s2* are the number of species in the respective treatment and control plots. This index is designed to equal 1 in cases where sites are completely similar and 0 if the sites have no species in common (Magurran 1998). Calculations were based on live vegetative cover and biomass data. Mean species richness was calculated for treatment and control plots for each site using both live cover and live biomass data.

RESULTS

Species Abundance

Table 4.1 quantifies species abundance on baseline, treatment and control plots for Years 1 & 2 based on percent cover. Baseline species composition in the treatment plots consisted of 50% *Panicum hemitomon*, 8% *Nymphaea odorata*, 5% *Nymphoides aquatica*, 4% *Sagittaria lancifolia*, and 3% *Brasenia schreberi*. Sixteen other species made up 7% of

Table 4.1. Mean percent cover by species for baseline, Year 1 treatment (Y1T), Year 1 control (Y1C), Year 2 Treatment (T2T), and Year 2 Control (Y2C) plots at the Lacassine National Wildlife Refuge.

Species	Common name	Baseline	Y1T	Y1C	Y2T	Y2C
Alternanthera philoxeroides Griseb	alligator weed	1.16	1.73	2.04	1.06	0.72
Azolla caroliniana Willd.	mosquito-fern	-	-	0.07	-	-
Bacopa coroliniana (Walt.) Robins.	Carolina water-hyssop	0.67	2.45	1.69	1.75	1.02
Bidens sp.	aster family	-	0.49	-	0.27	0.12
Boehmeria cylindrica (L.) Sw.	small-spike false-nettle	-	0.04	0.02	0.26	0.25
Brasenia schreberi Gmel.	watershield	2.94	1.78	0.09	0.58	-
Cephalanthus occidentalis L.	common buttonbush	0.93	1.58	1.53	1.68	0.97
Cladium jamaicense Crantz	Jamaica sawgrass	-	-	0.05	-	0.05
Crinium americanum L.	southern swamplily	-	-	-	0.20	0.16
Cyperus sp.	flat sedge	-	0.86	0.09	0.98	6.90
Decodon sp.	loosestrife family	-	1.29	0.19	0.95	2.20
Dioda virginiana L.	buttonweed	-	0.08	0.05	0.13	0.12
Eichhornia crassipes (Mart.) Solms	water hyacinth	0.20	-	-	-	-
Eleocharis elongata Chapm.	slim spikerush	0.44	0.34	-	-	-
Eleocharis equisetoides (Ell.) Torr.	horse-tail spikerush	1.35	0.59	0.81	2.37	1.06
Eleocharis geniculata (L.) R. & S.	clustered spikerush	-	0.21	-	-	-
Eleocharis sp.	spikerush	0.03	1.67	0.83	3.60	-
Eupatorium sp.	boneset	-	0.14	-	-	-
Fuirena pumila (Torr.) Spreng.	hairy umbrella-sedge	-	-	-	0.06	-
Habenaria repens Nutt.	water-spider orchid	-	0.09	0.05	-	-
Hybiscus sp.	mallow family	-	-	-	-	0.05
Hymenocallis salisib	amaryllis family	0.42	0.29	0.76	0.01	-
Hypericum virginicum L.	marsh St. John's-wort	-	0.22	0.56	0.49	1.39
Hypericum sp.	St. John's-wort family	0.04	0.19	-	0.90	0.30
Ipomoea sagittata Poir. in Lam.	saltmarsh morning-glory	-	-	-	-	0.07
Leersia sp.		-	0.04	0.28	0.72	1.48
Ludwigia sp.	evening primrose family	0.59	4.80	3.61	1.84	1.09
Lymnobium spongia	American frog-bit	-	-	-	0.21	-
Nymphoides aquatica (S. G. Gmel.) Kuntze	big floating-heart	4.52	2.06	-	1.30	-
Nymphaea odorata Ait.	white water-lily	8.47	5.63	2.89	2.69	0.32
Phragmites australis (Cav) Trin. Ex Steud.	roseau cane	-	-	-	0.01	-
Panicum hemitomon Schult.	maidencane	49.82	59.61	85.83	71.93	87.45
Polygonum lapathifolium L.	willow-weed	-	0.03	-	0.05	-

Table 4.1 cont. *Species*	Common name	Baseline	Y1T	Y1C	Y2T	Y2C
Polygonum punctatum Ell.	dotted smartweed	0.61	3.33	1.48	1.77	2.11
Pontederia cordata *L.*	pickerelweed	0.24	0.45	0.49	0.18	0.21
Paspalum distichum *L.*	knotgrass	-	0.17	-	0.42	0.56
Rhynchospora sp.	sedge family	-	0.01	-	1.66	-
Sacciolepis striata (L.) Nash	American cupscale	-	0.24	0.23	0.06	1.39
Sagittaria lancifolia L.	bulltongue	3.62	4.71	3.91	3.38	4.81
Sagittaria latifolia Willd.	arrowhead	0.75	1.80	1.02	0.95	0.69
Saururus cernuus L.	lizard's tail	0.07	0.83	0.93	0.17	0.19
Scirpus californicus (C. Meyer) Steud.	California bulrush	0.34	0.23	0.09	0.21	0.09
Salix nigra Marsh.	black willow	-	0.03	0.69	-	0.51
Typha sp.	cattail	-	0.09	0.09	0.19	0.05
Vigna sp.	deer pea	-	0.04	-	-	-
Total species present		**20**	**36**	**28**	**34**	**29**

the total cover. Dominance by *Panicum hemitomon* increased slightly in Year 1 following the 3-D survey to 60% in treatment plots and 86% in control plots. *Panicum hemitomon* remained the dominant species in Year 2 with 72% and 87% cover in treatment and control plots respectively. *Eleocharis spp.* colonized open areas created by the vehicle traffic and comprised approximately 6% of the treatment plots in Year 2, whereas it was approximately 1% in control plots.

Similar results were found using biomass data where the average treatment plot in Year 1 was composed of 79% *Panicum hemitomon*, 5% *Sagittaria lancifolia*, 4% *Ludwigia peploides*, and 2% *Bacopa caroliniana* (Table 4.2). Twenty-four other species combined made up 10% of the biomass. The average control plot was composed of 89% *Panicum hemitomon*, 4% *Sagittaria lancifolia*, and 3% *Bacopa caroliniana*. Thirty-eight other species combined made up 3% of the total biomass.

In Year 2, *Panicum hemitomon* made up 91% of the treatment and control biomass, *Sagittaria lancifolia* made up 1% biomass in both the treatment and control plots, and

Table 4.2. Data reported as mean percent live biomass by species Year 1 treatment (Y1T), Year 1 control (Y1C), Year 2 Treatment(T2T), and Year 2 Control (Y2C) plots at the Lacassine National Wildlife Refuge.

Species	Y1T	Y1C	Y2T	Y2C
Alternanthera philoxeroides Griseb	0.29	0.05	0.17	0.13
Baccharis halimifolia L.	-	-	-	0.01
Bacopa coroliniana (Walt.) Robins	1.71	2.56	0.28	0.76
Biden laevis (L.) BSP.	0.86	0.05	0.25	-
Boehmeria cylindrical (L.) Sw.	-	-	-	0.02
Brasenia schreberi Gmel.	-	0.04	0.01	0.02
Carex folliculata L.	-	-	0.10	-
Cephalanthus occidentalis L.	1.58	0.62	0.35	-
Cladium jamaicense Crantz	0.12	-	-	3.43
Crinium americanum L.	0.11	0.01	-	0.15
Crinium sp.	0.04	-	0.07	-
Cyperus haspan L.	-	-	0.04	0.01
Cyperus sp.	0.04	-	0.20	-
Decodon sp.	-	0.86	0.07	0.06
Decodon verticillatus (L.) Ell.	1.06	0.54	0.13	0.77
Dioda sp.	-	0.07	-	-
Dioda teres Walt.	0.02	-	-	-
Eleocharis equisetoides (Ell.)	0.32	0.23	0.30	-
Eleocharis olivacea Torr.	-	-	0.02	-
Eleocharis quadrangulata (Michx.) R. & S.	-	0.01	0.20	-
Eleocharis sp.	0.20	0.09	0.21	0.01
Eupatorium sp.	-	-	0.06	-
Fuirena pumila (Torr.) Spreng.	-	-	0.01	-
Habenaria repens Nutt.	0.01	0.04	-	0.07
Hydrocotyle sp.	0.02	0.01	-	-
Hydrocotyle unbelleta L.	0.02	0.03	0.05	0.06
Hypericum sp.	-	0.23	-	-
Hypericum virginicum L.	0.16	-	0.26	0.41
Ipomoea sagittata Poir.in Lam.	0.35	-	0.01	-
Juncus elliottii Coville	-	-	0.09	-
Leersia hexandra Sw.	1.59	0.73	0.99	0.66
Leersia oryzoides (L.) Sw.	-	-	0.07	-
Limnobium spongea	-	-	0.01	-
Ludwigia alterniflora L.	0.18	-	0.04	-
Ludwigia leptocarpa (Nutt) Hara	-	-	0.20	-
Ludwigia peploides (HBK.)	4.18	0.16	-	0.33
Ludwigia sp.	0.02	-	0.30	-
Myriophyllum heterophyllum Michx.	-	0.30	-	0.01
Nymphaea odorata Ait.	0.10	0.03	-	-
Nymphoides aquatica (S. G. Gmel.) Kuntze	0.03	0.04	-	-
Orchidaceae	-	0.02	-	-

Table 4.2 cont. Species	Y1T	Y1C	Y2T	Y2C
Orontium aquaticum L.	0.03	0.13	0.01	-
Panicum hemitomon Schult.	79.33	88.90	90.94	90.75
Polygonum lapathifolium L.	0.32	-	0.34	-
Polygonum punctatum Ell.	2.23	-	0.27	0.02
Polygonum sp.	-	-	0.34	-
Psilocarya scirpoides Torr.	-	-	0.29	-
Sacciolepis striata (L.) Nash	0.25	0.07	0.03	-
Sagittaria lancifolia L.	4.51	4.00	1.40	1.46
Sagittaria latifolia Willd.	0.12	0.18	0.48	0.10
Salvinia sp.	-	-	0.08	-
Saururus cernuus L.	0.06	0.01	0.10	0.12
Scirpus californicus (C. Meyer)	-	-	1.06	-
Typha sp.	-	-	0.06	-
Total species present	**31**	**28**	**40**	**22**

Cladium jamaicense made up 5% of the total control biomass. All other species accounted for 1% or less of the total biomass.

The increase in abundance of *Eleocharis spp.* was expected because, as an early succession species, it typically has a large seed bank and is capable of quickly colonizing gaps created by disturbance events. This small shift in abundance is probably short-lived because *Eleocharis spp.* is a favorite food of waterfowl and eventually is out-competed by species such as *Panicum hemitomon*, which is capable of rapid lateral growth, high biomass production, and is tolerant to a wide range of water levels. Surprisingly, the vehicle traffic did not appear to have a noticeable effect on *Sagittaria lancifolia*, which made up between 3% and 5% of the live cover and between 2% and 4% of the biomass. I assumed that this species is shade-tolerant because I observed it growing beneath dense mats of *Panicum hemitomon*. Unlike *Panicum hemitomon*, which has a sprawling growth form and spreads laterally by a dense network of rhizomes, *Sagittaria lancifolia* has large, fleshy leaves, and a thick rhizome, which is not conducive to rapid lateral growth into openings created by the 3-D survey disturbance.

No visible pattern of change developed in the floating-leaved aquatic community in response to the vehicle traffic. The abundance of *Nymphaea odorata*, *Brasenia schreberi*, and *Nymphoides aquatica* did not increase following the 3-D survey. This is consistent with observations that vehicle trampling did not cause significant increases in open-water habitat. Another important finding of this study was that the 3-D survey resulted in no measurable increases in invasive species abundance at the LNWR. *Sapium sebiferum* (Chinese tallow-tree), an exotic pest species that is prevalent on spoil banks, and which has spread into portions of the marsh interior following disturbances, was not recorded in treatment or control plots during this investigation. Similarly, *Eichornia crassipes* (water-hyacinth), an

exotic floating species that is common in the canals throughout LNWR, was not observed in the Pool following the 3-D survey. To prevent its spread into the Pool, the seismic survey equipment operators were required to clean the marsh buggies and airboats before they were allowed into the Pool. These precautionary measures likely prevented the spread of this species into interior portions of the Pool.

Live Cover

The traffic effect was significant ($P < 0.0001$), indicating an overall negative effect of vehicle traffic on live cover (Table 4.3) (Figures 4.4 and 4.5). The Site * Traffic interaction was also highly significant, which indicated that there were treatment differences between sites (Table 4.3, Figures 4.4 and 4.5).

The Bonferroni test revealed that baseline cover at Grand Lake (93%) was significantly higher than the Pool (74%) ($P = 0.00003$), Lacassine Bayou (78%) ($P = 0.0019$), and Lakeside Oil Field (76%) ($Pr = 0.0016$) (Table 4.4). Furthermore, the Bonferroni test indicated that live cover after multiple-pass treatments at the Pool was significantly lower than the other sites (See the Equipment*Site*Traffic in Table 4.5).

Statistical differences were not found between the remaining sites. The Statistically-significant Equipment * Site interaction (Table 4.3) indicated that the equipment types affected the sites differently. However, the three-way interaction (Traffic*Equipment*Site effect) was not statistically significant ($P = 0.4701$) (Table 4.3).

The Bonferroni test revealed that single-pass airboat traffic had a significantly greater negative effect on cover at the Pool than at Lacassine Bayou and Lakeside ($P < 0.0001$). Multiple-pass airboat treatment affects were also significantly greater at the Pool than the other three sites (Table 4.5). The equipment types did not have a statistically

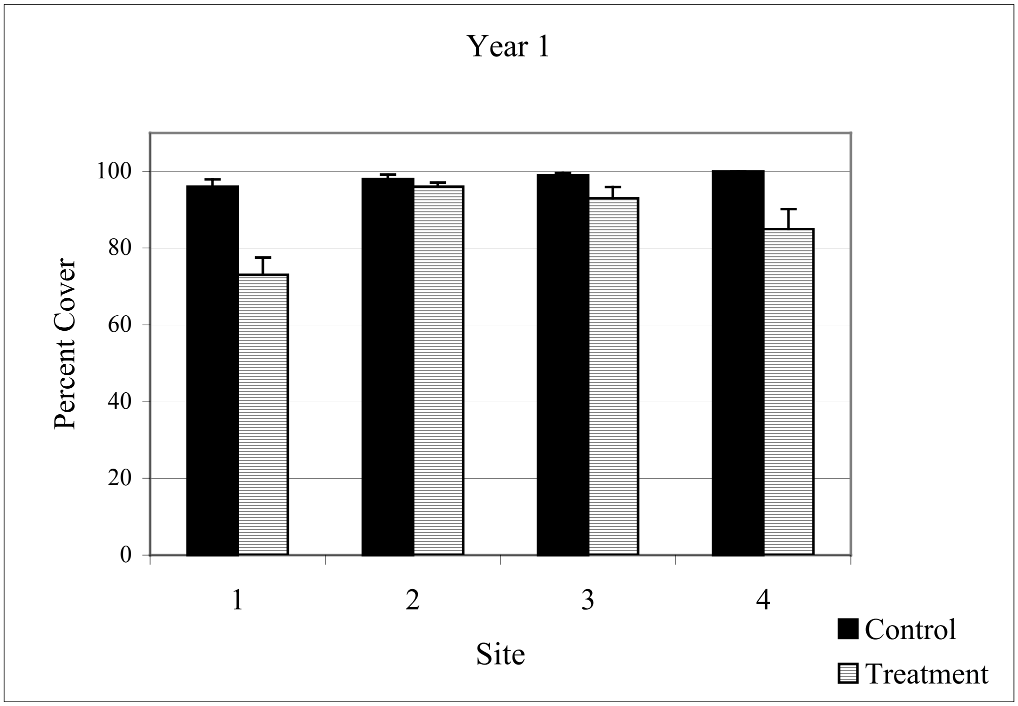


Figure 4.4. Year 1 mean percent live cover in treatment and control plots at study sites used to evaluate the effects of seismic exploration on the plant communities at the Lacassine National Wildlife Refuge. Means with different letters are significant (Bonferroni Test). Site 1 = Pool, Site 2 = Lacassine Bayou, Site 3 = Lakeside Oil Field, and Site 4 = Grand Lake

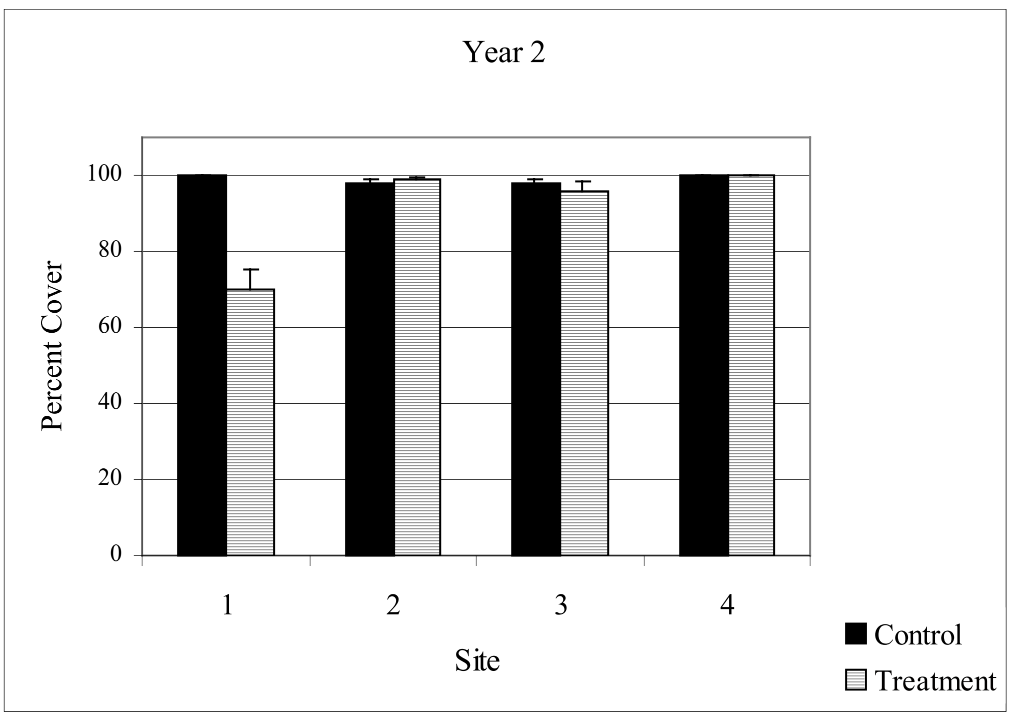


Figure 4.5. Year 2 mean percent live cover in treatment and control plots at study sites used to evaluate the effects of seismic exploration on the plant communities at the Lacassine National Wildlife Refuge. Means with different letters are significant (Bonferroni Test). Site 1 = Pool, Site 2 = Lacassine Bayou, Site 3 = Lakeside Oil Field, and Site 4 = Grand Lake.

Table 4.3. Statistical results from the mixed linear model used to test the hypotheses on live vegetation cover. Note: * indicates statistically significant values and DF = degrees of freedom).

Effect	DF	F Value	Pr > F
Site	3	5.37	0.0015*
Equipment	1	1.45	0.2303
Equipment * Site	3	3.20	0.0249*
Traffic	4	27.30	<0.0001*
Equipment * Traffic	4	0.74	0.5654
Site * Traffic	10	6.71	<0.0001*
Equipment * Site * Traffic	7	0.95	0.4701

significant effect because pairwise comparisons of means of single-pass and multiple-pass airboat treatments were not significantly different.

A closer look at the results of the Bonferroni test revealed interesting differences within sites (Table 4.4). At the Pool, cover was lower for both single-pass ($P < 0.0001$) and multiple-pass treatments ($P = 0.0002$) compared to controls. The multiple-pass marsh buggy + airboat treatment also resulted in statistically lower cover values compared to the controls ($P = 0.0015$). The Bonferroni test indicated no statistical differences between the treatments and controls in the remaining sites.

Live Biomass

The results of the ANOVA indicated no significant overall effects of treatment, site, or equipment on live biomass (Table 4.5). All interactions were non-significant. Eq. 2 is modified to (Eq. 5) $Lbio_{ijkl} = \mu + \varepsilon_{ijkl.}$ Although the interactions were non-significant, I looked further into the results of the Bonferroni test for general patterns.

Table 4.4. Selected results of the mixed procedure differences of least squares means and Bonferroni test for the Site*Treatment interaction and Equipment*Site*Traffic three-way interaction using live percent cover data. Results of pairwise comparisons of percent live cover between sites using baseline data, traffic intensities, and airboats are provided (BL= baseline, EQ = equipment type, TMT = treatment, and DF = degrees of freedom). Adjusted P values were rounded up.

Effect	EQ	Site	TMT	EQ	Site	TMT	Estimate	Standard Error	DF	T Value	Pr > t	Adjusted P
Site*Treatment	NA	Pool	BL	NA	L. Bayou	BL	-3.97	3.76	419	-1.06	0.2920	1
	NA	Pool	BL	NA	Lakeside	BL	-1.97	3.92	419	-0.50	0.6163	1
	NA	Pool	BL	NA	Grand Lake	BL	-19.47	5.37	419	-3.62	0.0003	0.0498
	NA	L. Bayou	BL	NA	Lakeside	BL	1.998	3.33	419	0.60	0.5492	1
	NA	L. Bayou	BL	NA	Grand Lake	BL	-15.51	4.96	419	-3.13	0.0019	0.2900
	NA	Lakeside	BL	NA	Grand Lake	BL	-17.51	5.09	419	-3.44	0.0006	0.0972
	combined	Pool	MP	combined	L. Bayou	MP	-22.59	3.49	419	-6.48	<.0001	<.0001
	combined	Pool	MP	combined	Lakeside	MP	-17.52	4.10	419	-5.14	<.0001	<.0001
	combined	Pool	MP	combined		MP	-17.55	4.10	419	-4.28	<.0001	.0035
Equipment *Site* Traffic	Airboat	Pool	SP	Airboat	Grand Lake	SP	-33.29	4.89	419	-6.8	<.0001	<.0001
	Airboat	Pool	SP	Airboat	Lakeside	SP	-35.02	6.86	419	-5.11	<.0001	0.0003
	Airboat	Pool	MP	Airboat	L. Bayou	MP	-29.87	5.11	419	-5.84	<.0001	<.0001
	Airboat	Pool	MP	Airboat	Lakeside	MP	-24.91	4.81	419	-5.18	<.0001	0.0002
	Airboat	Pool	MP	Airboat	Grand Lake	MP	-23.21	5.73	419	-4.05	<.0001	0.0320

The Bonferroni test revealed several interesting results within sites. The single-pass airboat treatments at the Pool had significantly greater biomass than the controls at that site (Pr = 0.039). Single-pass airboat treatment receiver lines at Lacassine Bayou also had significantly greater biomass compared to the single-pass airboat+marsh buggy shot line treatments at that site (Pr = 0.0153) (Table 4.6).

Dead Biomass

There was a significant difference in dead biomass due to vehicle traffic ($P < 0.0001$). This effect of vehicle traffic was seen across sites for all treatments (Table 4.8). As such, Eq. 3 is modified to (Eq. 6) $Dbio_{ijkl} = \mu_{Dbio} + \delta_l + \varepsilon_{ijkl}$..

The Bonferroni test revealed that significant within-site traffic effects exist between multiple-pass treatments and controls at the Pool and Lakeside (Table 4.8). Single-pass treatments differed significantly from controls in Lacassine Bayou (Table 4.8).

There were no significant site or equipment effects and no other significant interaction effects on dead biomass (Table 4.7). The Bonferroni test on the Equipment*Site*Traffic interaction compared different combinations of equipment and traffic intensities with controls (Table 4.8). The marsh buggy + airboat multiple-pass treatments had significantly less dead biomass than controls at the Pool ($P = 0.0147$) and Grand Lake ($P < 0.0001$). The single-pass marsh buggy + airboat treatment had significantly less dead biomass than controls at Lacassine Bayou ($P = 0.0210$). The multiple-pass airboat treatment differed significantly from the control at Lakeside ($P = 0.0023$)

Species Richness and Community Similarity

Table 4.1 provides a comparison of species present and mean percent live cover for treatments and years. Total species present (richness) was higher in treatment than control plots for both years based on live cover and live biomass data. However, a comparison of

Table 4.5. Statistical results from the mixed linear model used to test the hypotheses on live biomass. Note: * indicates statistically significant values and DF = degrees of freedom).

Effect	DF	F Value	Pr > F
Site	45	1.16	0.3353
Equipment	45	0.34	0.5637
Equipment * Site	45	2.28	0.1138
Traffic	119	0.32	0.8083
Equipment * Traffic	119	0.25	0.8647
Site * Traffic	119	0.85	0.5507
Equipment * Site * Traffic	119	0.63	0.6429

community similarity coefficients (Table 4.9) showed a relatively low degree of similarity in the species encountered in these study plots. Species richness was 9% greater in Year 1 treatment plots than control plots and showed a higher degree of similarity. Correspondingly, Year 2 treatment plots had 14% greater species richness than baseline study plots and a relatively low degree of similarity. Species richness was slightly higher in Year 2 treatment plots than control plots and species in these plots exhibited a relatively low degree of similarity.

Richness and community similarity based on biomass data exhibited a similar pattern with treatment plots having 44% greater richness in Year 2 and relatively low degree of similarity that year (Tables 4.2 and 4.9).

The differences in species richness and community similarity among treatment and control plots do not appear to be significant in terms of the overall plant community. These

Table 4.6. Selected results of the mixed procedure differences of least squares means and Bonferroni test for the Equipment*Site*Traffic interactions using live biomass data. (BL= baseline, EQ = equipment type, TMT = treatment, and DF = degrees of freedom).

Effect	EQ	Site	TMT	EQ	Site	TMT	Estimate	Standard Error	DF	T Value	Pr > t	Adjusted P
Equipment*Site* Traffic	Airboat	Pool	Control	Airboat	Pool	SP	132.9	63.67	119	2.09	0.0390	1
	Airboat	L. Bayou	SP	Airboat/ Marsh buggy	L. Bayou	SP	139.94	56.88	119	2.46	0.0153	1

minor herbaceous species made up a relatively small percentage of the overall plant community and contributed little to the overall community biomass. For instance, in Year 1, species contributed less than 1% each to the overall live biomass. Thirty-one species made up approximately 25% of the total live cover. Likewise, in Year 2, 37 species contributed less than 1% each to the overall live biomass.

This assessment was supported by historical information contained in the Narrative Reports that have been maintained at LNWR since the early 1930s (Chapter 2). These Narrative Reports include summaries of refuge habitat conditions including species composition, water levels, climatic conditions, habitat management practices, and oil and gas activities. These records indicated that numerous human and natural disturbances have resulted in slight changes in abundance of minor species in response to flooding, droughts, grazing, and fire. These changes appeared to be ephemeral except in some instances in the Pool where emergent marsh was converted into ponds by mechanical disturbance and where continuous flooding in the Pool initially reduced the cover of emergent species in favor of floating and submerged aquatic species. These historical records indicate that the plant communities at LNWR are relatively stable despite the refuge's attempts to shift species composition away from the *Panicum hemitomon*-dominated emergent community toward early-successional and submerged aquatic communities. No obvious patterns emerged with respect to community composition shifts as a result of this 3-D survey, and certainly no species exhibits the potential to displace *Panicum hemitomon* as the dominant species.

DISCUSSION

This investigation provides the first quantification of vegetative disturbance to freshwater vegetation caused by vehicle traffic during a 3-D seismic survey in coastal Louisiana. The study was designed to investigate the effects of traffic management on

Table 4.7. Statistical results from the mixed linear model used to test the hypotheses on dead biomass.

Effect	**DF**	**F Value**	
Site	45	1.23	0.3097
Equipment	45	0.61	0.4403
Equipment * Site	45	2.05	0.1409
Traffic	119	11.95	<0.0001*
Equipment * Traffic	119	0.49	0.6875
Site * Traffic	119	0.50	0.8307
Equipment * Site * Traffic	119	0.44	0.7822

Table 4.8. Selected results of the mixed procedure differences of least squares means and Bonferroni test for the Site*Traffic and Equipment*Site*Traffic interactions using dead biomass data. (BL= baseline, EQ = equipment type, TMT = treatment, DF = degrees of freedom, and Adj = adjusted).

Effect	EQ	Site	Tmt.	EQ	Site	Tmt.	Estimate	Standard Error	DF	T Value	Pr > t	Adj P
Site*Traffic	NA	Pool	Control	combined	Pool	MP	96.00	47.01	119	2.04	0.043	1
	NA	L. Bayou	Control	combined	L. Bayou	SP	124.97	51.62	119	2.42	0.017	1
	NA	Lakeside	Control	combined	Lakeside	MP	170.33	54.61	119	3.12	0.0023	0.2073
Equipment*Site* Traffic	NA	Pool	Control	Marsh buggy/airboat	Pool	MP	133.76	54.05	119	2.47	0.0147	1
	NA	Grand Lake	Control	Marsh buggy/airboat	Grand Lake	MP	155.83	35.87	119	4.34	<.0001	0.0082
		Lakeside	Control	Airboat	Lakeside	MP	196.24	70.01	119	2.69	0.0082	1

Table 4.9. Comparison of Sorensen community similarity coefficients among baseline, treatment,and control transects based on percent cover and biomass data.

Comparison	Coefficient
Baseline vs Y1T (cover)	0.69
Baseline vs Y2T (cover)	0.65
Y1T vs Y1C (cover)	0.83
Y2T vs Y2C (cover)	0.79
Y1T vs Y1C (biomass)	0.72
Y2T vs Y2C (biomass)	0.26

overall disturbance and to compare the effects of different equipment types across a range of habitat conditions present at the LNWR. The overall goal of the LNWR at the onset of the 3-D survey was to minimize disturbance on the refuge while allowing the geophysical company to collect the data needed to explore petroleum resources in the area. Although oil and gas exploration has been present on the refuge since the 1940s, 3-D survey technology is relatively new and presents many new management challenges. The shear magnitude of a 3-D seismic operation in terms of the number of airboats, equipment operators, density of survey lines, logistical and environmental constraints such as access and water levels, present land managers with many challenges on how to best regulate these activities while allowing industry to acquire quality geophysical data. Public and private landowners are cognizant of the destructive capabilities of buggies and airboats on the marsh because of widespread historical evidence throughout coastal Louisiana. Ruts caused by buggies can be seen from the air or on aerial photographs in almost any given area where oil and gas exploration, production, or transmission occurs. Many of these ruts have turned into distinct waterways or have eroded completely (Whitehurst et al. 1977; Sikora et al. 1983). The USFWS has managed oil and gas activities at the LNWR since the 1940s, and numerous seismic surveys have been conducted there during that time. Damages caused by marsh

buggy use during these surveys have been documented with photographs and described in the Narrative Reports maintained at the LNWR headquarters (U.S. Fish and Wildlife Service 1943; U.S. Fish and Wildlife Service 1978; U.S. Fish and Wildlife Service 1981). These damages eventually led to the USFWS temporarily banning the use of marsh buggies during seismic surveys in 1957 (U.S. Fish and Wildlife Service 1957).

The minerals beneath many state and federal lands in coastal Louisiana, including the LNWR, are privately owned. This entitles oil and gas companies with the legal right to explore for these resources. It is therefore important for public and private landowners and/or managers to obtain as much information as possible on how to best manage these activities to reduce overall disturbance. The overall results of this study suggest that the South Thornwell 3-D seismic survey may have minimal long-term adverse impacts to the vegetation at the LNWR. Disturbance was minimized by restrictions placed on the seismic company in terms of equipment used, number of vehicle passes, and timing. Furthermore, oversight was provided by experienced biological monitors who had the authority to make logistical changes in the field based on marsh conditions. Unsupervised exploration can result in significant damage to the marsh that may never recover. Several interesting findings of study warrant further discussion.

Significant reduction in live cover occurred only in the Pool. Live cover in the other three sites was not significantly affected, regardless of vehicle type and traffic level. These results were generally consistent with recent studies by and Mendelssohn et al. (1997) and Wilson et al. (1998). Mendelssohn et al. (1997) found no residual impacts on fresh marsh vegetation at Delta National Wildlife Refuge two years following an intensive oil spill clean-up effort in which airboats were used intensively. Wilson et al. (1998) reported similar results following a seismic survey nearby in a brackish marsh at Rockefeller Wildlife

Refuge. Receiver lines in his investigation were subjected to 114 to 118 airboat passes and shot lines subjected to 30 to 45 airboat passes and one marsh buggy pass.

The habitat conditions at the Pool were dramatically different from the conditions at the other three sites. The lower cover values recorded at the Pool could be the result of a combination of factors, including sampling bias associated with the fragmented nature of this marsh, mobility of some of the floating marsh islands, water levels, and susceptibility of the organic soils in the Pool to compaction caused by vehicle traffic.

The amount of live biomass was not significantly affected by vehicle traffic. It was only slightly higher in control plots than treatment plots in both years. The different statistical results obtained for live cover and live biomass likely occurred because of the larger sample size for live cover, which would allow for the detection of smaller differences in live cover in treatment and control plots.

The amount of dead biomass was significantly lower in treatment compared to control plots. Schemnitz and Schortemeyer (1973) found similar results in a controlled experiment in the Florida Everglades where airboats and marsh buggies operated at different speeds and intensities across vegetative transects. In three out of four of their study plots, the weight of live biomass in airboat plots did not significantly differ from biomass at control sites.

Panicum hemitomon was crushed and matted on the shot and receiver lines throughout most of the study area because of vehicle traffic. The rhizomes did not appear to be damaged regardless of traffic levels. Any reduction in live biomass because of the mechanical damage was probably offset by the secondary effects of the mechanical disturbance to the dense mat of live and dead plant material. By reducing the canopy,

especially the dead portion, more resources became available to the existing plants for re-growth and for colonization by species represented in the seed bank.

In the field, disturbed areas appeared to have had less biomass than undisturbed areas, although this was not obvious in the samples. The undisturbed areas were barely penetrable on foot because of the dense stands of *Panicum hemitomon*. These stands contained live and dead plant material. The canopy in the disturbed areas was lower and less dense.

The reduced dead biomass found in the treatment plots of this study most likely resulted from increased decomposition rates at disturbed sites. This increased decomposition would also lead to increased regeneration of nutrients available for plant uptake that would compensate for stresses placed on the vegetation associated with the 3-D survey.

The higher species richness and reduced dominance of *Panicum hemitomon* in treatment plots relative to control plots was anticipated. Small-scale disturbances associated with the 3-D survey increased spatial heterogeneity and provided conditions favorable for the propagation of a variety of early succession species, most notably *Eleocharis spp*. The level of disturbance caused by vehicle trampling reduced dominant plant cover, which appeared to decrease single species competitive dominance over space, sunlight, and nutrients. These findings support the intermediate disturbance hypothesis proposed by Connell (1978), which predicts that highest species richness is maintained at intermediate levels of disturbance because competitively superior species are more susceptible to disturbance, which allows the coexistence of competitively inferior colonizing species. I anticipate that these effects will be short-lived, and that colonizer species such as *Eleocharis spp.*, and *Bacopa coroliniana*, will be readily consumed by waterfowl and replaced by *Panicum hemitomon* within several years. The anticipated outcome may have been less

favorable if the vehicles had caused ruts and damaged the root mat as seen in other cases across coastal Louisiana (Bass 1997; Sikora et al. 1983; U.S. Fish and Wildlife Service 1943; U.S. Fish and Wildlife Service 1978; U.S. Fish and Wildlife Service 1981; Whitehurst et al. 1977).

In a study at Sabine National Wildlife Refuge, Nidecker et al. (1993) found only one incident of significant changes in species composition as a result of a 3-D survey when *Eleocharis spp*. invaded disturbed areas. In that study, the dominant species were infrequently replaced by less dominant species because of the seismic-related disturbance and, overall, airboat traffic had little effect on *Spartina patens* occurrence. They did report severe impacts to vegetation in frequently traveled access routes. Wilson et al. (1998) found no long-term effects of seismic activity on *Spartina patens*, but did find short-term increases in *Cyperus oderatus* the first year following a 3-D survey at Rockefeller Refuge in Cameron Parish, Louisiana. Duever et al. (1981) reported that species composition changed by the addition or loss of at least one dominant species in medium and heavily impacted plots in a study of off-road vehicle impacts in the Big Cypress National Preserve in Florida. However, they found virtually no species composition change in the airboat treatment plots.

The low species similarity between treatment and control plots in Year 2 possibly indicates a delayed response of colonizer species such as *Eleocharis spp.* and *Ludwigia spp.* to the disturbance. The increase in colonizer species abundance simultaneously with the increase in *Panicum hemitomon* abundance possibly indicates coexistence among these species despite the obvious competitive advantage possessed *by Panicum hemitomon*.

Panicum hemitomon, the dominant herbaceous species on the Refuge, formed dense stands of live and dead plant material. The stems flattened into a dense mat on the marsh

surface when run over by either a marsh buggy or an airboat. This acted as a protective layer that allowed the equipment to pass without disturbing the soil.

Several operational factors associated with the South Thornwell 3-D survey helped to minimize impacts of 3-D seismic activities. In particular, the biological monitors closely supervised the equipment operators and enforced the conditions established in the special use permit. Furthermore, technological advances in geophysical data gathering equipment and helicopter transportation led to significant reductions in airboat passes. A similar 3-D survey at Rockefeller Wildlife Refuge in 1995 required 30-45 passes on shot lines and 114-118 passes on receiver lines, compared to approximately 6 passes on shot lines and 6-12 passes on receiver lines required in this project.

CONCLUSIONS

Vegetation at four independent study sites was intensively sampled prior to disturbance in the summer of 1997, and annually thereafter for two consecutive years.

The following findings are based on this study:

- Vegetative cover was significantly reduced by equipment traffic, but live biomass was not significantly reduced.
- The effects of traffic on percent cover were consistent at three of the four study sites.
- There were no significant effects of traffic on biomass among the study sites.
- Dead biomass was significantly lower in treatment plots.
- There was no overall significant traffic effect. Single-pass treatments did not create significantly less disturbance in terms of percent cover and live biomass than multiple-pass treatments.
- Equipment type did not have a significant effect on either percent cover or live biomass.
- Species richness ranged 10 to 45% higher in treatment than control plots.

In conclusion, the South Thornwell 3-D Seismic Survey at Lacassine National Wildlife Refuge probably represents a best-case scenario in terms of pre-project planning, monitoring, equipment selection, and communication. Potential disturbances were reduced by oversight by refuge personnel, and also by equipment selection and operation by the contractors. These findings are specific to LNWR and should not be interpreted to be representative other marsh types. Significantly different results are likely in other less resilient marshes, especially fragmented saline and brackish marshes found in the Mississippi Deltaic Plain. Further research is needed in these marsh types because seismic surveys are conducted extensively in all areas of coastal Louisiana. Most importantly, the results of this study should not be applied to seismic surveys conducted on private land where operational guidelines are not established and where trained personnel do not provide biological oversight.

Recent improvements to vehicle design, and technological advances in geophysical data gathering equipment have resulted in reduced impacts on the marsh. Lightweight aluminum marsh buggies have replaced the heavy steel buggies and wheeled vehicles used in the past. Improvements made to seismic data gathering equipment have reduced traffic along seismic lines.

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CHAPTER 5

MINIMIZING ENVIRONMENTAL DISTURBANCES ASSOCIATED WITH 3-D SEISMIC SURVEYS IN COASTAL MARSHES

INTRODUCTION

Background

The coastal wetlands bordering the northern Gulf of Mexico are ecologically and economically some of the most productive ecosystems in the world. They serve as nursery grounds and critical habitat for many wildlife species, including wintering grounds for migratory waterfowl; provide a buffer from flooding, winds, and waves associated with hurricanes and tropical storms; support commercial and recreational fisheries; and provide improved water quality by filtering sediment, nutrients, and chemical pollutants from the water. Underlying this fragile marshland are vast quantities of hydrocarbons that make this area one of the richest oil and gas regions in the United States. With the increase in petroleum exploration activity in the 1990's, a management challenge has been to explore for, and develop, these subterranean resources without damaging the surface features that make this area so ecologically productive. The purpose of this chapter is to provide a general overview of 3-D seismic survey programs, potential impacts, and management strategies to be used by private landowners, wetland managers, agency field investigators, and industry to effectively reduce disturbances caused by 3-D seismic survey operations in coastal wetlands. Information contained in this chapter has come from numerous sources, including personal interviews, field investigations, controlled field experiments, private consulting experience, and literature reviews. Sources of professional experience include: Louisiana Department of Wildlife and Fisheries (LDWF), private land managers, U.S. Fish and Wildlife Service (USFWS) Refuge Managers and Biologists, equipment manufacturers, seismic service contractors, Louisiana Department of Natural Resources (LDNR), and third-party biological monitors.

The objectives of this chapter are to:

- Provide a general overview of seismic survey technology and typical 3-D survey procedures;
- Identify potential disturbances to coastal wetlands;
- Discuss strategies to minimize disturbances;
- Review state and federal environmental regulations pertaining to seismic activities in Louisiana, Alabama, and Texas; and
- Identify restoration strategies.

Overview of Seismic Survey Technology

Seismic surveys have been used for oil and gas exploration since the 1950s. Prior to the 1980s, most of the seismic surveys were two-dimensional (2-D). A typical 2-D survey consisted of the following procedures: a survey crew would mark the shot points using a marsh buggy for transportation. A drilling crew would then use a marsh buggy to travel down the line, often towing a steel sled containing the drilling rig and receiving equipment. After the shot holes were drilled, a shot crew would travel down the same line again detonating the charges and collecting data. After the charges had been detonated, a clean-up crew would then make another trip down the same line in a marsh buggy to pick up the recording equipment. Four passes down a single line by a heavy buggy (once towing a sled) resulted in scars on the marsh that are still visible today (Figure 5.1).

The first three-dimensional (3-D) survey was conducted in Louisiana in 1980. An increased public awareness of the value of coastal wetlands and the need for greater efficiency in seismic operations prompted technological advances in vehicle design and 3-D survey technology. Older steel buggies were replaced with light-weight aluminum models

(Figures 5.2 and 5.3). These new models were much lighter, had wider tracks, exerted much less ground pressure, and could be equipped with a drilling rig, which eliminated the need for pull sleds. Large airboats equipped with drilling rigs and powered by two engines were developed for use in shallow water areas (Figure 5.4).

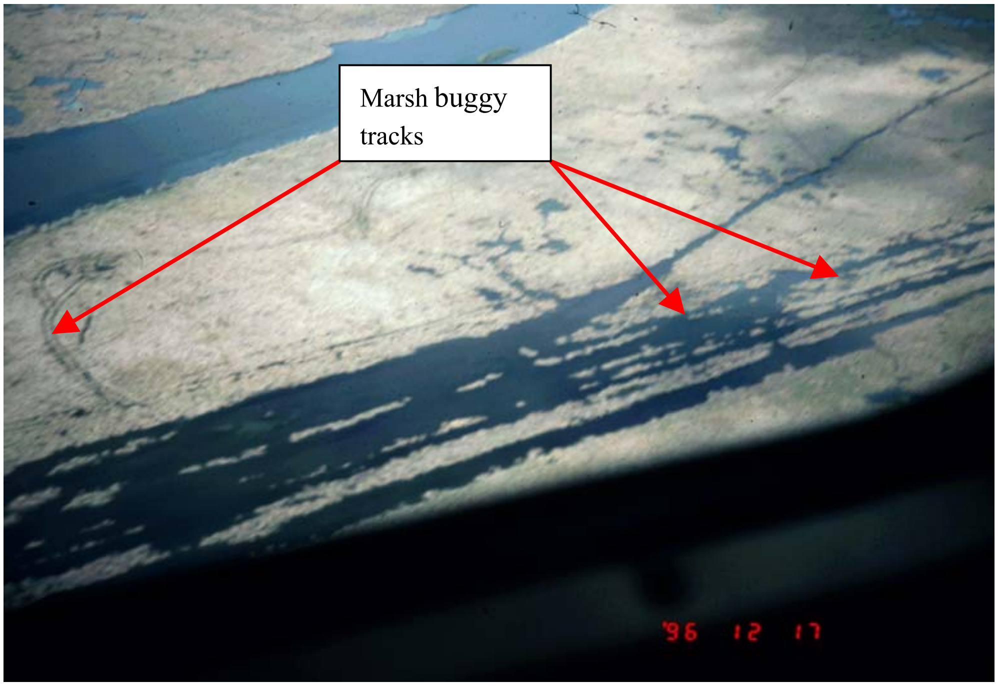

Figure 5.1. Marsh buggy tracks in a brackish marsh in Lafourche Parish, Louisiana (photograph by Aaron Bass).

Three-Dimensional Surveys.

Standard 3-D seismic surveys involve similar activities used in 2-D surveys: surveying, drilling shot holes, laying out receiving equipment, and recording. The primary differences between 2-D and 3-D surveys are in the coverage, quality of data obtained, and surface area affected.

Figure 5.2. Steel marsh buggy equipped with drilling equipment (left) and swamp buggy (right) (photograph by Aaron Bass).

Figure 5.3. A lightweight aluminum marsh buggy at a manufacturing facility in Houma, Louisiana (photograph by Aaron Bass).

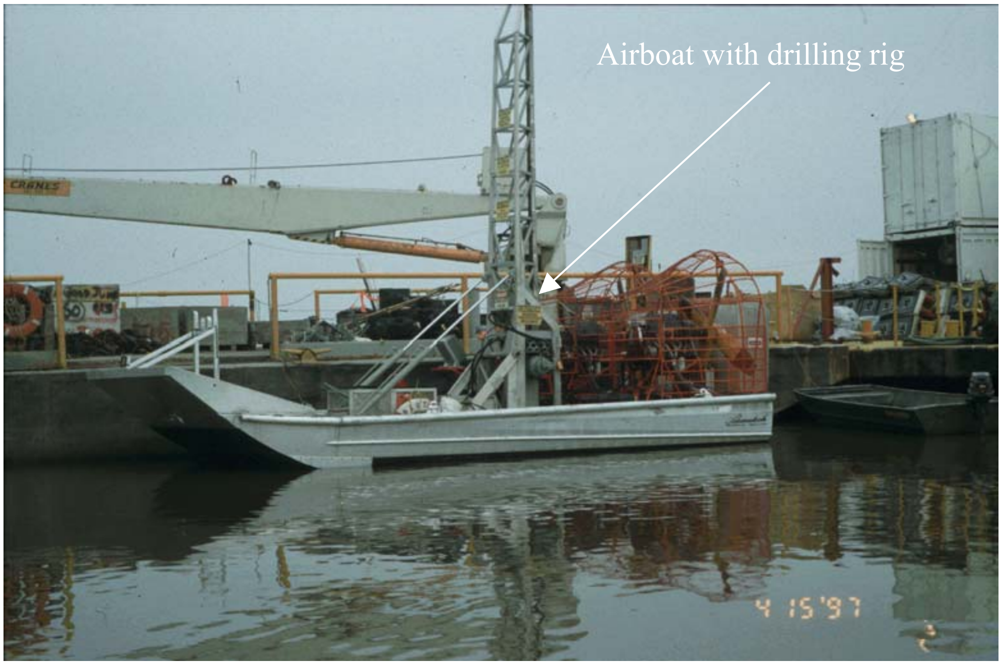

Figure 5.4. An airboat equipped with two engines and a drilling rig (photograph compliments of the Louisiana Department of Wildlife and Fisheries).

Cross-array field designs are used for land surveys. These designs resemble a checkerboard pattern and consist of shot and receiver lines generally oriented north/south and east/west, respectively. Three primary types of cross-array patterns exist: perpendicular, brick, and diagonal patterns. The perpendicular pattern consists of receiver lines running east/west at approximately 667 meters apart, and source lines running perpendicular to the receiver lines at approximately 667 meters apart (Figure 5.5). Shot holes are drilled approximately 100 meters apart along the source lines and receiver stations are placed approximately 67 meters apart along receiver lines. The brick pattern consists of receiver lines running east/west at approximately 545 meters apart and source lines running north/south at approximately 485 meters apart (Figure 5.6). Shot holes are drilled approximately 61–133 meters apart along the shot lines and receiver stations are also placed approximately 61–67 meters apart along the receiver lines. The diagonal pattern, which is similar to the perpendicular pattern with source lines oriented at approximately forty-five

degree angles to the receiver line, is often used in sensitive habitats because it reduces the number of vehicle turns, thus reducing impact to the environment.

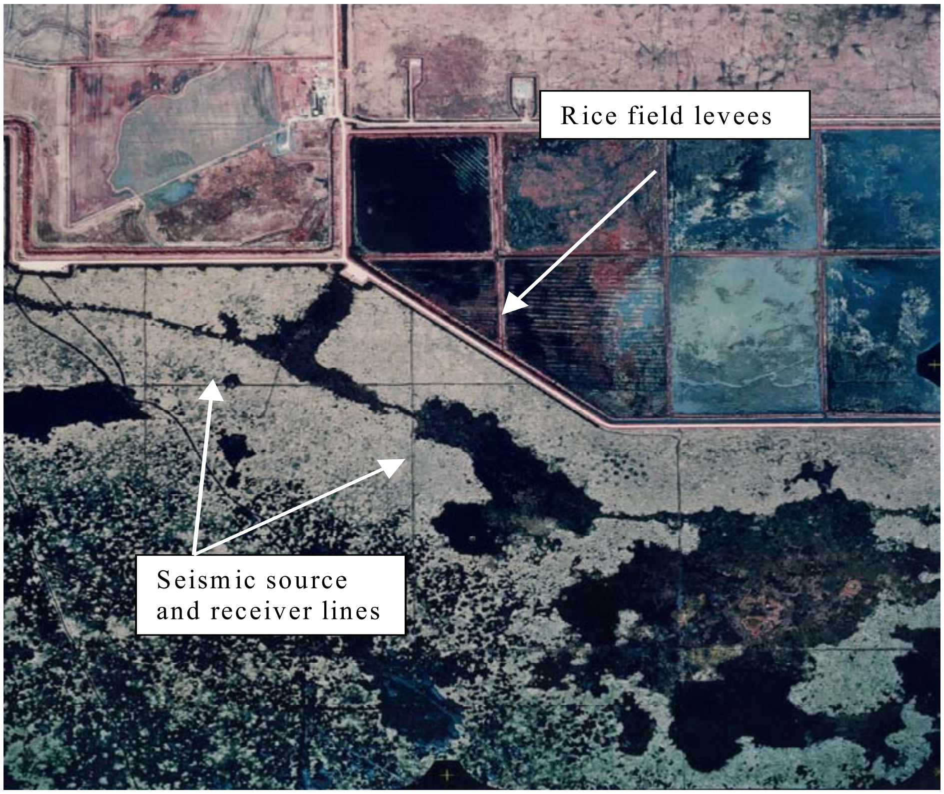

Figure 5.5. Aerial photograph of a perpendicular seismic pattern used at Lacassine National Wildlife Refuge near Lake Arthur, Louisiana. The red arrows indicate the source and receiver lines (photograph by the Louisiana Geological Survey).

The equipment used to conduct these surveys varies, depending on environmental conditions. Marsh buggies or airboat drills are normally used to drill shot holes (Figure 5.7). Airboats are used to service receiver stations (Figure 5.8).

Data can be processed to produce a three-dimensional representation of subsurface structure by analysis of information on numerous axes or directions. In contrast to 2-D seismic surveys, 3-D technology provides high-resolution data that is ideal for locating and computing the volumes of structural features such as faults and potential hydrocarbon-bearing zones. 3-D techniques greatly enhance the subsurface imaging.

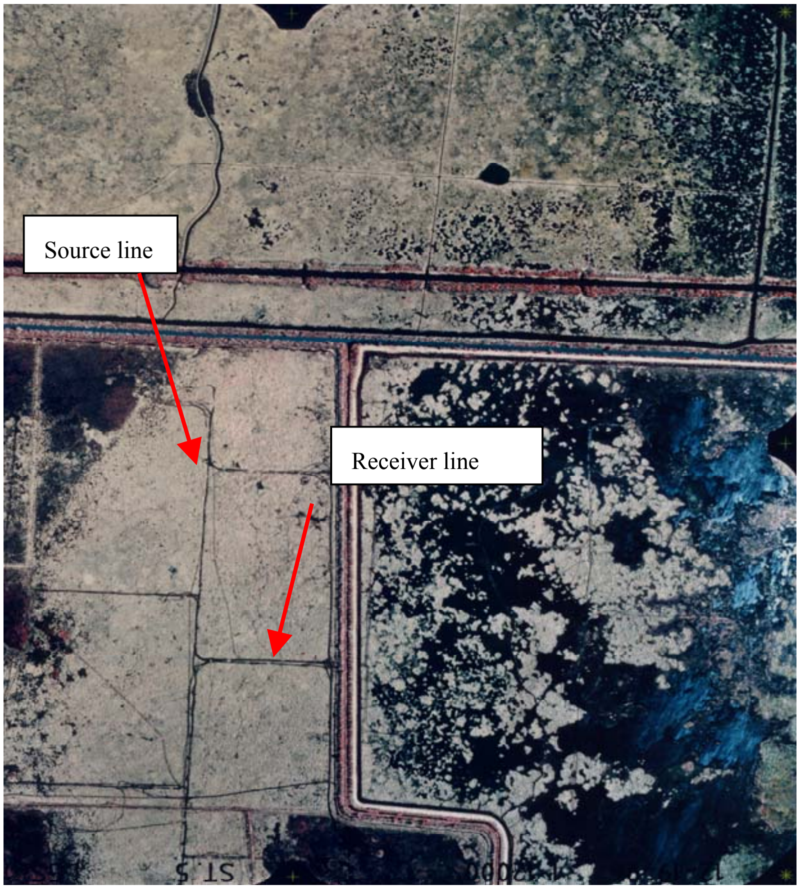

Figure 5.6. Aerial photograph of a brick seismic pattern used at Cameron Prairie National Wildlife Refuge near Cameron, Louisiana. The red arrows indicate the source and receiver lines (photograph from the Louisiana Geological Survey).

With the development of 3-D technology, petroleum geologists are able to find previously hidden resources, and are able to increase the precision of drilling, thus potentially reducing surface impacts. Fields previously thought depleted, or not economically feasible to develop further, have been reopened to exploration and production by using the data from 3-D seismic surveys. Because of these improvements, the risks associated with dry holes have been reduced.

Figure 5.7. A marsh buggy equipped with a drilling rig used to drill shot holes for a seismic survey (photograph by Aaron Bass).

Figure 5.8. Typical airboats used to transport personnel and equipment during a seismic survey (photograph by the Louisiana Department for Wildlife and Fisheries).

Typical 3-D seismic surveys are conducted in three phases: surveying, drilling, and recording. These activities are carried out simultaneously throughout the duration of the survey. Shot holes and receiver points are located during the surveying phase. In the drilling phase, shot holes are drilled and loaded with explosive charges. Recording equipment is deployed next, then charges are detonated, and the reflected energy is recorded.

<u>3-D Survey Procedures</u>

Surveying Phase

The initial survey begins by locating and flagging shot holes and receiver points using a Global Positioning System (GPS) (Figure 5.9). Shot hole and receiver locations are marked with cane poles and biodegradable flagging. The cane poles, flagging, and any other debris are typically removed when receiver lines are extracted.

Drilling Phase

The shot hole drilling crew follows the survey crew. One airboat or marsh buggy equipped with a drill is accompanied by a separate supply airboat. If surface water is not available, pumps may be used to collect water for drilling. The explosive is typically placed approximately 30 meters below the surface.

Recording Phase

After drilling personnel have completed the shot holes, the receiving crew deploys geophones (receivers) and cables according to the grid pattern. The recording instruments, battery charging generators and antennae are normally located on a barge or other facility located nearby.

Figure 5.9. Cane pole marking a shot hole location in a seismic survey spread (photograph by Aaron Bass).

POTENTIAL DISTURBANCES TO COASTAL WETLANDS

Disturbances resulting from 3-D seismic surveys are normally associated with vehicle traffic. Three resources are affected by marsh buggy and airboat traffic in vegetated wetlands: marsh soils, aquatic vegetation, and hydrology. The direct and secondary impacts are all related to one another. Table 5.1 summarizes the potential impacts caused by airboats and marsh buggies in coastal marshes.

Soil

The direct impacts to soil include rutting and compaction. Rutting can be a severe impact if the soil never recovers fully or leads to other problems such as altered hydrology, which can impact vegetation (Figure 5.10). Proper equipment selection, effective project planning, biological monitoring, and company practices can reduce the adverse impacts such as rutting and soil compaction. This is accomplished by matching the equipment used with

Table 5.1. Impacts associated with airboats and marsh buggies in coastal marshes.

Impact	Source
Mat break-up	U.S. Fish and Wildlife Service (1983); Chabreck (1958) (Figure 5.1)
Pop-ups	U.S. Fish and Wildlife Service (1978); Furman (1996); Bass (1997)
Rutting	U.S. Fish and Wildlife Service (1978); Bass (1997); (Figures 5.1, 5.10 and 5.11)
Altered hydrology	U.S. Fish and Wildlife Service (1981); Chabreck (1994) (Figures 5.1, 5.10 and 5.11).
Bank erosion	Chabreck (1994)
Vegetative cover	Bass (2001) (Figures 5.1, 5.10 and 5.11)
Vegetative species composition	U.S. Fish and Wildlife Service (1943); U.S. Fish and Wildlife Service (1978); Wilson et al. (1998); Bass (2001) (Figure 5.12)
Standing litter	Bass (2001)
Introduction and spread of exotic species	U.S. Fish and Wildlife Service (1981)

the site-specific habitat conditions, identifying sensitive areas and adjusting travel routes accordingly, and using 3-D seismic technology that reduces the amount of traffic necessary. Examples of effectively managed seismic programs are often found on U.S. Fish and Wildlife Service (USFWS) National Wildlife Refuges because of the long history of managing oil and gas activities and the heightened environmental sensitivity in these areas. Each USFWS refuge regulates seismic activities through specific conditions outlined in the Special Use Permit. Figure 5.10 shows an example of an instance where a marsh buggy caused significant rutting.

Most of the controlled field studies of seismic survey impacts have been conducted in the Chenier Plain of southwestern Louisiana, where the potential for soil rutting is less than

it is in the Deltaic Plain. Chabreck (1994) reported no evidence of rutting caused by airboats and found soil rutting associated with marsh buggies in only four out of the 21 sites inspected at the Sabine National Wildlife Refuge (NWR). Bass (1997) reported moderate compaction on some shot lines at Cameron Prairie NWR and insignificant levels at Lacassine NWR. Hess (1998) also reported no significant soil compaction at Rockefeller Refuge. Rutting and soil compaction can be reduced by minimizing the frequency of vehicle passes along shot and receiver lines, minimizing turns, using lightweight vehicles, and using helicopters to transport equipment. When a marsh buggy turns, one of the tracks spins and the other track remains in place. This often tears the marsh surface, leaving permanent scars (Figure 5.6).

Aquatic Vegetation

Damage to live vegetation can affect height, cover, standing litter, and species composition. Biologists at Sabine NWR reported the rapid re-growth of vegetation along airboat trails following a 3-D seismic survey. Bass (1997) reported that the vegetative cover was > 80% on shot and receiver lines after one growing season following 3-D seismic surveys at Cameron Prairie NWR and at Lacassine NWR. Chabreck (1994) reported significant growth of emergent vegetation compressed by airboats and/or marsh buggies at Sabine NWR. Chabreck (1994) also reported that the submergent vegetation was moderately impacted on access routes and receiver shot point lines, but that it was almost completely recovered during a non-growing season.

Hydrology

Hydrologic alterations also impact vegetation when new pathways for tidal exchange occur and result in stress due to increased scouring, salinity, and ponding. Hydrologic

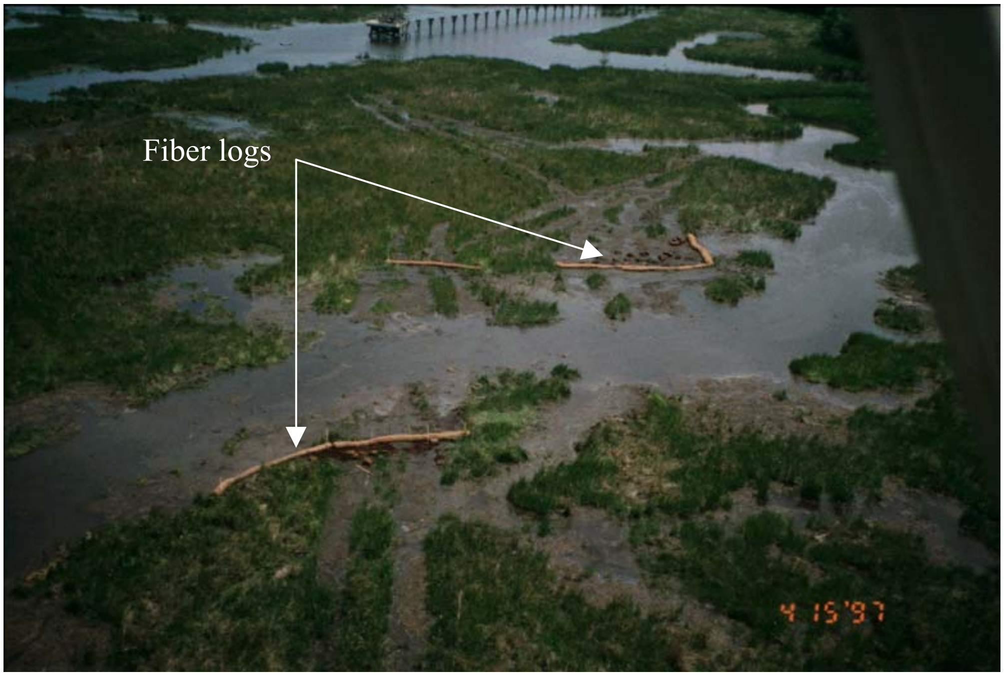

Figure 5.10. Marsh buggy ruts in a brackish marsh near Lake Salvadore in Jefferson Parish, Louisiana. The arrows point to fiber logs that are used to restore the ruts (Photograph by Aaron Bass).

modifications include direct effects due to erosion, channel modification and damage to hydrologic barriers, such as natural levees or berms (Figure 5.11). Repeated travel or rutting may lead to altered sheet flow and drainage patterns, which can increase ponding and effect sediment distributions to the interior marsh. Chabreck (1994) reported that there was a short-term temporary deepening of channels due to airboat traffic, but anticipated that this would be offset by organic matter production and inorganic matter deposition. He also reported bank erosion along canals where vegetation was not present. This erosion was limited to areas of high wave action where natural erosion was already occurring. Water quality may be affected by increased turbidity in areas where repeated travel occurred. Biologists at Sabine NWR assessed the effects of 3-D seismic surveys on turbidity and found increased turbidity to be a temporary and local impact (Nidecker et al. 1993). Altered hydrology may

also result in the spread of exotic species. Lacassine NWR (1983) documented that boat trenches created by hunters altered the local marsh hydrology by causing it to drain more rapidly. This resulted in the rapid spread of Chinese tallow-tree (*Sapium sebiferum*), an unwelcome exotic tree species.

Figure 5.11. Impact to a spoil bank caused by excessive airboat traffic during a seismic survey (photograph by Aaron Bass).

Other impacts include the introduction of exotic species via equipment transfer and floating organic mat formation (pop-ups) resulting from the mechanical disturbance to organic matter on the bottom of ponds (Figure 5.12). Impounded marshes are especially susceptible to introductions of exotic species such as *Lemna minor* (duckweed) and *Eichhornia crassipes* (water hyacinth). Survey crews are often required to wash equipment prior to entering impoundments on National Wildlife Refuges. Biologists at Lacassine NWR first documented pop-ups in 1953 and attributed them to marsh buggy disturbance in 1978 (Lacassine NWR 1978). They hypothesized that gas from decomposing plant matter

causes the organic matter to become buoyant. When disturbed, the organic matter, which is held together by live plant roots, floats to the surface and is colonized by *Eleocharis spp.* (spike rush). Bass (1997) and Furman (1996) also documented pop-up formation at Lacassine NWR because of marsh buggy disturbance. Anecdotal evidence suggests that they remain floating and eventually become colonized by other plant species.

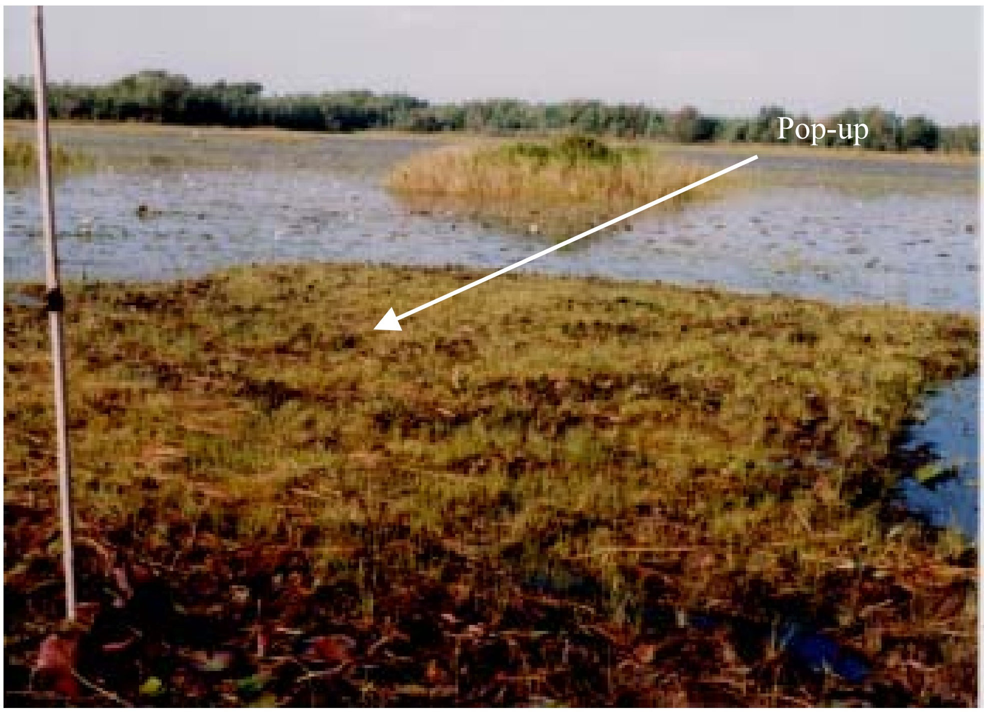

Figure 5.12. Floating mat of organic matter (pop-up) caused by disturbance to the bottom of a shallow marsh pond by a marsh buggy during a seismic survey (photograph compliments of Lacassine National Wildlife Refuge).

MINIMIZING IMPACTS

Strategies that can be implemented to minimize disturbance caused by 3-D seismic surveys include project planning and coordination, project design, timing, equipment selection, and operation and oversight.

Planning and Coordination

Data available to assist in project planning include: historical aerial photography, United States Geological Survey (USGS) habitat change maps (specific to coastal Louisiana), and soil surveys published by the Natural Resources Conservation Service (NRCS).

Pre-survey and post-survey aerial photography of the affected area is required by LDNR as a condition of the Coastal Use Permit (CUP). Pre-existing damages in the project area should be identified. Aerial photographs are also useful in identifying sensitive areas such as actively eroding shorelines, stressed vegetation, hydrologic patterns, alternate access routes, and past disturbance events. The soil surveys provide soil maps, soil descriptions including soil weight-bearing tolerances. Tidal predictions are extremely helpful when planning the various elements of the survey. Based on the equipment selected and habitat conditions, peak high tide events should be targeted if airboats are being used to survey and drill shot holes.

Aerial and ground reconnaissance should be conducted to further document existing marsh damages, identify areas susceptible to disturbances by vehicles such as floating mats, fragmented marsh, undercut shorelines, and natural hydrological barriers. A Global Positioning System (GPS) is especially useful in mapping the exact locations of the features identified in the field. The coordinates of these features can be transferred to the survey contractor to be added to the database and included on the survey maps and used to design offsets where feasible.

Coordination and Project Design

A critical step to minimize the damages to sensitive habitats is early coordination between the geophysicist(s) developing the seismic layout pattern and an ecologist, landowner, or manager familiar with specific features on the property being surveyed. Early detection of sensitive areas, access routes, existing coastal restoration projects, and cultural resources can save time and money spent revising the seismic pattern. Maximizing flexibility in project design and tolerance to offsets allows the project to be designed around and avoid sensitive areas.

Sensitive areas can be avoided by offsetting the source and receiver locations and placing them in open water. Offsetting is frequently done to avoid wading bird rookeries, bald eagle nest sites, archaeological sites, and fragile marsh areas. Offsetting was used during a survey at Bayou Sauvage NWR at the request of the Refuge Manager because a sensitive area, susceptible to mechanical disturbance, was identified. As a condition of the Special Use Permit, the US Fish and Wildlife Service required that all shot holes within the refuge boundary be offset to open water bodies, when possible. They required that attempts be made to offset 75 to 80 percent of the shot holes into open water, with a minimum of 50 percent being offset.

Different seismic patterns may also cause a difference in the amount of disturbance. For perpendicular and slant patterns, vehicles can travel along a line from start to finish without turning, which minimizes disturbance (Figure 5.5). The brick pattern has parallel receiver lines with shot lines staggered between them. The marsh buggy used to drill the shot holes requires many turns, which tears the marsh turf (Figure 5.6).

Logistical planning is important to reducing impacts. If the project is in a remote area and a quarter boat is used, it should be located in an area that is easily accessible by open water. The quarter boat is the headquarters for the seismic operations and contains living quarters, field offices, and equipment storage and repair areas. A place to park a large number of airboats is required. Ideal areas are often spoil banks or natural levee ridges because they generally have firm substrate and are less susceptible to rutting. This area will receive the most traffic and is most susceptible to long-term damage (Figure 5.13).

Figure 5.13. Airboat parking area near a seismic survey field headquarters in a brackish marsh in Terrebonne Parish, Louisiana (photograph by Aaron Bass).

<u>Timing</u>

Consideration should also be given to the timing of the survey. Substantial seasonal differences in water levels occur as a result of tides and weather patterns. If seismic surveys are conducted in the fall, then the timing for vegetative recovery may be prolonged due to the winter dormant season and increase the marsh's susceptibility to erosion and invasion by

exotic species. Seasonal migratory waterfowl patterns should also be taken into consideration because many federal and state wildlife refuges prohibit seismic activity between October and March.

Equipment Selection

Equipment selection should be based on water levels, vegetation, and soil conditions. In the relatively firm, fresh marshes dominated by *Panicum hemitomon* (maidencane) found in many parts of the Louisiana Chenier Plain, lightweight aluminum marsh buggies have been shown to cause less disturbance during survey and drilling operations than heavier equipment. Extreme care should be taken when operating in fragmented brackish or salt marshes dominated by *Spartina patens* (wiregrass). The clumpy growth forms of this vegetation make the substrate especially susceptible to damage, although it is often hard to detect where damages have occurred. Floating mats, typically found in fresh marshes, are resilient to disturbances if the root mats are kept intact, especially in impounded marshes (Bass 2001). Severing the root mat of floating marsh can lead to large scale wetland losses, such as those reported by Chabreck (1958) at Marsh Island, Louisiana, and Lacassine NWR (1983). Chabreck (1958) reported large areas of wetland loss following Hurricane Audrey where marsh buggies severed the root mat. Lacassine NWR (1983) reported that several hundred acres of *Alternanthera pholoxeroides* (alligatorweed) floating mat severed by marsh buggy tracks were“washed away” following a large storm event.

Helicopters have been used on seismic surveys since the 1950s to transport equipment and explosives around the project location. Their use reduces the need for airboat passes along receiver lines. Radio telemetry systems also greatly reduce airboat passes along the receiver lines. Older recording devices require constant maintenance such

as battery recharging, and the data must be downloaded daily. Newer systems can transmit the data by radio signal to a central location, eliminating the need to service recorders once they are deployed. This improvement has reduced airboat passes from over 100 passes to 10 or 12 passes along a given line.

<u>Oversight</u>

Third-party biological monitors have been successfully used to provide enforcement and oversight during 3-D surveys on Louisiana Department of Wildlife and Fisheries Wildlife Management Areas (WMAs) and US Fish and Wildlife Refuges in Louisiana. Figure 5.14 is an aerial photograph of federal wildlife refuge and adjacent private land in southwest Louisiana. The photograph shows considerably more ancillary tracking on the private land, which supports the conclusion that biological monitors are active deterrents of marsh damage. To be effective, the monitors must be familiar with access routes within the site, sensitive habitat types, and threatened or endangered plant/animal species. They should accompany the survey crews at all times to record traffic along each line, plan and adjust access routes, assist the crew to identify alternative routes and sensitive areas, and to avoid and designate shoreline ramp sites. They must be given the authority to restrict ancillary field activities, enforce traffic guidelines, and other rules established in the permit or landowner agreement, and to shut down field activities if warranted. These monitors should have access to airboat transportation, and be equipped with two-way radio communication for tracking the movements of the field crews.

RESTORATION TECHNIQUES

Impacts that typically require restoration include rutting (Figures 5.11 and 5.10) and breaching of natural or man-made hydrological barriers (Figure 5.11). Severe vegetative

impacts appear to recover well in the absence of soil impacts. Rutting, however, can lead to changes in hydrology, erosion, and tidal scouring. The restoration alternatives generally include placing hydrological barriers, such as hay bales or organic fiber mats or logs in ruts or along damaged shorelines (Figure 5.15). Vegetative plantings, seedings, and fertilizers are also frequently used in wetland mitigation and restoration in Louisiana (Figure 5.16). Hydrologic dredges may also be used to place fill material in ruts if the severity of rutting warrant their use.

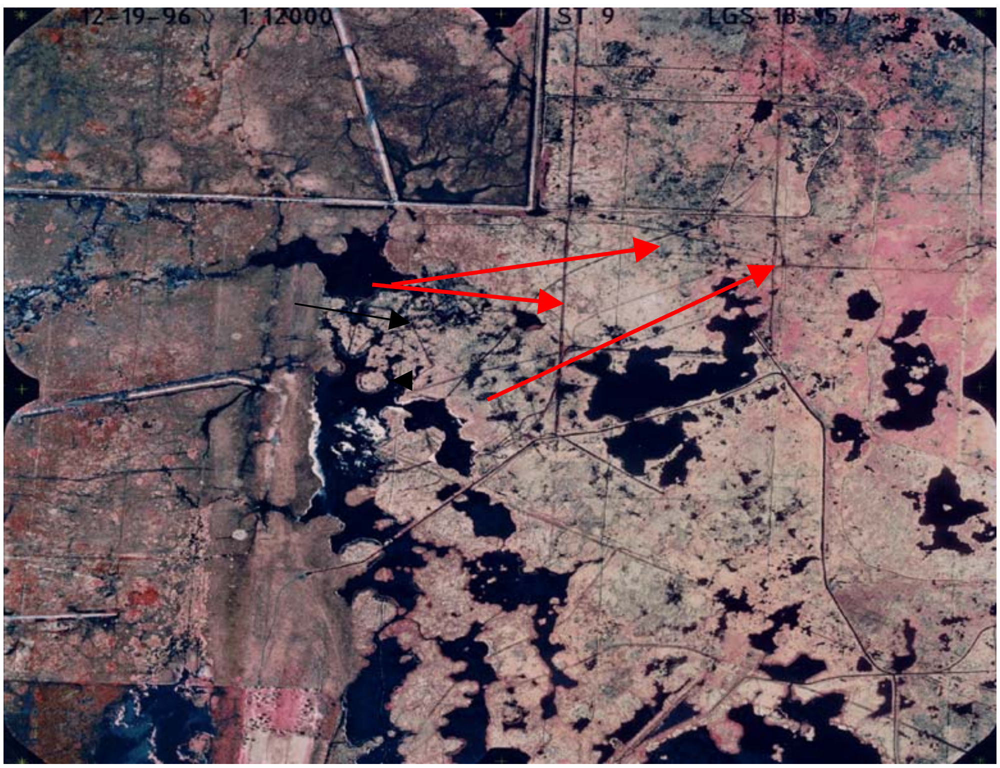

Figure 5.14. Aerial photograph showing vehicle trails from a seismic survey near Cameron, Louisiana. The majority of impacts are on private land (right site of photograph). Fewer impacts are visible on the wildlife refuge (left side of photograph) where seismic monitors were used to oversee all operations in the field.

Table 5.2. Pre-project planning and operational factors used to reduce or avoid marsh disturbance.

Strategy	Rationale
Planning and Coordination	
Review environmental literature	Determine soil and vegetation types.
Review maps and aerial photography to determine fragile and sensitive marsh areas.	Habitat change maps and aerial photography should be used when designing the layout pattern and to plan access routes and staging areas.
Coordinate with state and federal agencies to locate sensitive biological and archaeological resources.	A buffer zone is required around wading-bird rookeries, threatened/endangered species, oyster beds/leases, and archaeological features.
Project Design	
Select layout pattern that maximizes use of open water and minimizes turns and backtracking.	Coordination between a biologist and the geophysicist using aerial photography and field reconnaissance to maximize the use of open water to reduce overall disturbances.
Offset shot holes into open water to the maximum extent possible.	Placing shot holes in open can often be done without sacrificing geophysical data quality.
Timing	
Consider seasonal weather patterns and predicted tidal events.	Higher water levels reduce impacts caused by airboats in the marsh and may eliminate the need for marsh buggies.
Equipment Selection	
Select equipment based on site conditions	Airboat-only surveys may be conducted if several inches of water on marsh surface. Marsh buggy drill rigs may be more appropriate if marsh is relatively dry.
Utilize aluminum marsh buggies, lightweight air boats, helicopters	Technological advances in marsh buggy and airboat design have made this equipment less intrusive than older, heavier models.
Utilize hydraulic ram technology to push charges and geophones into ground rather than drilling holes.	Eliminates digging pits, drill cuttings, and hole plugging associated with rotary rigs and eliminates background noise from reaching the recording sensors.
Utilize a radio telemetry system for transmitting data.	Eliminates the need to traverse the entire seismic line with cables, and eliminates the need to check and retrieve data at the recorders.
Global Positioning System (GPS), radio or cellular communication	GPS reduces the amount of passes necessary for surveying and radio or cellular communication allows for accounting of all field activities.

Table 5.2 cont.	
Strategy	**Rationale**
Operation and Oversight Strategy	
Minimize the number of passes.	Reduce rutting; less monitoring required; restrict ancillary field activities.
Avoid shoreline crossings when possible and use existing open water bodies.	Shorelines are susceptible to damages caused by airboats and marsh buggies and may result in increased erosion and hydrological changes to the marsh.
Plan access routes to avoid sensitive areas.	Access routes are susceptible to damages because they receive a high level of traffic. Open water routes should be utilized if available.
Leave equipment in the marsh at the end of the day when feasible.	Leaving marsh buggy or airboat drill rigs in the marsh at the end of each day eliminates unnecessary backtracking.
Use existing waterways when possible.	Open water routes reduce marsh impacts and should be utilized.
Periodically adjust routes if erosion becomes evident.	Open water routes may cause bank erosion.
Designate ramp sites at the shoreline when repeated passes are necessary.	Ramps may be constructed out of PVC pipe or plywood and may greatly reduce shoreline rutting caused by repeated passes.
Spill prevention and control measures and fueling areas. Designate ramp sites at the shoreline when repeated passes are necessary.	Have containment booms and clean-up equipment on hand in case of fuel spills. Ramps may be constructed out of PVC pipe or plywood and may greatly reduce shoreline rutting caused by repeated passes.
Use biodegradable hydraulic fluids in equipment and soap in airboat sprays. Require penalty bond.	Eliminates the harmful affects of accidental spills and provides for greater ease of operation and less friction on the marsh surface. Have containment booms and clean-up equipment on hand in case of fuel spills. Provides a financial incentive to avoid/reduce disturbance.
Project oversight by third-party monitors.	Provides opportunity for on-site quick fix before 2nd time offense.
Follow-up site inspection.	Provides responsible party with an opportunity to restore damaged areas while at the site and reduces mobilization costs associated with accessing the site.

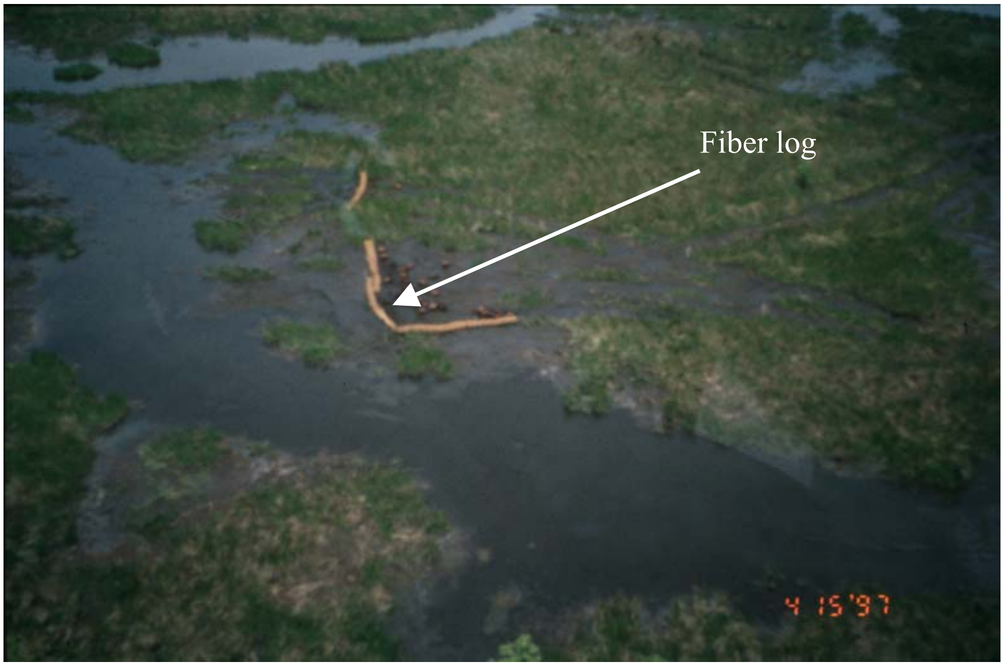

Figure 5.15. Fiber logs placed in marsh buggy tracks to minimize changes to local hydrology caused by rutting (photograph by Aaron Bass).

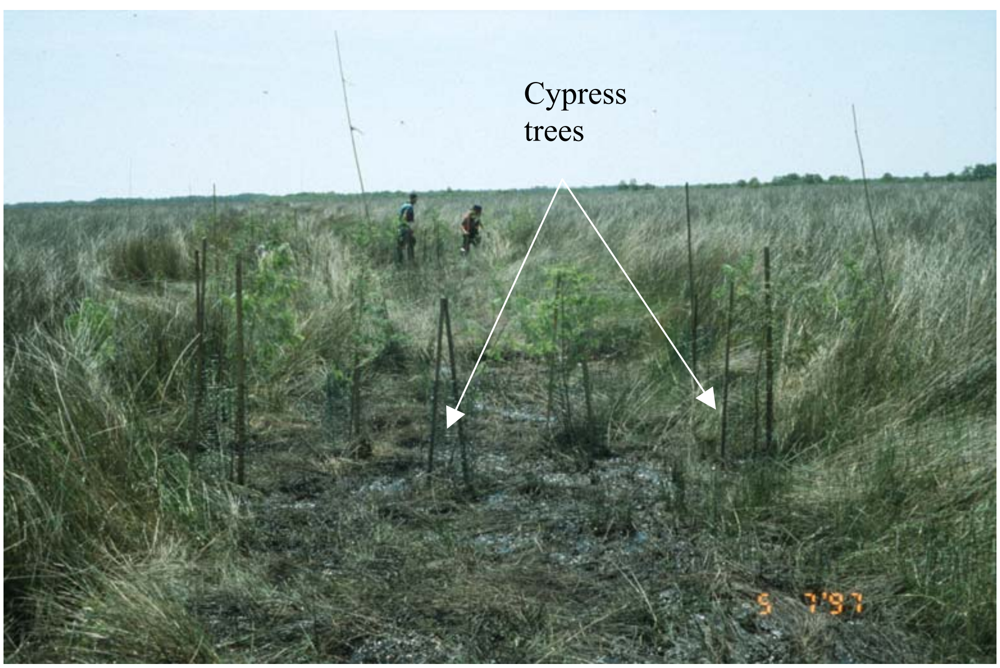

Figure 5.16. Cypress tree plantings on a seismic survey line in a marsh west of Bayou Perot in Jefferson Parish, Louisiana (photograph by Aaron Bass).

Table 5.3. Techniques used to restore marsh habitat impacted by vehicle traffic.

Technique	Rationale
Place fiber mats or logs in ruts (Figure 5.15)	Reduces tidal scouring, may allow organic matter deposition to fill in ruts, provides substrate for vegetation to re-establish
Vegetative plantings (Figure 5.16)	Provides cover to bare areas, may reduce likelihood of invasion of exotic species, adds stability to shorelines
Hydraulic dredging	Restore marsh surface to original condition, reduces tidal scouring and provides substrate for vegetation re-establishment

REGULATIONS

The following section summarizes state and federal regulatory authorities over seismic activities in the primary oil-and gas-producing states in the northern Gulf of Mexico: Louisiana, Texas, and Alabama.

The U.S. Army Corps of Engineers (Corps) regulates geophysical activities through the issuance of the *Nationwide 6 Permit (NWP-6) for Geophysical Activities* (Federal Register 2002). The Nationwide 6 Permit covers all survey operations including surveying, drilling and plugging of seismic shot holes, but does not authorize the construction of roads or other permanent structures. *NWP-6* does not place any restrictions on equipment, operational practices, and does not specify compensatory mitigation requirements.

Louisiana

The Louisiana Department of Wildlife and Fisheries (LDWF), and the Louisiana Department of Natural Resources (LDNR) have environmental regulatory authority over

seismic survey activities in Louisiana. Table 5.4 highlights the rules for seismic activities in Louisiana.

Seismic activities are under the supervision of the LDWF Seismic Section. The regulations state that seismic activities must be conducted in a manner to minimize impacts. There are no specific regulations pertaining to equipment types or traffic levels. Buffers are established to protect sensitive resources such as oyster reefs, threatened and endangered species, and bird rookeries. The LDWF requires a $75,000 surety bond for damages to state land, water bottoms, and other natural resources and LDNR requires a mitigation plan as a condition of the General Permit. The LDNR allows one full vegetative growing season before impacts to emergent marsh are assessed. As of July 2002, compensatory mitigation has been required for three 3-D seismic projects in coastal Louisiana (Morgan 2002). Table 5.4 provides a summary of these regulations.

Alabama

Seismic activities in Alabama are regulated by the Alabama Department of Conservation and Natural Resources. Table 5.5 includes highlights of these regulations. The State of Alabama also may require that a state representative be present at all times when seismic activities are occurring in environmentally sensitive areas and that equipment must be used so as to cause minimum disturbance to the lands, water bottoms, and wildlife and fisheries resources. The detonation of explosives is not allowed within 76 meters of any oyster reef or bed, and no geophysical exploration activity is allowed in inshore waters during the first two weeks following the opening of summer shrimping season.

Texas

The Texas Parks and Wildlife Department (TPWD) and the Texas General Land Office are responsible for regulation of seismic activities on lands and water bottoms owned by the state of Texas. Table 5.6 includes highlights of these regulations. The TPWD may also require that a state representative be present at all times during seismic operations. The statutes are broadly written and require that adverse impacts be minimized when conducting operations in critical areas. The detonation of explosives is not allowed within 122 meters of any oyster reef, marked oyster lease, or marked artificial reef, and the use of propeller-driven boats is discouraged in areas with submerged vegetation. TPWD also has a fish kill monitoring protocol and recording procedure in place when working in open water areas. At the end of each day, a state representative inspects the shoreline for dead fish associated with the seismic activities. Each is identified by species, and measurements are recorded. The seismic operator may be charged a fee for damages associated with the loss of these fisheries resources. The Texas General Land Office (GLO) prohibits staging areas from being established in sensitive areas, including coastal wetlands, and airboats may be required in waters less than three feet deep. The GLO also established specific restoration guidelines that include constructing terraces and vegetative plantings to offset erosion caused by the seismic activities.

Table 5.4. Summary of regulations pertaining to seismic surveys in Louisiana.

Law/Regulation	Highlights
Louisiana Louisiana Department of Wildlife and Fisheries *Louisiana Administrative Code (LAC), Title 76 Wildlife and Fisheries, Subchapter A. Seismic Exploration*	• $75,000 surety bond for damages to state land, water bottoms, oysters, fish, wildlife, or other natural resources. • Minimum required depth of charges in all water areas depending on size of charge. • Permission required to place shot points within 250 feet of any oyster reef or bed. • Boats, marsh buggies, and airboats must be used so as to minimize disturbance or damage to lands, water bottoms and wildlife and fisheries. *Source: Office of the State Register 2000.*
Louisiana Department of Natural Resources (LDNR) State Mineral Board Coastal Management Division *Coastal Use Permit – General Permit 22*	• Permit required to conduct any geophysical or geological exploration on state-owned lands or water bottoms. • Notification to oyster leaseholders who may be affected prior to commencement of seismic activities. • Activities shall not adversely affect threatened/endangered species. Adverse impacts on fish, wildlife, and the environment shall be minimized. Discharge of pollutants consistent with Louisiana Department of Environmental Quality, Office of Water Resource standards. • Applicant shall implement a compensatory mitigation plan onsite prior to issuance of General Permit. *Source: Louisiana Department of Natural Resources 2000.*

Table 5.5. Summary of regulations pertaining to seismic surveys in Alabama.

Law/Regulation	Highlights
Alabama Alabama Department of Conservation and Natural Resources *Geophysical Exploration of State of Alabama Lands (Regulation 90-SL-1).*	• A state representative may be required to be present at all times when operating in environmentally sensitive areas. • No explosives shall be discharged within 250 feet of any oyster reef or bed. • Minimum required depth of charges in all water areas. • Written permission to work on any wildlife refuge, scenic stream, game preserve, waterfowl refuge, fish preserve or hatchery, or oyster seed ground reservation. • Boats, marsh buggies or other types of vehicles must be used so as to cause minimum disturbance to the lands, water bottom, and wildlife and fisheries resources thereon. • No geophysical exploration activity shall be conducted in inshore waters during the first two weeks following the opening of the summer shrimping season. *Source: Alabama Department of Conservation and Natural Resources 1990.*

Table 5.6. Summary of regulations pertaining to seismic surveys in Texas.

Law/Regulation	Highlights
Texas Texas Parks and Wildlife Department, Resource Protection Division *Interim Recommendations for Implementation Regarding Geophysical Exploration in Coastal Submerged Lands and Marshes*	• Areas with submerged vegetation should be avoided with propeller driven boats. • All shell reefs should be avoided by at least 400 feet by all explosive devices and drills. • During bird rookery season, all activities should remain a minimum of 1,000 feet away from nest areas. • Each seismic program should have an official observer present. • Fish kill monitoring protocol and recording procedure. *Source: Texas General Land Office 1996.*
Texas Administrative Code, Title 31. Natural Resources and Conservation, Part 1. General Land Office ***Chapter 9, Subchapter B, Rule 9.11***	• Persons using wheeled or tracked vehicles on state-owned lands shall use reasonable efforts to avoid impacts. • No geophysical surveying within 1,000 feet of a known bird rookery. • Permittee is liable to the state for the value of fish or wildlife taken, injured or, killed by work under a permit. • Staging areas must be approved by the GLO and must not be in sensitive coastal areas including vegetated areas of submerged aquatic vegetation or coastal wetlands. • Airboats may be required at the discretion of the GLO in waters less that three feet deep. • No high velocity energy source discharged within 500 feet of any oyster reef or oyster lease. • Permittee is liable to the state for any damages. *Source: Office of Texas State Register.*

CONCLUSIONS

This chapter provided a general overview of 3-D seismic technology and the regulations governing these activities in Louisiana, Alabama, and Texas. None of these states explicitly limit the use of any particular equipment type. Biological monitors may be required in each state, but not specifically required. Regulations are provided to protect sensitive biological resources such as oyster reefs, bird rookeries, and threatened/endangered species. Table 5.7 provides a summary comparison between Louisiana, Texas, and Alabama.

Table 5.7. Summary comparison of requirements for seismic operators in Louisiana, Texas, and Alabama.

Requirement/Restriction	Louisiana	Texas	Alabama
Monitors	no	in sensitive areas	in sensitive areas
Limit on number of passes	no	no	no
Restriction on equipment type	no	yes	no
Proximity to sensitive biological resources	yes	yes	yes
Liable for wildlife and fisheries resources killed	no	yes	no
On-site restoration	no	yes	no
Mitigation plan	yes	no	no

Seismic surveys conducted on public lands such as federal wildlife refuges require Special Use Permits that impose specific restrictions on the seismic activities and normally specify that third-party biological monitors be present at all times to oversee the seismic activities. It has been shown through several field studies that adverse impacts can be minimized through oversight, planning, and management on federal refuges. Small, private landowners can also use these techniques to minimize impacts to their land.

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CHAPTER 6

CONCLUSION

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Studies of a plant community's historical disturbance regime show that disturbance may significantly affect a community's resilience to current and future natural and anthropogenic disturbances. Comprehensive, long-term, accurate information on past disturbance events for a given study area is necessary to provide reliable tests of ecological theory and to predict future community conditions. Improvements in the quality and quantity of information on the relationships (if any) between disturbance and resilience in wetland communities are desirable, because this kind of information is sparse and because these valued ecosystems are heavily impacted by continuing population growth, uses, and resource exploitation. This study attempted to fill that important void by examining various practical and theoretical aspects of disturbance in a coastal wetland marsh in southern Louisiana.

The literature review (Chapter 2) approached disturbance ecology from both practical and theoretical perspectives. It expanded on work done by McKee and Baldwin (1999) and others that attempted to fill a void in the literature because few studies have explicitly examined disturbance as a factor in shaping the structure and function of wetlands. From an applied perspective, this chapter presented disturbances common in coastal wetlands and discussed their effects to wetland plant communities.

These disturbances included: storms, fire, herbivory, hydrology, salinity, cattle grazing, toxins, and vegetation trampling. From a theoretical perspective, this chapter presented current disturbance theory and assessed its applicability to developing broad predictive models.

Theoretical concepts such as the Intermediate Disturbance Hypothesis, Patch Dynamics Concept, and the Dynamic Equilibrium Model are useful tools to organize

concepts on the effects of disturbance on wetland plant communities. However, specific knowledge of environmental variables, competitive relationships, and the interactive effects of multiple disturbances are required for meaningful usage of these models. Furthermore, extrapolating the effects of a disturbance using these general concepts across plant communities, habitats, or landscapes should be done with caution because of the overriding influence of the site and species on disturbance effect.

The Lacassine National Wildlife Refuge (LNWR) provided an ideal laboratory to test various aspects of ecological disturbance theory because of the historical data available in the narrative reports the LNWR has maintained since it was established by United States Fish and Wildlife Service in the 1930s. Interviews with refuge personnel and a review of data on weather conditions, water levels, management practices and disturbance events confirm that the LNWR is a disturbed landscape that has been influenced by constant and variable manipulations. The primary disturbances affecting the refuge have been hurricanes, droughts, water-level manipulations, prescribed burning, oil and gas recovery activities, grazing by nutria, and managed cattle grazing. Other disturbances include mechanical clearing of targeted plant species, herbicide application, and ditch construction.

The LNWR wetlands, like much of coastal Louisiana, overlie oil and gas deposits, and are subjected to frequent disturbances associated with mineral exploration and production activities, which landowners and regulatory agencies have tried to minimize. The application of three-dimensional (3-D) seismic technology, in particular, is used to find hidden resources, increase drilling precision, develop previously abandoned fields, and optimize drilling success. The increase in 3-D seismic activity in the 1990s challenged landowners, governmental regulators, and industry to develop innovative ways to recover

these resources without damaging the fragile surface features. A conservative estimate is that an area exceeding 2.5 times the area of Louisiana's coastal wetlands was covered by overlapping seismic surveys in southern Louisiana from 1997 through 2002, equal to 22.5 km^2/year at 40% impact. I conducted field studies on how a freshwater marsh responded to the disturbances created by the vehicular traffic associated with 3-D seismic surveys at the LNWR. A general overview of 3-D seismic survey programs, potential adverse impacts, and management and restoration strategies were provided. Aerial photographs of 3-D seismic survey grid patterns and photographs of equipment used and associated impacts were also included.

I measured vegetative cover, live and dead biomass, and species composition on control and treatment transects before, and for two years after, a 3-D survey over the entire LNWR. The treatment consisted of two types of vehicular traffic and of single and multiple vehicle passes. Vegetative cover and the amount of dead plant biomass were significantly lower in treatment lots, but live biomass was not different in treatment and control plots. Species richness was higher in treatment plots compared to control plots, but the live biomass and cover of the dominant species (*Panicum hemitomon*), was lower. The live biomass and cover of *Eleocharis spp*., colonizing species, was greater in treatment plots compared to control plots. There was no significant effect of equipment type or traffic level within treatment plots. Clear trends on the disturbance effects across disturbance types and habitats were not revealed. The available conceptual models used mostly for non-wetland communities are useful tools to organize and classify disturbance effects in a broad sense; however, knowledge of site-specific environmental factors, disturbance mechanics, interactions between species and multiple disturbances, and species traits is required to assess the effect of a given disturbance on a plant community, especially in wetland

communities. Further studies need to be conducted to determine the effects of vehicle traffic on plant communities in other coastal marsh habitats. Specific emphasis should be placed on those wetlands in the Mississippi River Deltaic Plain, where extensive oil and gas exploration and production occurs, and where approximately 400,000 ha of estuarine wetlands have converted to open water since the 1930s (Dunbar et al. 1992).

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APPENDIX A

LACASSINE NATIONAL WILDLIFE REFUGE NARRATIVE REPORT SUMMARIES

1937 – 1950

The LNWR was purchased in 1937 when the dominant vegetation at the LNWR was *Cladium jamaicense* and *Phragmites communis* (USFWS 1940). Levee construction around the Pool began in 1939 and ended in 1944. The objective of constructing the impoundment was to provide food and habitat for waterfowl. This required reducing the abundance of *Phragmites communis*, *Panicum hemitomon*, and *Cladium jamaicense* and increasing the amount of open water areas and submerged and floating aquatic vegetation. *Brasenia schreberi* spread throughout the Pool as a result of high water levels and reduced competition from emergent species. The 1943 Narrative Report described the spread of this species as "remarkable" and noted that its natural spread was facilitated by transplanting done by the LNWR during the summer. Nutria also created open water areas when they grazed on *Sagittaria lancifolia* and *Scirpus californicus*. In addition to the disturbances previously discussed, large patches of *Cladium jamaicense* were intentionally broken up with an underwater weed cutter and with mud boat trails in 1943. Five miles of boat trails were cut through the marsh, open water areas were created with an underwater weed cutter, and herbicides were used to kill unwanted species. The 1941 Narrative Report noted that 425 ha of *Cladium jamaicense* burned in 1940 were replaced by species more favorable for waterfowl habitat. In 1944*, Brasenia schreberi* spread rapidly throughout the Pool. The spread of this species was aided when 10 hectares of open water was created in the Pool using an underwater weed cutter in 1944. *Sagittaria spp*. appeared to come back after three cuttings, but *Panicum hemitomon* was killed after one cutting (USFWS 1944).

Significant plant species composition shifts occurred between 1944 and 1947. In 1940, the dominant vegetation in the Pool was *Cladium jamaicense* and *Panicum hemitomon* (USFWS 1939 and USFWS 1940). *Cladium jamaicense* dominated the eastern, southern, and western portions of the Pool in 1945. *Panicum hemitomon* dominated the central and northern portions of the Pool. The spread of species desirable as waterfowl food occurred, especially in open areas of *Cladium jamaicense* that resulted from the high water levels since 1943. The dominant species in the Pool were *Brasenia schreberi*, *Eleocharis equisetoides*, and *Orontium aquaticum* (USFWS 1945). *Cladium jamaicense* abundance decreased as a result of the flooding, but *Panicum hemitomon* demonstrated its ability to survive flooding by growing in floating mats (USFWS 1946). Managers observed in 1946 that nutria would be a greater factor in reducing and controlling the encroachment of emergent species than flooding. They noted numerous nutria "eat-outs" in stands of *Scirpus californicus* and also noted that nutria favored *Cladium jamaicense*, *Sagittaria lancifolia*, and *Pontederia cordata*. Managers also observed that the high water levels in the marsh outside of the Pool resulted in less *Panicum hemitomon* and *Cladium jamaicense*, and increases in *Sagittaria lancifolia*, *Nymphaea odorata*, *Utricularia sp*., and *Eleocharis sp*.

Much of the *Cladium jamaicense* had been replaced with submerged aquatic and floating-leafed species by 1947. The 1947 narrative report provides an excellent account of the ecological changes that occurred in the Pool following the completion of the levee system. In the narrative report issued for the first quarter of 1947, the LNWR personnel described the visible changes in plant species composition that occurred between 1946 and 1947 as "startling." The shift was from emergent vegetation, primarily *Panicum hemitomon* and *Cladium jamaicense* towards floating leafed and submerged aquatics. The abundance of

Eleocharis spp. was also noted. *Typha sp*., *Scirpus californicus*, and *Zizaniopsis miliacea* appeared to be less affected by the higher water levels. The areas that were previously occupied by *Panicum hemitomon* and *Cladium jamaicense* were dominated by *Brasenia schreberi*, *Utricularia sp.,, Cabomba caroliniana*, and *Nymphaea odorata*. In the 1947 narrative report, the LNWR personnel state "the primary objective of killing out the *Cladium jamaicense* and *Panicum hemitomon* has now been carried to completion. The remnants of these species which once dominated the Pool are now hardly noticeable from the air" (USFWS 1947).

Eleocharis sp. and *Limnobium spongia* colonized areas in the pool treated with herbicide to kill *Nelumbo lutea* in 1949. High water levels in 1949 created noticeable changes in decreased coverage of *Panicum hemitomon, Eleocharis equisetoides*, and *Sagittaria lancifolia*.

<u>1951 – 1960</u>

No significant species changes were noted in the Pool in 1951; however, the dry conditions promoted the first good growth of wild millet in the marshes. High waters in 1952 continued to retard the growth of *Panicum hemitomon* and promoted the spread of *Brasenia schreberi*. *Sagittaria lancifolia* was virtually gone and replaced with *Eleocharis equisetoides*. The stands of *Cladium jamaicense* continued to thin out and floating turf in the Pool was observed. In 1953, the observation was made that the Pool was a solid stand of *Zizaniopsis miliacea* with many openings. This observation was not consistent with previous descriptions of the habitat within the Pool. Low water conditions allowed *Panicum hemitomon* to grow, but in general, the Pool continued to "open up" with more open water areas.

Hurricane Audrey (June 27, 1957) created significant changes in vegetative cover outside of the Pool. It was observed that all species except *Sagittaria lancifolia* and *Scirpus californicus* were drowned by the high water associated with the storm. The *Cladium jamaicense* south of the Pool killed by Hurricane Audrey was replaced with *Sagittaria lancifolia*. Intensive grazing by nutria combined with the effects of the hurricane also created many large openings in the southern portion of the Pool. *Brasenia schreberi* continued to spread into these open water areas. The 1958 narrative report indicated that most of the marshes had recovered from Hurricane Audrey, except the marsh south of the GIWW.

In 1959, *Brasenia schreberi* and *Eleocharis equisetoides* continued to spread over the open water areas and between patches of *Sagittaria lancifolia. Najas quadalupensis* (Southern naiad), and *Utricularia spp*. covered old burn areas in the Pool. Walter millet (*Echinochloa walteri*) colonized the higher marshes outside the Pool. *Cladium jamaicense* began to come back, and submerged aquatics also grew due to lack of competition from emergent species. These species included: *Potamogeton sp., Vallisneria amerricana*, *Otillia alismoides*, and *Brasenia schreberi. Sagittaria lancifolia*, *Potamogeton sp*., and some *Cladium jamaicense* grew in the higher areas of the marsh outside the Pool.

Dry conditions in 1960 continued to benefit the marsh following Hurricane Audrey in 1957. Some of the areas that were bare of vegetation dried out enough to permit growth of new plants species including *Salix nigra*, *Sagittaria lancifolia*, *Ludwigia sp*., *Alternanthera philoxiroides, Sagittaria lancifolia*, *Panicum lividum*, *and Eleocharis spp*. *Cladium jamaicense* stumps were also observed re-sprouting.

<u>1961 – 1970</u>

High water levels in 1961 prevented germination of *Cladium jamaicense* in the natural marsh. These species were replaced by *Sagittaria falcatta*, duck lettuce, *Najas quadalupensis* and *Utricularia spp.* *Eleocharis equisetoides* and duck lettuce appeared to be increasing in the Pool. *Sagittaria lancifolia* also thrived in the high water conditions found in the Pool in 1961. This was contrary to previous theories that depth of water controlled the growth of *Sagittaria lancifolia* and that flooding would reduce the coverage of this species.

The 1962 Narrative Report noted that a drought killed much of the floating aquatic vegetation inside and outside of the Pool. It was replaced with *Sagittaria lancifolia*, *Scirpus californicus*, *Cladium jamaicense*, *Zizaniopsis miliacea*, and *Panicum hemitomon*. *Brasenia schreberi*, *Eleocharis equisetoides*, and *Bacopa caroliniana* thrived following the drought. Managers also eradicated 243 hectares of *Nelumbo lutea* and 41 hectares of *Sagittaria lancifolia* with herbicide mixed with diesel in an attempt to create more open water in the Pool.

In the early part of 1963, the Pool was almost completely open water as a result of the drought in the previous year and because of feeding by waterfowl over the fall and winter. The low water conditions in the Mermentau Basin permitted the re-vegetation of the marshes that had been barren since Hurricane Audrey. The species colonizing these patches included coastal arrowhead and *Sphenocles zeylandica* (gooseweed). *Cladium jamaicense* also appeared to be coming back in some areas. *Cladium jamaicense* once covered the entire marsh south of the GIWW. *Brasenia schreberi* continued to cover all open water areas in the Pool. The dominant emergent species in the Pool through 1965 were *Sagittaria lancifolia*, *Panicum hemitomon*, *Eleocharis equisetoides*, and scattered stands of *Cladium*

jamaicense. The Misere Marsh, located south of the GIWW, was dominated by *Sagittaria lancifolia, Alternanthera philoxeroides*, and slim *Eleocharis elongata*. The vegetation in the unmanaged marshes was determined by the water levels in the Mermentau River basin. Vegetation studies conducted in 1965 revealed that there was a slight increasing in perennial species in the Misere Marsh. These species included *Sagittaria lancifolia*, *Alternanthera philoxeroides*, *Pontederia cordata* and several species of *Eleocharis sp. Psilocarya nitens* covered approximately 259 hectares in the Misere marsh.

Vegetation transects conducted in 1966 and 1967 showed continued increases in *Alternanthera philoxeroides*, *Sagittaria lancifolia*, and *Pontederia cordata* in the 2023-hectare Misere marsh. *Panicum hemitomon*, *Sagittaria lancifolia*, and *Eleocharis equisetoides* continued to be the dominant species in the Pool. Submerged species included *Utricularia spp*., *Ceratophyllum demersum*, and *Cabomba caroliniana*.

Habitat conditions in the Pool in 1968 and 1969 were similar to those that existed since 1965 and no changes were noted in the natural marsh. Water level fluctuation was more pronounced in 1969 than in the previous years since 1963. *Panicum hemitomon* continued to be the most abundant emergent species in the Pool, followed by *Sagittaria lancifolia*. *Alternanthera philoxeroides* was the dominant species along waterways and on the edges of lakes, and *Panicum hemitomon*, *Sagittaria lancifolia*, and *Eleocharis equisetoides* dominated the interior marshes. Water levels did not fall below 0.37 m MSL during 1969; therefore, few annual species were produced. An eight-year low of 0.49 m MSL occurred in 1970. These dry conditions temporarily affected the submerged and floating-leaved species in the Pool. *Panicum hemitomon* continued to dominate in the high marsh areas of the natural marsh and *Alternanthera philoxeroides* grew in dense stands in

the lower areas. Significant species composition changes did not occur during this time period.

1971 – 1980

Hurricane Edith (September 16, 1971) raised water levels in the natural marsh in September 1971 and overflowed the Pool levees. As a result, *Eichhornia crassipes* spread throughout the Pool area into places where it had previously not existed. This wet period was followed by extremely dry conditions in the summer of 1971. Heavy water use outside the LNWR exacerbated the naturally dry conditions in the marsh by lowering the water level in the Mermentau River to 0.34 m MSL by the end of June. The biologists described the LNWR as being 35% rather than 99% marsh because of the dry conditions. However, by December, the rains had returned, water levels in the Mermentau River were 1.55 m MSL, and the natural marsh was under 1.50 to 1.80 m of water. The dry conditions earlier in the year resulted in growth of *Panicum hemitomon*, *Sagittaria lancifolia*, and *Pontederia cordata* toward the center of the Pool, which reduced open water in the Pool to 10%. The LNWR biologists described the new vegetation growth in the Pool as "impenetrable." Nutria expanded their range into the Pool in response to the vegetation growth. Nutria had not previously existed in the interior of the Pool.

The high water level at the end of 1971 extended into the spring of 1972, resulting in high production of submerged aquatic and floating-leaved plant species. There were no significant changes in species composition in the Pool. The dominant emergent species are *Panicum hemitomon*, *Sagittaria lancifolia*, and *Eleocharis equisetoides*, with small stands of *Scirpus californicus* and *Cladium jamaicense*. In the natural marsh, *Eichhornia crassipes* spread into the interior marsh as a result of the high water levels from the previous year.

Species composition in the Misere marsh in 1972 was 70 percent *Sagittaria lancifolia*, followed in abundance by *Nymphaea odorata*, *Alternanthera philoxeroides*, and *Eleocharis elongata*.

High water conditions in 1974 resulted in good conditions for the floating and submerged aquatic species in the Pool. Up until this time, the LNWR had been successful at reducing the growth of *Panicum hemitomon* and other emergent species and promoting the growth of *Nymphaea odorata*, *Brasenia schreberi* and submerged aquatic species by maintaining high water levels in the Pool. The LNWR biologists observed that the Pool was filling in with organic matter, resulting in a shallower marsh, which was promoting the growth of undesirable vegetation types.

The high water conditions of 1974 continued through 1975. The marsh remained under water all year. The LNWR managers wrote that the natural marshes would be more productive in terms of waterfowl habitat and food if they were de-watered in the summer. The LNWR noted that water levels in the Mermentau Basin were consistently higher than historical levels. They attributed high water to alterations to the drainage system by the US Army Corps of Engineers. Species composition changes were observed in response to significant changes in water levels.

Water levels in the Pool dropped to the lowest levels in five years in 1976 due to the lack of rainfall. This exposed mudflats in the natural marsh and in the Pool, which promoted the growth of *Eleocharis parvula*, *Eleocharis equisetoides*, and annual grasses. *Bidens laevis* was observed for the first time west of the Atchafalaya River. Saltwater intrusion into the Mermentau Basin occurred as a result of the lack of rainfall, and a malfunctioning water control structure in an oil company canal located between fresh and

brackish marshes. No vegetation damage was noted on the LNWR. In contrast to conditions in 1976, the marshes remained flooded throughout 1977 and 1978. The LNWR biologists noted that the varying water levels benefited perennial species and resulted in fewer seed-producing plants.

Habitat changes associated with floating mat formation in the Pool were first described in 1979. The LNWR biologists noted that vegetative succession was moving at a faster rate inside the Pool than outside because of the accumulation of organic matter in the Pool. Gasses formed during decomposition lifted the mats of decaying matter to the water surface. Vegetation became established on these floating mats and formed small islands.

Mermentau River water levels fluctuated significantly in 1980 from a high of 0.36 m MSL in February to 1.59 m MSL in May. The LNWR biologists noted that the vegetation was stable and did not change because of the water level fluctuations. However, *Sapium sebiferum* and *Bidens laevis* spread into the marsh because of the dry conditions.

<u>1981 – 1990</u>

No noticeable habitat changes occurred in 1981 and 1982. "Even though we didn't change any habitat this year, we were successful in preventing any from being changed, and that is our greatest challenge here" (USFWS 1983). The LNWR biologist noted the critical part that water levels play on the LNWR ecosystem. High water levels result in shoreline erosion along Grand and Misere Lakes. Low water levels result in the spread of brush, especially *Sapium sebiferum*. There was an estimated 121 hectares of this species in 1988. *Bidens laevis* also continued to spread across the LNWR during this period.

Hurricane Juan caused an all-time high water level of in November 1985. No significant habitat changes were noted in 1985. Water levels remained optimum in the Pool

throughout most of the year. The natural marsh became dry in April and June, which allowed germination of annual plants.

A major change in USFWS habitat management was implemented in 1988. The emphasis in wildlife management policy switched from providing sanctuary for waterfowl to providing food. The "farming for waterfowl" theme prevailed in the southeastern United States during this period. The farm units north of the Pool were converted to moist soil units and a 283-hectare sub-impoundment (Unit D) was constructed in the Pool in 1989 (Figure 4.2). The purpose of Unit D was to experiment with methods of removing organic matter that was filling in the Pool and to produce moist soil crops for waterfowl. Pumps were installed in Unit D so that water levels could be controlled. In 1990, the pumps operated for 700 hours in an effort to dry this area out.

<u>1991 – 1999</u>

No significant habitat changes were noted in 1991. Pumping continued in Unit D every month of the year for a total of over 1,300 hours. The US Soil Conservation Service (SCS) identified three plant communities: *Brasenia* schreberi, Nymphaea *odorata*, and *Panicum hemitomon*. The drawdown in 1990 caused terrestrial species such as *Eupatorium capillifolium* and *Bidens laevis* to replace *Sagittaria lancifolia, Brasenia schreberi*, and *Nymphaea odorata* in the *Brasenia schreberi/Nymphaea odorata* community. Soil core samples revealed 40.6 cm compaction of the organic layer in Unit D as a result of dewatering. It was determined that long-term dewatering would be required to maintain the water table below the organic layer in order to continue to reduce the elevation through compaction and biochemical oxidation.

There was above-average rainfall in 1992, which kept water levels high in the natural marsh and hindered the LNWR's efforts to de-water Unit D. Pumping continued through August. Little vegetation change was noticed in Unit D with the exception of a decrease in *Bidens laevis*. Sampling also showed that the rate of loss of organic matter was less than the previous year. New stop-logs were placed in the water control structures in the Pool levees to hold an additional 15 cm to 31 cm of water. Water levels were maintained at 1.34 m to 1.52 m MSL in an effort to stress the emergent vegetation. *Panicum hemitomon* was observed putting growing above the water level and the 1994 NR reported that the stress put on the vegetation was minimal. The narrative reports for this period note that the open water areas in the Pool continue to decrease because of the buildup of organic matter and floating island formation.

APPENDIX B

TIMELINE OF EVENTS AT THE LACASSINE NATIONAL WILDLIFE REFUGE FROM 1935 THROUGH 1999

1935 : Federal government began purchasing the LNWR lands.

1937 : LNWR was established.

1939 : Levee construction began at the Pool (6,475 ha).

1941 : Shell Oil Company dredged a canal in the Pool.

1942 : Cattle grazing on northern portion of refuge resulted in vegetation species shift from *Spartina spp.* to other species more favorable for geese forage.

1942 : 5,455 meters of boat trails were cut through the marsh in the Pool.

1943 : Marsh buggy and mud boat damage to *Cladium jamaicense* in Pool. *Myocastor coypus* (nutria), was first documented on LNWR. Standard Oil and Gas Company explored a major portion of LNWR. US Army Corps of Engineers re-dredged the GIWW through LNWR.

1944 : Levees were completed around the Pool. Ten hectares of open water were created with an underwater weed cutter

1946 : Four thousand-five hundred nutria were estimated to be in Pool.

1947 : Species composition changed in the Pool away from emergent vegetation to floating aquatics species.

1948 : Low water levels resulted in saltwater intrusion into the GIWW, Mermentau River, and Lacassine Bayou. Saltwater locks were under construction by the USACE near Grand Lake and near the junction of the Calcasieu River and the GIWW.

1951 : Seismic operations in Pool area caused disturbance to nesting birds. Approximately 1,012 hectares of the *Cladium jamaicense* marsh located between Lake Misere and the ICWW were burned.

1953 : Nutria eat-outs and pop–ups documented for first time. Seedling hyacinth were in greatest abundance around the pop-ups.

1954 : Wildfire burned most of the marsh on LNWR.

1955 : First identification of *Heteranthera reniformis* (kidney-leaf mud plantain) in the Pool.

1956 : *Bubulucus ibis* (cattle egret) was first reported in Louisiana by LNWR personnel.

1957 : A solid *Cladium jamaicense* marsh south of the GIWW was broken up by old burns; marsh buggies allowed in the Pool; Hurricane Audrey struck on June 27.

1957 : Nutria cuttings on bulltongue, sawgrass, and *Eleocharis equisioites* in the southern portion of the Refuge create large openings in vegetation.

1958 : LNWR biologist documented that the *Cladium jamaicense* stands south of the GIWW were killed by Hurricane Audrey and replaced by *Sagittaria lancifolia*. All marshes except marsh south of GIWW were re-vegetating after Hurricane Audrey. *Cladium jamaicense* killed by Hurricane Audrey was replaced with *Sagittaria lancifolia*.

1959 : *Cladium jamaicense* began to recover from Hurricane Audrey and many submerged aquatics species colonized due to decreased competition from emergent species.

1960 : Nutria die-off, drought conditions improved emergent plant growth in marsh that had almost been bare since Hurricane Audrey.

1961 : Heavy feeding by ducks and geese in the Pool resulted in only *Panicum hemitomon* remaining. This was an annual occurrence.

1962 : During drought conditions, the Refuge personnel calculated that the Pool lost over 45,420 kiloliters (120,000,000 gallons) of water per day due to evaporation and transpiration.

1963 : Mermentau River fell to lowest level since locks were installed in 1951. Low water levels in Mermentau River Basin resulted in re-vegetation of these marshes with gooseweed and *Sagittaria lancifolia*. *Salix nigra* also spread as a result of the drought. *Sagittaria lancifolia* was the dominant vegetation in marshes outside of Pool. Several stands of *Cladium jamaicense* were found south of the GIWW. This area was previously a solid stand of *Cladium jamaicense*.

1965 : Oil and gas canals were excavated in the Streeter Canal area.

1967 : A new species at LNWR, *Potamogeton nodosus* (longleaf pondweed), invaded the open water areas along Lacassine Bayou and Mermentau River.

1969 : The natural marsh was dominated by *Sagittaria lancifolia*, *Panicum hemitomon*), and *Eleocharis sp.). Alternanthera philoxeroides* was dominant along the waterways.

1971 : On September 16, Hurricane Edith passed ten miles from the refuge. Heavy rains in December resulted in floodwaters from Lacassine Bayou and Bell City ditch to overflow the three Pool spillways. *Eichhornia crassipes* entered the Pool and spread over the 6,475 hectares.Drought conditions in the natural marsh and consumption of water by rice farmers lowered the Mermentau water levels to 0.34 m MSL (end of June). The natural marsh dried up and the bottom was exposed. Low rainfall also resulted in increased coverage of and *Pontederia cordata* (pickerelweed) which encouraged nutria to move into areas of the natural marsh where they previously did not exist because of deep water.

1972 : Jacob Valentine noted that *Sagittaria lancifolia* was dominant (70%) in Misere marsh. Water hyacinth became a problem in natural marsh and high water has transported it into areas it previously did not exist.

1976 : Low water levels led to the spread of *Bidens laevis* (bur-marigold), this was the first documented occurrence west of the Atchafalaya River. Salt water intrusion occurred into the Mermentau River due to a malfunctioning structure in a Superior Oil Company canal between fresh and brackish marshes and low rainfall.

1976 : The LNWR established new grazing policy that eliminated year-round grazing along and south of the GIWW.

1976 : The LNWR established 1,155-hectare wilderness area south of GIWW.

1978 : Began to describe oil and gas impacts, marsh buggy impacts, noted marsh buggy-induced floating organic mats (pop-ups) and spread of pest plant species.

1979 : Three tropical storms resulted in a yearly total of 28.4 cm of rain (5.5 cm above average).

1980 : Narrative Report noted that a portion of the LNWR was brackish in the 1930s before the US Army Corps of Engineers put in a structure in the Mermentau River to eliminate saltwater from the Mermentau Basin. The water level at the Mermentau gauge near the Refuge headquarters reached 0.37 m MSL on February 22. This was a near record low. Three months later the water levels reached 1.6 m MSL. This was a near record high.

1980 : The refuge manager described the rapid spread of Chinese tallow-tree into the marsh as of "ominous significance." Noted was that Chinese tallow-trees were not present four years ago.

1981 : Oil and gas activities on the refuge increased dramatically. The refuge received numerous requests for seismic surveys. The LNWR revised seismic rules and began requiring mitigation for seismic damages. The LNWR also changed the grazing policy to winter only.

1982 : The Narrative Report noted that a disturbed abandoned well site was rapidly colonized by *Bidens laevis*.

1983 : Greg Linscomb (Louisiana Department of Wildlife and Fisheries) documented marsh buggy damage to a sensitive zone near Bayou Lacassine that resulted in 81 hectares of wetland loss in one night. Severe erosion was also documented along shorelines of Grand Lake and Lake Misere. Boat trenches created by hunters in the Wilderness Area altered the local hydrology and resulting in tallow invasion.

1984 : December was the coldest on record (1935-1984).

1985 : The grazing program ended at the LNWR and outboard motors were banned in the Wilderness Area marsh. Hurricane Juan resulted in a record high water level of 1.69 m mean sea level (6.35'MGL) at the Mermentau River gauge at the headquarters.

1987 : The refuge began trying to control the spread of *Sapium sebiferum* on the refuge. Refuge biologists noted that Chinese tallow-trees affected *Sagittaria lancifolia* and *Panicum hemitomon* growth. They started building levees along the northeastern portion of the Pool to enable managers to better control water levels. The goal was to reduce the build-up of organic matter by drying and burning the peat deposits.

1988 : The refuge banned marsh buggy use in pool and documented damage and initiated a program to control Chinese tallow-trees in the marsh. It was noted that the refuge had approximately 121 hectares of tallow-trees.

1991 : The Louisiana Geological Survey evaluated the survival of cypress trees planted along Grand Lake several years before and determined that survival was good.

1992 : *Salvinia spp.* (duckweed) first appeared at LNWR.

1993 : New stop-logs were installed at Pool to maintain the water level at 1.83 m MSL.

1997 : South Thornwell 3-D Seismic Survey conducted.

1998 : Drought conditions existed on the refuge.

1999 : Drought conditions existed on the refuge.

VITA

Aaron was born in New Orleans, Louisiana, on January 13, 1967. He graduated from Carencro High School, in Lafayette, Louisiana, in 1985. He then attended Louisiana State University, where he received a bachelor of science degree in business administration in 1990. Aaron then entered graduate school and received a master of science degree in oceanography and coastal sciences in 1993 from Louisiana State University. After working as environmental consultant in Alabama and Florida for one year, Aaron was hired by the Louisiana Geological Survey in Baton Rouge in 1994. He entered into the doctoral program within the Department of Oceanography and Coastal Sciences on a part-time basis shortly thereafter. Aaron is currently employed by Conestoga-Rovers and Associates in Baton Rouge as an Environmental Scientist. He is married to Cherami Lyn Hanks of Rayne, Louisiana, and has three children, Lauryn (6), Claire (3), and Tyler (1.5).