# Environmental Effects and Effectiveness of *In Situ* Burning in Wetlands: Considerations for Oil Spill Cleanup

**Technical Report Series**
**169-30-4156**
**May 31, 1995**

# Environmental Effects and Effectiveness of *In Situ* Burning in Wetlands: Considerations for Oil Spill Cleanup

Irving A. Mendelssohn
Mark W. Hester
James W. Pahl
Wetland Biogeochemistry Institute
Louisiana State University
Baton Rouge, LA 70803

**Technical Report Series**
**169-30-4156**
**May 31, 1995**

# DISCLAIMER



# REPORT AVAILABILITY

Questions or requests for this publication should be directed to:

Louisiana Applied Oil Spill Research and Development Program (OSRADP)
1993-1994 Research
Room 258 Military Science
Baton Rouge, LA 70803

# CITATION

Mendelssohn, I. A., M. W. Hester, and J. W. Pahl. 1996. Environmental effects and effectiveness of *in situ* burning in wetlands: Considerations for oil-spill cleanup. Louisiana Oil Spill Coordinator's Office/Office of the Governor, Louisiana Applied Oil Spill Research and Development Program, Baton Rouge, Louisiana, 53 pp.

# ACKNOWLEDGMENTS

We would like to thank the sponsors of this research: the Louisiana Applied Oil Spill Research and Development Program, the American Petroleum Institute (API), the Marine Spill Response Corporation, the Department of Energy, and the National Oceanic and Atmospheric Administration (NOAA). The combined funding and assistance from these agencies were essential to the successful completion of this research. In addition, we greatly appreciate the help of the staff of the Louisiana Department of Wildlife and Fisheries' Pass-a-Loutre Management Area, Mr. Marty Savoie of Texaco, Mr. Paul Frederick of Exxon, Mr. Beau Hardegree and Dr. John Tunnel of Texas A&M University-Corpus Christi, and Ms. Diane Lindstedt of Louisiana State University for their assistance in various aspects of data collection. Also, we acknowledge Mr. Charles Henry and Ms. Pauline Roberts of the Institute for Environmental Studies, LSU for conducting the oil chemistry analyses. Additionally, we extend our thanks to the Data Review Committee consisting of Pat Bergeron, Louisiana Department of Environmental Quality, Dr. Andrie Chen, Exxon Production Research, Dr. Don Davis, Louisiana Applied Oil Spill Research and Development Program, Ms. Heather Finley, Louisiana Oil Spill Coordinator's Office, Mr. David Fritz, Amoco, Mr. Paul Frederick, Exxon, Ms. Pauline Roberts, Louisiana State University, Mr. Steve Underwood, Louisiana Department of Natural Resources, and Ms. Ruth Yender, National Oceanic and Atmospheric Administration. Their assistance in evaluating our initial findings was extremely helpful. Our most sincere appreciation also goes to those individuals who critically reviewed this document: Dr. Andrie Chen, Mr. David Fritz, Dr. Ron Goodman (Imperial Oil), Ms. Victoria Huyck (API), Dr. Alan Mearns (NOAA), Ms. Alexis Steen (API), and Ms. Ruth Yender. Their insightful comments considerably improved this report.

# TABLE OF CONTENTS

Page

# LIST OF FIGURES

# LIST OF TABLES

# Environmental Effects and Effectiveness of *In situ* Burning in Wetlands: Considerations for Oil-Spill Cleanup


## Abstract

Oil spilled in sensitive wetland environments poses unique problems associated with cleanup. In fact, oil spill cleanup in wetlands may result in more damage to the wetland than the oil itself. Hence, there is a need to develop less damaging oil spill cleanup methodologies that are compatible with wetland environments and consistent with present wetland management practices. *In situ* burning of oiled wetlands potentially meets these criteria. The overall goal of this study was to evaluate the environmental effects and effectiveness of *in situ* burning of oil in wetlands. We reviewed and analyzed the literature concerning the ecological effects of prescribed burning in wetlands and the literature concerning the ecological impacts and effectiveness of *in situ* burning for oil spill cleanup. Also, we sampled a number of field sites to empirically assess the recovery of fresh, brackish, and saline marshes after *in situ* burning. Fire is a natural phenomenon in most, if not all, wetland systems. Additionally, prescribed burning has historically been used to manage wetlands and to increase the presence of more desirable plant species. The literature documents that most wetlands, except forested wetlands, recover from fires within one to five years. However, even marsh fires in herbaceous wetlands can be problematic if peat and root burns occur. The review of the *in situ* burn literature as well as the field sampling of six *in situ* burn sites indicated that recovery rates will vary, but recovery of herbaceous wetlands from *in situ* burning is likely to occur within a few growing seasons although complete recovery may take as long as a decade. Wetland recovery from *in situ* burns can likely be promoted by avoiding summer burns, insuring that the water level is above the marsh surface before burning, and refraining from burning at times when post-burn water levels are likely to rise. Also, *in situ* burning of forested and shrub wetlands should generally be avoided due to their slower recovery times. *In situ* burning represents a viable alternative to other oil spill cleanup techniques in wetlands under some, but not all, circumstances. *In situ* burning for wetland oil spill cleanup should be evaluated on a case by case basis before a final decision to burn is made.

# 1.0 Introduction

The cleanup of oil spills in wetland environments is problematic. Cleanup activities in these sensitive wetland habitats can do more damage than the oil itself (McCauley and Harrel, 1981, DeLaune *et al.* 1984, Kiesling *et al.* 1988). Hence, there is a need for less intrusive oil spill cleanup procedures that exert little to no long-term impact on the wetland system. A cleanup technique that is compatible with the wetland environment and present wetland management procedures would be highly valued. *In situ* burning of oiled wetlands is a possible candidate.

Wetlands, both coastal and inland, are often burned in order to provide better wildlife habitat (Chabreck, 1975, Kirby *et al.* 1988, Schmalzer *et al.* 1991). Although marsh burning is a widespread and accepted management practice in North America, the published literature reports that the impacts of marsh burning can be beneficial, detrimental, or without effect (e.g. see Turner, 1987 and references therein). Turner (1987), for example, found that a late winter burn in a Georgia salt marsh reduced net aboveground primary productivity compared to controls. A fall burn in a salt marsh in Florida also reduced the biomass of the vegetation by more than 50% one year after the burn, although species composition was unaffected (Schmalzer *et al.* 1991). The degree of impact can vary with the season. In a *Phragmites* marsh in the Netherlands, a winter burn conducted before new shoots emerged caused little or no impacts, while burning during the spring emergence period caused death among a majority of the plants (van der Toorn and Mook, 1982). However, winter and early spring burns in Gulf Coast marshes resulted in increased aboveground productivity (Whipple and White, 1977; Hackney and de la Cruz, 1983). Although season and wetland type are likely important factors controlling the outcome of marsh burning, an analysis, integration, and synthesis of the existing literature has not been attempted. The conclusions derived from such a synthesis could be used as guidance for the application of *in situ* burns for oil spill cleanup in wetlands.

Even less is known about the impacts and recovery of wetlands subjected to *in situ* burning after an oil spill. Few *in situ* burns have been quantitatively evaluated with regard to wetland impacts and recovery, let alone effectiveness in removing the spilled oil. Research studies that have compared *in situ* burning with other oil spill cleanup techniques in wetlands are limited in number and scope (McCauley and Harrel, 1981, Kiesling *et al.* 1988) and sometimes result in different conclusions (Holt *et al.* 1978; Baker, 1970; McCauley and Harrel, 1981). For example, Holt *et al.* (1978) found that burning an oiled *Spartina alterniflora* marsh in Texas resulted in better recovery than an uncleaned marsh, supporting earlier findings by Baker (1970). In contrast, burning an oiled *S. patens* marsh in Texas had a more negative impact on the vegetation than no action at all (McCauley and Harrel, 1981). There is not enough data to address these contradictory results and to adequately determine the value of *in situ* burning for oil spill clean up in wetlands.

In light of the need for benign methods to clean up oil in wetlands, the potential value of *in situ* burning, and the limited information from which to draw conclusions concerning this method's suitability, the objective of this research was to assess the environmental effects and effectiveness of *in situ* burning of oil in wetlands. Specifically, this research addressed the following questions:

(1) What factors control whether burning, in the absence of an oil spill event, results in positive or negative impacts to the wetland?

(2) What are the ecological effects of *in situ* burning for oil spill cleanup?

(3) How effective is *in situ* burning in removing oil from the wetland environment?

In order to satisfactorily answer these questions without using manipulative field experiments, we have reviewed and analyzed the literature concerning the ecological effects of prescribed burning in wetlands and the literature concerning the ecological impacts and effectiveness of *in situ* burning for oil spill cleanup. We have also sampled a number of field *in situ* burn sites to empirically make these determinations.

# 2.0 Methodology

## 2.1 Literature Evaluations

References on the use of fire as a management tool in marsh ecosystems were obtained using resources at the Louisiana State University Library. Computer searches were conducted through the following databases:

- AGRICOLA
- Current Contents
- General Science Index
- Science Citation.

Additional references were obtained from a 36 citation subset of a bibliography on oil spill issues compiled by the Louisiana Applied Oil Spill Research and Development Program (1995). The bibliography was compiled using 43 separate databases, including American Petroleum Institute Literature, Biosis Previews, Chemical Abstracts, Energyline, National Technical Information Service, and Pollution Abstracts. The bibliography included over 4000 citations.

Burn management references were analyzed both for environmental factors at the time of the burn and for system response to burning. Environmental factors included season of the burn, water level on the subject wetland, wetland type (salt marsh, brackish marsh, freshwater marsh, etc.), and community type. System responses included the following vegetative parameters: biomass, productivity, cover, species composition, tissue chemistry, stem density, plant height, basal diameter, root effects, and leaf effects. In addition, sediment chemistry responses were noted, as were any faunal responses.

References concerning the use of *in situ* burning as a tool to remove spilled oil were derived from the oil spill issues bibliography provided by the Louisiana Applied Oil Spill Research and Development Program (1995). References were also analyzed for both independent and dependent factors relating to burn success. Independent factors included season of the burn, water level on the subject wetland, system type (wetland, open water, experimental, etc.), community type, and oil type. Dependent responses included burn characteristics such as thermodynamics, removal efficiencies, aerosol formation, residue formation, soot/smoke formation, general burn chemistry, vegetative response, substrate response, faunal response, and any noted contributing or complicating factors.

## 2.2 Field Sampling

A questionnaire was prepared to identify field sites where previous, documented petroleum hydrocarbon spills had occurred and where *in situ* burning was used in the site cleanup. This questionnaire requested information concerning any knowledge of the occurrence of *in situ* burns in wetlands and general information on the topic of *in situ* burns for oil spill cleanup. Questionnaires were mailed to members of the oil industry, governmental regulatory agencies, and other relevant organizations both on a national and international level. Target individuals were identified from a mailing list provided by the Louisiana Oil Spill Coordinator's Office that listed individuals who attended the latest Clean Gulf Conference and the 1993 API Oil Spill Conference. A total of approximately 150 questionnaires were mailed. We received responses from more than one-third of the mailed questionnaires.

Respondents made us aware of several possible *in situ* burn sites in North America. Site selection was based on age of the spill (sites that were oiled and burned within the last 12 years were preferable to older sites), the type of wetland impacted (wetlands with species that also occur in Gulf Coast marshes were preferred), and adequate documentation of the spill and burn. A final consideration was the feasibility of sampling the site before the first frost. This eliminated three northern freshwater *in situ* burn sites from further consideration located in Maine, Canada, and Alaska.

In addition to the questionnaire, direct phone contact with relevant individuals in the Gulf Coast area was used to obtain information on possible study sites. Phone contact with Exxon was responsible for identifying an *in situ* burn *Phragmites* marsh adjacent to Southeast Pass in the Pass-a-Loutre Wildlife Management Area. Texaco informed us of three oil spills and *in situ* burns of different ages in the Lafitte, Louisiana oil field.

Prior to visiting a site, aerial photographs and/or USGS quad maps were obtained and studied to identify the impact of the oil spill and *in situ* burn and to identify possible control sites. Potential environmental gradients, particularly elevation and flooding gradients, and discontinuities in plant community composition were also identified from these photographs and maps. Whenever possible, pre-spill aerial photographs were acquired to identify pre-spill plant communities and potential control sites of similar plant community composition.

Our general sampling procedure for each site was to establish a transect in the oiled and burned site and also in an adjacent unimpacted control site (oiled and unburned sites were not identifiable). To reduce sample variance the transects were positioned so as to minimize any environmental gradient that existed in the sampling sites. This was generally accomplished by positioning transects parallel to an existing shoreline or spoil bank, such that plots would be established at approximately the same distance from the water body, and thereby approximately the same relative elevation. Transects were established along the same gradient at both the *in situ* burn sites and the control sites.

Each transect was divided into five equidistant zones. A random numbers table was used to determine plot placement within each zone. At each sampling plot, all aboveground vegetation (both live and dead, regardless of species) was harvested from within a sampling quadrat placed at ground level, whose size varied depending on the heterogeneity of the vegetation at the *in situ* burn site, but typically was 0.25 to 0.5 $m^2$. Sediment in the quadrat was sampled to a depth of 12 cm for analysis of total petroleum hydrocarbons (TPH, APHA 1989) in each plot and GC/MS analysis of hydrocarbon constituents (Roques *et al.* 1994) in composited samples from each *in situ* burn site and control site. Both of these soil analyses were performed by the Institute of Environmental Studies at Louisiana State University.

The vegetation samples were sorted into live and dead aboveground biomass by species, dried to a constant weight at 65 C, and weighed. All biomass values were standardized to g $m^{-2}$, and ANOVA was used to test for statistically significant differences in live, dead, and total biomass between *in situ* burn sites and their respective control sites. Below are descriptions of the six *in situ* burn sites that were sampled and any variation in sampling technique specific to a particular site. Recovery is herein defined as no significant difference in response variables between burned and control marshes.

### 2.2.1 Pass-a-Loutre, Louisiana

This *in situ* burn site is located in the Southeast Pass region of the Mississippi River Delta. The burn occurred on 31 August, 1990 in response to a pipeline leak of several hundred barrels of South Louisiana Crude in a *Phragmites australis* marsh. The type of accelerator fluid used to start the burn is unknown. Flares were used to start the fire, which lasted about one hour and burned itself out when the primary fuel source (oiled cane) was used up, resulting in a burn area approximately 150 to 200 m wide by 300 m long. The burn was documented on videotape, and the vegetative recovery was evaluated from the video tape at 18 and 34 months post-burn. The site was visited for investigation and sampling on 28 and 29 July, 1994, 48 months after the *in situ* burn was undertaken. Access to the site and to surrounding control sites was facilitated by use a Louisiana Department of Wildlife and Fisheries air boat and the department's Pass-a-Loutre Wildlife Management Area headquarters as a staging area. Two control sites were established, one on each side of the *in situ* burn site. Sampling plots for the controls and the *in situ* burn site were located on transects that ran parallel to the spoil bank of the canal.

### 2.2.2 Chiltipin Creek, Texas

This *in situ* burn site is located in a high elevation brackish/saline marsh in Chiltipin Creek adjacent to the Arkansas River in the Copano Bay region of Texas. The *in situ* burn was conducted in response to a pipeline blowout in January 1992. Approximately 2,950 barrels of South Texas Light Crude was spilled. Sorbent booms and pads were utilized prior to the burn. A mixture of diesel and varsol was used as the accelerator. The burn lasted approximately 16 hours. Following the burn, additional cleanup employed pom-poms and low pressure flushing. The Center for Coastal Studies (CCS) at Texas A&M University, Corpus Christi implemented a long-term study of the site's recovery. The CCS staff allowed us to access their data and reports to assess the success of this *in situ* burn. In addition to their existing data, the CCS staff assisted us during the field sampling of the site. On 25 and 26 August, 1994 we conducted the field sampling, 32 months after the *in situ* burn. Mr. Beau Hardegree of the CCS accompanied us to the site where three main classes of marsh sites were designated as control, oiled and burned, and oiled/pooled and burned. Sites designated as oiled/pooled and burned were areas of apparently slightly lower elevation where oil was observed to have pooled and where initial CCS sampling had shown potentially higher soil TPH values. Within each of the two burn classes of marsh sites we randomly selected five areas, and then within each area randomly sampled a plot. In the control marsh area a transect was established that ran between the two bordering ridges of the marsh and was randomly sampled approximately every 100 m. Biomass data from this site was processed by CCS staff in the same manner their earlier sampling of the site, and therefore did not include separation into live and dead components.

### 2.2.3 Meire Grove, Minnesota

This *in situ* burn site is located along the southern extent of the prairie pothole region of north central Minnesota, near the town of Meire Grove. In September 1992, an oil pipeline leak resulted in what Amoco estimated to be up to 2,500 barrels of oil product impacting a two acre freshwater wetland pond dominated by *Typha* spp. The pipeline leak occurred approximately 1 km to the south of the pond and was undetected for approximately 10 days, during which time the pipeline transported fuel oil and gasoline. The petroleum product entered a drainage tile and traveled underground until it emptied into a drainage ditch that entered the southern edge of the pond. The oil product primarily impacted the southeastern half of the pond and exited the pond via another drainage tile on the northeastern shore. The spill was burned no more than 16 hours after the leak was reported by the property owner. No accelerators were needed to ignite this fairly volatile mixed petroleum product. The burn lasted approximately three hours. The following morning several spot burns were ignited over a two hour period. Sorbent pads were then utilized in the cleanup, as was some vegetation clearing and soil excavation in the area of the pipeline leak, but apparently not in the area of the wetland. Nonetheless, a fair amount of human impact resulted from trampling of the marsh edge and pond bottom during the various ignitions and cleanup activities.

On 10 and 11 October, 1994 we conducted the field sampling of the site. Upon visiting the site, residual signs of human trampling were visible along the southeastern shore and pond bottom. A transect was established that ran along the southeastern shoreline between the inflow and outflow tiles. Sampling distances along the transect were randomly selected as described above, and samples were taken at the 30 cm depth contour of the pond. Conversation with the property owner confirmed that the water level at that time was similar to that at the time of the spill and that our sampling zone was well within the sector impacted by the spill. The area had been a fairly wide shoreline fringe of *Typha* with some sedge (*Carex sp*.). The same procedure was utilized in sampling the 30 cm depth contour of the southeastern shoreline of a control pond located approximately 1 km to the west on the next adjoining property. Conversations with both property owners confirmed that the control pond and the oiled and burned pond previously had similar plant species and plant cover along their southeastern shorelines.

### 2.2.4 Lafitte Oil Field, Louisiana Station 1

This *in situ* burn site was the result of an oil spill of less than one barrel of South Louisiana Crude in a coastal brackish marsh. The spill and *in situ* burn occurred in June, 1992. Diesel fuel is believed to have been used as the accelerator. The duration of the burn is unknown. On 2 November, 1994, 29 months after the spill and burn, we conducted the field sampling of this site. Texaco provided water transportation to the field camp and the marsh sites. Sampling transects were established in the *in situ* burn marsh site and in a control marsh site identified from aerial photography and ground truthed for suitability. In both sites plots were randomly selected along transects that paralleled canal banks to minimize elevation differences between the oiled and burned marsh site and the control marsh site.

### 2.2.5 Lafitte Oil Field, Louisiana Station 2

This *in situ* burn site is also located in Texaco's Lafitte oil field and was the result of an oil spill of 282 barrels of South Louisiana Crude oil in a coastal brackish marsh. The spill and *in situ* burn occurred in May, 1983. Diesel fuel is believed to have been used as the accelerator. The duration of the burn is unknown. Several other cleanup methodologies were reported to have been used at this site including oil mops, skimmers, sorbent pads, and hay. On 17 November, 1994, 11 years after the spill and burn, we conducted the field sampling of this site. Texaco provided logistical support and a shallow draft flat bottom boat for accessing the marsh sites. Sampling transects were established in the *in situ* burn marsh site and in a suitable control marsh site previously identified from aerial photography and ground truthed for suitability. In both sites plots were randomly selected along transects that paralleled canal banks to minimize elevation differences between the oiled and burned marsh site and the control marsh site.

### 2.2.6 Lafitte Oil Field, Louisiana Station 3

This final *in situ* burn site is also located in Texaco's Lafitte oil field and was the result of an oil spill of four barrels of South Louisiana Crude oil in a coastal brackish marsh. The spill and *in situ* burn occurred in September 1986. The duration of the burn is unknown, but diesel fuel is believed to have been used as the accelerator. Pollution booms and sorbent pads were reported to have been employed in the cleanup. On 17 November, 1994, eight years after the spill and burn, we conducted the field sampling of this site. Texaco provided logistical support and a shallow draft flat bottom boat for accessing the marsh sites. As in the other Lafitte oil field *in situ* burn sites, sampling transects were established in the *in situ* burn marsh site and in a suitable control marsh site previously identified from aerial photography and ground truthed for suitability. In both sites plots were randomly established along transects that paralleled canal banks to minimize elevation differences between the oiled and burned marsh site and the control marsh site.

# 3.0 Results and Discussion

## 3.1 Literature Review: Burning for Wetland Management

### 3.1.1 Introduction

Fire is a natural phenomenon in many, if not most, natural ecosystems. Habitats as varied as the giant sequoia forests of the California Sierra Nevada mountains to the grasslands of the central plains of the United States require fire for regeneration and/or persistence. Thus, it is not surprising that the role of fire in the ecology and management of these and other fire adapted communities has been extensively studied. In contrast, our literature review and the review conducted by the U.S. Fish and Wildlife Service (Kirby *et al*. 1988) confirmed that the effects of fire on wetland systems have not been intensively investigated even though fire has been used as an important management tool. In fact, as early as 1938 reference was made to the value of fire in managing wetlands for waterfowl (Furnis, 1938). By the 1940s, the significance of fire in the development and maintenance of several wetland communities was acknowledged (Atlantic coast–Griffith (1941), Smith (1942); Southeastern–Wells (1942), Garren (1943); Gulf Coast–Lynch (1941); Texas Gulf Coast–Lay and O'Neil (1942); Delta Marsh, Manitoba–Ward (1942).

The majority of published papers discuss fire as one of a number of management tools suitable in the wetland environment. Information concerning the optimum time to burn, which marsh types respond best to burning, the importance of water level prior to and after the burn, and the effects of fire on wetland functional processes, such as primary productivity, nutrient cycling, decomposition, succession, etc., have generally received little attention. Additionally, a synthesis of the existing literature, from which overall conclusions about fire in wetlands could be formulated, is not available. Such a synthesis would be especially valuable in an attempt to apply the present state of knowledge concerning prescribed burning of wetlands to the effective and ecological safe use of *in situ* burning for oil spill cleanup in wetlands. The following discussion attempts to fill this information gap.

Prescribed burns in wetlands may provide benefits such as: (1) retarding succession and allowing for a more diverse community, (2) increasing the availability of seed bearing food plants to waterfowl, (3) providing succulent young growth for browsing waterfowl and mammals, (4) opening up areas for better trapper access, (5) creating open water for waterfowl, and (6) removing dense stands of vegetation and attracting waterfowl. These goals can be achieved from one of three types of burns: (1) cover burns that occur in marshes with saturated soils or standing water and remove only aboveground plant material, (2) root burns that may occur during low water conditions and result in the consumption of both aboveground plant material and surface roots, and (3) peat burns that most frequently occur during drought conditions and consume the organic marsh substrate, forming shallow ponds (Lynch, 1941). Of course, the ability of wetlands to recover from fire is very much dependent on the type of burn.

### 3.1.2 Vegetative Growth

The effects of fire on wetland systems have been investigated in many different wetland habitats both coastal and inland, from Canada to Florida and include salt marsh, brackish marsh, fresh marsh, swamp, and bog (see Kirby *et al*. 1988). In this review, we have drawn upon 27 published papers that discuss the response of wetlands to burning. Salt marsh studies comprise 8% of the 27, while brackish and fresh marsh investigations account for 22% and 70%, respectively. Thus, an imbalance exists regarding our knowledge base; much more information is available concerning the effects of fire in freshwater wetlands than in salt marshes. This imbalance is understandable since fire is used more extensively to manage freshwater marshes than salt marshes, and the importance of fire as a management tool in brackish marshes is intermediate. Vegetative response to fire is most commonly evaluated using measures such as biomass, primary productivity, stem number, stem height, cover, community structure, and species richness, diversity and composition. As might be expected, the vegetative response of wetlands to fire is highly variable. Immense stimulation in biomass production is possible, as occured when a 2,735% increase in the yield of a freshwater marsh was created in North Florida (Vogl, 1973). Dramatic reductions in plant growth can also occur. In some cases, a specific plant population may virtually disappear, as occurred with *Distichlis spicata* in a fresh marsh adjacent to the Great Salt Lake in Utah (Smith and Kadlec, 1985). Much of this variation can be explained as a function of season of the burn, water level in the marsh prior to or after the burn, the marsh type and species composition, and the specific conditions of the burn as discussed below.

#### 3.1.2.1 Season of Burn

Although the ability of a marsh to recover from a burn appears to be related to the season of burn (Tables 3.1 and 3.2), only a handful of studies have been designed to specifically investigate this factor (Forthman, 1973; Hess, 1975; Chabreck, 1981; Diiro, 1982; Mallik and Wein, 1986; Shay *et al.* 1987). Nonetheless, a general trend of inhibited marsh recovery from summer burns is evident. In a well designed experimental study of burning in a freshwater *Phragmites australis* marsh in Manitoba, Canada (Shay *et al.* 1987), summer burning produced significantly lower biomass production compared to fall and spring burns four years after the burn (biomass resulting from the summer burn, however, was equal to that of the control). The depletion of rhizome carbohydrate reserves by late summer growth, followed by the burn, may have reduced subsequent regrowth in the summer burn treatment. The higher biomass production from the fall and spring burns compared to the control was likely due to the input of inorganic nutrients from the burned litter and to greater light penetration of the marsh surface, thereby increasing soil temperatures and warming the soil more rapidly in the spring (Shay *et al*. 1987). Diiro (1982) also found that fall burns stimulated the biomass production of a northern grass, *Scolochloa festucacea*, in Canada; spring burns had no stimulatory effect. Thus, depending on the season of a burn, fire can either stimulate or retard wetland plant growth. In more southern latitudes, fall burns have an effect similar to the summer burns in Canada. A fall burn in a *Cladium jamaicense* marsh in Florida yielded incomplete recovery after one year while a spring burn resulted in complete recovery (Forthman, 1973). In Louisiana, although Hess (1975) found that the season of burn had no statistically significant effect on the stem density of *Spartina patens* or *Scirpus olneyi*, stem densities for *S. olneyi* were generally lowest with fall burns and highest with winter burns. Chabreck (1981), investigating these species' responses to burning, found that both species could recover from burning, although recovery was slower after fall burns.

**Table 3.1** Percent of wetland burn events resulting in either an increase, no change, or decrease in vegetative growth compared to controls for recovery times < 1.5 yr.[1]

| Season | Number of Observations | % Increase | % No Change | % Decrease |
|---|---|---|---|---|
| Spring | 9 | 44 | 44 | 11 |
| Summer | 11 | 0 | 45 | 55 |
| Fall | 5 | 40 | 40 | 20 |
| Winter | 8 | 25 | 38 | 37 |
| | | | | |
| Overall | 33 | 24 | 43 | 33 |

1 Growth response includes biomass, productivity, cover, stem height and number. Responses from fresh, brackish and salt marsh studies are combined (Diiro, 1982; Forthman, 1973; Hackney and de la Cruz, 1977; Hess, 1975; Kirkman and Sharitz, 1994; Messinger, 1974; Neckles *et al.* 1985; Schmalzer *et al.* 1991; Shay *et al.* 1987; Smith, 1973; Smith and Kadlec, 1985; Steward and Ornes, 1975; Taylor *et al.* 1994; Turner, 1987 & 1988; VanArman and Goodrich, 1979; Vogl, 1973).

In order to generalize about the impact of wetland burning on vegetative recovery and the effect of season, we assessed what percentage of the burn events resulted in either an increase, decrease, or no change in plant growth compared with the appropriate control (Tables 3.1 and 3.2). Because some studies present data from more than one burn event, the total number of burn events (34 for recovery times < 1.5 years and 20 for recovery times > 1.5 years) can be greater than the number of research studies (27). The results are consistent whether the recovery times are relatively short (Table 3.1) or prolonged (Table 3.2). Summer burns resulted in the greatest percentage of burn events exhibiting a decrease in vegetative growth, (i.e. incomplete recovery). For recovery times less than 1.5 years, 55% of the summer burn events resulted in growth lower than the controls, compared to 11%, 20% and 37% for spring, fall and winter, respectively. For recovery times greater than 1.5 years, 42% of the summer burn events generated growth lower than the controls, compared to 0%, 25%, and 0% for spring, fall and winter, respectively. Regardless of season, burning only resulted in lower growth response than controls in 20 to 33% of the cases depending on recovery time (Tables 3.1 and 3.2). Hence, for the 53 burn observations found with usable data, 67 to 80% of the post-burn growth response events were equal to or greater than the control, indicating recovery. We can conclude that although in the large majority of cases burning in wetlands has no negative impacts on the growth response of vegetation, there is still a significant minority of cases (20 to 33%) when burns resulted in negative growth responses. Avoiding summer burns may reduce this impact.

**Table 3.2** Percent of wetland burn events resulting in either an increase, no change, or decrease in vegetative growth compared to controls for recovery times > 1.5 yr.[1]

| Season | Number of Observations | % Increase | % No Change | % Decrease |
|---|---|---|---|---|
| Spring | 6 | 50 | 50 | 0 |
| Summer | 7 | 29 | 29 | 42 |
| Fall | 4 | 50 | 25 | 25 |
| Winter | 3 | 100 | 0 | 0 |
| Overall | 20 | 50 | 30 | 20 |

1 Growth response includes biomass, productivity, cover, stem height, and number. Responses from fresh, brackish, and salt marsh studies are combined (Davison and Bratton, 1988; Hackney and de la Cruz, 1981; Mallik, 1990; Mook and van der Toorn, 1982; Shay *et al.* 1987; Thompson and Shay, 1989; Timmins, 1992; Young, 1986).

#### 3.1.2.2 Marsh Water Level

Water level during or after the burn is another factor that can influence post-burn recovery. In a *Typha glauca* dominated freshwater marsh impoundment in Canada, Mallik and Wein (1986) demonstrated that burning the drained portion of the impoundment resulted in lower plant cover after three years of recovery compared to the controls with the summer burn generating the greatest negative impact. However, the burn in the flooded portion of the impoundment stimulated plant cover above that of the controls regardless of season. Hess (1975) also found that burning during higher water levels produced greater stem density and height of *Scirpus olneyi*; however, *Spartina patens* was unaffected. In a New Zealand bog, burning also resulted in a more favorable response at wet compared to drier sites (Timmins, 1992). In contrast, Vogl (1973) reported that the burning of a drier (wet mesic) site in a freshwater marsh in northern Florida gave a much better post-burn growth response than burning a site with standing water. In this case, the burn at the drier site removed much of the dead litter mat which was inhibiting new growth of *Panicum hemitomon* in the marsh. In some cases, no difference in growth response to burning was apparent between dry and wet plots, such as for a *Phragmites australis* marsh in the Netherlands (Mook and van der Toorn, 1982). In general, however, it appears that burns that take place with some water over the marsh surface are likely to recover more rapidly than marshes without surface water. The beneficial effect of surface water covering the marsh may be due, in part, to its preventing an elevation in soil temperatures during the burn (Hoffpauir, 1961).

The marsh water level after the burn is as important as the water level at the time of the burn. For example, an increase in water level after a burn of a fresh marsh in Utah resulted in the virtual elimination of *Distichlis spicata* (Smith and Kadlec, 1985). Similar results were found in a greenhouse study where an increase in water depth to 30 cm after a burn decreased the stem density of *Distichlis spicata* and *Spartina patens* compared to low water controls (Babcock, 1967). Davison and Bratton (1988) reported that two freshwater marshes in Georgia exhibited greater open water as water levels increased over a two year period following a burn. Kirkman and Sharitz (1994) found that rhizomes from a burned *Panicum hemitomon* marsh produced fewer and shorter stems than rhizomes from an unburned marsh. They attributed this effect to the removal of the previous years' stem material, which reduced survival by preventing oxygen transport to the roots. Many wetland plants are adapted to life in anoxic soils because they can transport oxygen via air space tissue (aerenchyma) from the atmosphere to the roots and rhizomes where the oxygen is used to support plant metabolic processes. Even dead stems that remain upright during the winter are important as conduits for oxygen movement; the removal of the standing dead stems can reduce growth the following growing season (Jordan and Whigham, 1988). Thus, burning even during the dormant period can influence subsequent growth. This is especially likely if water levels are elevated after the burn and soil temperatures during the winter are high enough to allow for some metabolic activity of rhizomes. Increases in water level after a burn, do not however always result in reduced plant growth. For example, a low water, summer burn in a freshwater marsh dominated by *Panicum hemitomon* and *Pontederia lanceolata* in Florida followed by an increase in water level that flooded the marsh surface had no significant effect on the biomass production of either species after one growing season (VanArman and Goodrich, 1979). In this case, the plants were probably able to produce new shoots before the water level increase or to grow through the water to reach the atmosphere. Flooding after a burn can even stimulate plant production if the flooding event occurs at the time of active growth as observed in Delta Marsh, Canada for whitetop, *Scolochloa festucacea*, which increased in yield 55% compared to unburned controls after spring flooding (Neckles *et al.* 1985). Regardless, changes in post-burn water levels must be considered in predicting the vegetative response of a marsh to fire.

### 3.1.2.3 Species Effect

One of the primary objectives of burning wetlands is to suppress the dominance of some species in order to enhance the dominance of others. This often results in an overall increase in species richness or diversity (Table 3.3). Therefore, it is not surprising that some species respond more favorably to burning than others. A well known example of this phenomenon is the dominance of *Scirpus olneyi* over *Spartina patens* after burns in brackish marshes where these two species both occur (Hess, 1975; Chabreck, 1981; Taylor *et al.* 1994). For example, although overall plant biomass was lower in burned plots than in the controls two months after a burn in a brackish marsh in Louisiana, the biomass of *S. olneyi* increased while that of *S. patens* decreased (Taylor *et al.* 1994). Thompson and Shay (1989) reported that burning a freshwater marsh in Canada decreased the biomass of *Phragmites australis*, the normal dominant, but increased the biomass of typical understory species such as *Cirsium arvense*, *Lycopus asper*, *Mentha arvensis*, *Teucrium occidentale*, and *Urtica dioica*. However, the season of burn controlled the species composition of the post-burn community. Species specific differences to fire were readily observed in a freshwater marsh adjacent to the Great Salt Lake in Utah (Smith and Kadlec, 1985). Of the four monotypic vegetation types burned in early fall and subsequently flooded in the spring, *Scirpus maritimus* and *S. lacustris* showed no difference in biomass between burn and control plots after one year, *Typha latifolia* had a somewhat lower biomass when burned, and *Distichlis spicata* did not recover from burning and was eliminated from the community. Smith and Kadlec (1985) suggested that these species differences were likely due to the rapidity with which the species were able to produce new aboveground tissue after the burn. Species that could more rapidly reestablish a connection for oxygen movement between the atmosphere and the waterlogged roots and rhizomes were less impacted by subsequent flooding. Three years following the burning of two freshwater marshes in Georgia, the *Spartina bakeri* dominated community had completely recovered while the *Cladium jamaicense* dominated community had not yet reached the vegetative cover of the unburned controls (Davison and Bratton, 1988). In some cases, species specific differences in growth response after a burn were not apparent. After four years of recovery, both a *Juncus roemerianus* dominated community and a *Spartina cynosuroides* dominated community in a brackish marsh in Mississippi exhibited increased net aboveground primary productivity compared to the unburned controls (Hackney and de la Cruz, 1981). Schmalzer *et al.* (1991) also found that two brackish marsh communities, one dominated by *J. roemerianus* and the other by *Spartina bakeri*, responded similarly to burning, however, in this case burning reduced biomass compared to controls one year after the burn.

**Table 3.3** Percent of wetland burn events resulting in either an increase, no change, or decrease in species richness compared to controls for recovery times < 1.5 yr[1].

| Season | Number of Observations | % Increase | % No Change | % Decrease |
|---|---|---|---|---|
| Spring | 2 | 50 | 50 | 0 |
| Summer | 9 | 56 | 44 | 0 |
| Fall | 2 | 50 | 50 | 0 |
| Winter | 5 | 0 | 100 | 0 |
| Overall | 18 | 39 | 61 | 0 |

1 Species richness is the number of different species in the marsh. Responses from fresh, brackish, and salt marsh studies are combined (Davison and Bratton, 1988; Hackney and de la Cruz, 1977 and 1981; Messinger, 1974; Schmalzer *et al*. 1991; Taylor *et al.* 1994; Thompson and Shay, 1989; Timmins, 1992; VanArman and Goodrick, 1979; Vogl, 1973)

### 3.1.2.4 Soil Type

Although little information is available concerning the effect of soil type on the vegetative response to marsh burning, this could be an important factor controlling post-burn response. For example, organic marsh soils would likely be more prone to peat burns that greatly impair recovery. In the greenhouse, Hess (1975) burned *Scirpus olneyi* and *Spartina patens* planted in pots that contained either an organic or a mineral soil. Although soil type had no significant effect on stem density, stem height for both species was greater in the organic soil compared to the mineral soil. In this case a peat burn did not occur, and the organic soil may have been generally more conducive to growth than the mineral soil. If the marsh soil is covered with thick mats of plant litter, a burn would likely remove the growth suppressing effect of the litter on the live vegetation as observed for a *Panicum hemitomon* marsh in Florida (Vogl, 1973).

Also, fire can release nutrients that stimulate plant growth (Faulkner and de la Cruz, 1982). How soil type controls the vegetative response to burning needs further study.

### 3.1.3 Vegetative Species Richness

Burning for marsh management is often conducted to increase the number of species that are of value as food for waterfowl and wildlife. Thus, a major goal of burn management is to increase the species richness (i.e number of species) of the wetland. Our literature review uncovered 10 papers containing 18 separate examples of the species richness response of specific marsh communities to burning. It is clear from the results presented in Table 3.3 that in all cases burning increased or had no effect on species richness. Even in the summer, burning did not decrease species richness in these examples of response one year post-burn. An increase in species richness is most likely to occur if the burn is in the summer (Table 3.3). Winter burns had no effect on species richness.

A common response of species composition to marsh burns is an increase in minor marsh species. Davison and Bratton (1988) reported that following the summer burn of a low water *Spartina bakeri* freshwater marsh in Georgia, the wettest plots, which experienced peat burns, were initially colonized by *Polygonum hydropiperoides*, *Sagittaria latifolia*, *Nymphaea odorata*, *Nymphoides aquatica*, *Limnobium spongia*, *Utricularia* spp. and *Decodon verticullatus,* while *Pluchea* spp., *Proserpinaca pectinata*, *Panicum* spp., *Xyris* spp., *Juncus* spp., *Eleocharis* spp., and *Andropogon virginicus* invaded drier plots. Similar increases in minor species were observed in a nearby *Cladium jamaicense* freshwater marsh after burning (Davison and Bratton, 1988). Different layers of the plant canopy can respond differently to burning. After burning two brackish marshes in Florida, Schmalzer *et al*. (1991) found that the lower zone of the canopy (0 to 0.5 m) increased in diversity in both *Juncus roemerianus* and *Spartina bakeri* marshes, but there was no burn effect on the > 0.05 m layer of the canopy. Species such as *Ludwigia repens*, *Sagittaria lancifolia*, *Pluchea rosea* and others invaded the *Juncus* marsh while *Eriantus giganteus*, *Ipomoea sagittata*, *Mikania scandens*, *Sagittaria lancifolia* and others invaded the *Spartina* marsh. Although there was an increase in minor species after the fire, the overall change in community composition was actually small. The time of the burn can also control the post-burn species richness. For example, a summer burn increased the species richness in a Canadian *Phragmites australis* marsh, while spring and fall burns caused no significant change (Thompson and Shay, 1989).

Although change in species richness, at least in the short-term, is common after burning, some burns do not generate this response. Vogl (1973) reported that the winter burn of a Florida freshwater marsh dominated by *Panicum hemitomon* and *Typha latifolia* resulted in no effect on species diversity. Also, in two brackish marsh communities in Mississippi, species richness did not respond to burning (Hackney and de la Cruz, 1981). However, even when species richness changes do occur, they are often only transitory. For example, although Schmalzer *et al*. (1991) noted changes in species richness in three separate Florida marsh communities one year after burning, no differences were evident relative to the controls after one additional year. In addition recovery had occurred during the one year period. These results are in agreement with the general statement made by McGlone *et al.* (1984) that vegetative changes in response to fire are short-lived. Therefore, it is not likely that burning will have long-lasting effects on the vegetative composition of wetlands. None the less, as cautioned by a some researchers (Hackney and de la

Cruz, 1981; Schmalzer *et al.* 1991), marsh burning should be used carefully as a management tool.

### 3.1.4 Faunal Effects

Although this review emphasizes the plant communities of wetlands, the effects of burning on wetland fauna are also of interest. One of the major objectives of wetland burning is to decrease plant cover and increase open water to attract waterfowl. Although fire in wetlands does serve this purpose (see Kirby *et al.* 1988), waterfowl use in a freshwater marsh in Iowa was not greatly affected by burning. Nest success was lower in burned plots possibly due to increased predation rates (Messinger, 1974). Despite these studies the effect of burning on the resident fauna remains in question. Vogl (1973) makes the strong statement that,"the impression that fires are usually lethal to warm blooded vertebrates appears to have been often based on incomplete, subjective, and perhaps biased information or unusual fires, because this and other recent studies report minimum mortality," (see references in Vogl, 1973). In addition, Vogl (1973) reported that in a freshwater marsh in Florida post-fire mammal numbers were about the same as before the burn, and birds were in fact attracted to the burned marsh. Tewes (1982) also found that although some birds were attracted to the burn site, other bird species were reduced following the burn of a *Spartina spartinae* marsh in Texas. Rodent populations in this marsh appeared higher the following year, but were reduced immediately after the burn (Tewes, 1982). Hence, the habitat value of burned marshes may not necessarily be reduced. Additionally, the invertebrates in a freshwater marsh in Florida were not detrimentally affected by a low water summer burn (VanArman and Goodrick, 1979). There was no significant effect on species diversity, and total numbers of species and individuals were greater in burned plots than in the controls. Matta and Clouse (1972) reported that adult forms of insects were not significantly affected by a burn in a coastal marsh in Virginia, however, the principal insect herbivore, a meadow katydid, had fewer numbers of individuals at a recently burned site. The benthic meiofauna of a *Spartina alterniflora-Juncus roemerianus* marsh in Alabama was immediately reduced in number by 60%, but recovered completely three to four months after the burn (Ivester and Harp, 1978). Although it would generally appear that marsh animals can readily recover from fires, more information is needed concerning the effects of marsh burning on the animal populations of wetlands before a complete understanding of this subject is attained.

### 3.1.5 Summary

Fire is a natural phenomenon in most, if not all, wetland systems. Additionally, prescribed burning has been historically used to manage wetlands and to increase the presence of more desirable plant species. The literature clearly documents that most wetlands recover from fires relatively quickly, within one to five years. An exception to this rule is the recovery of shrub and forested wetlands, which is slower in general than the recovery of herbaceous wetlands (Gunderson, 1984; Foster and Glaser, 1986). However, even marsh fires in herbaceous wetlands can be problematic. For example, peat and root burns can dramatically alter the structure and probably the function of the burned wetland. Wetland recovery from fire can be promoted by avoiding summer burns, insuring that the water level is above the marsh surface before burning, and refraining from burning at times when post-burn water levels are likely to rise. Burning of forested wetlands should also generally be avoided due to their much slower recovery times.

Given these qualifications, vegetative recovery from burning will likely proceed in a relatively short time period.

## 3.2 Literature Review: *In situ* Burning in Wetlands

### 3.2.1 Introduction

While *in situ* burning has been recognized as an acceptable response method for oil spills, it has been primarily used as a response option for open water burns, with only limited application to wetland or terrestrial spill events (Imperial Oil, 1988). Further complicating evaluation of the viability of *in situ* burning is that proper documentation of the procedures and results is at best limited and often absent. When complete documentation of a burn response event is available, the results are often of limited scientific application. One of the primary deficiencies in many documented events is that the effects of burning are not compared with other response options ( in particular leaving the spill untreated). This deficiency probably results from the understandable desire of response agencies to accomplish as complete a cleanup as possible. To that end, it is very rare for spill responders to leave any area untreated. This lack of adequate controls is less of a problem when *in situ* burning is evaluated through scientific experimentation.

### 3.2.2 Information from Open Water Burns

Most of the experience and hard data associated with *in situ* burning deals with open water spills. Burning oil, particularly crude oil, on a water layer consistently yields consumption efficiencies in excess of 90%, regardless of oil volume (Allen, 1991; Allen and Ferek ,1993; Evans *et al*. 1993; *Oil and Gas Journal,* 1993). The slick must be of adequate thickness to both reduce heat loss to the water below and maintain the necessary heat transfer between molecules to favor combustion (Fingas, 1992). The recognized minimum thickness is 2 to 3 mm (Allen and Ferek, 1993; Fingas, 1992; Smith and Diaz, 1985). Some transfer of heat to the water under a sufficiently thick oil layer may enhance combustion efficiency, as the boiling of the underlying water may result in the formation of an oil-in-water aerosol that burns more efficiently than pure oil (Evans *et al.* 1993).

Much of the concern over using *in situ* burning as a response option deals with the fate of oil components during the burn and with how much burn product is released into the environment. A component of particular concern is a class of compounds known as polycyclic aromatic hydrocarbons (PAHs). PAHs exist in crude oil generally in percentages not in excess of 1% by mass (Fingas, 1992), and although some of the lighter PAHs may be consumed in the fire, there is typically a conversion from low molecular weight species to more carcinogenic high molecular weight species (Allen and Ferek, 1993; Benner *et al.* 1990; Fingas, 1992; Tennyson, 1993). These remaining PAHs may either be released as aerosols (Allen and Ferek, 1993; Benner *et al.* 1990; Cofer *et al*. 1992; Fingas, 1992; Hobbs and Radke, 1992; Tennyson, 1993) or be associated with either the burn residue (Benner *et al.* 1990; Eufemia, 1993) or soot particles (Benner *et al.* 1990; Overton *et al.* 1981).

Also of concern in oil chemistry is the fate of heavy metals that may be present in the source oil. Unlike organic compounds, these elements are conserved during combustion and will be associated with the various burn products. Vanadium is common in oil and may be released aerially with burning, while other metals such as chromium, mercury and nickel are more common in the residue (Day *et al.* 1979).

While these components are of legitimate concern, they are rare in burning oil products. The most common compound released from burning oil is carbon dioxide, which may account for up to 95% of the total aerial carbon release by mass (Allen and Farek, 1993; Cofer *et al.* 1992; Tennyson, 1993). Other carbon components may include carbon monoxide (Allen and Ferek, 1993; Cofer *et al.* 1992; Day *et al.* 1979; Fingas, 1992; Hobbs and Radke, 1992; Tennyson, 1993) and organic compounds such as acetates, acids, aldehydes, esters, furans and ketones, found both in the burn residue as well as in aerial releases (Fingas, 1992; Tennyson, 1993). Also common in both source oil and burn products are sulphur compounds (Allen and Ferek, 1993; Cofer *et al.* 1992; Day *et al.* 1979; Fingas, 1992; Hobbs and Radke, 1992).

The exact compartmentalization of source oil into burn products is dependent on the specific spill. Residue production varies between 10 to 50% of the mass of the source oil, with thicker slicks producing less residue (Benner *et al.* 1990; Day *et al.* 1979; Gonzalez and Lugo, undated). Soot/smoke production is also dependent upon slick thickness, with thicker spills burning less efficiently due to a lower oxygen content fire and having an increased smoke production (Benner *et al.* 1990). In general, estimates for soot/smoke production are approximately 10% of source oil mass (Benner *et al.* 1990; Day *et al.* 1979; Evans *et al.* 1993; Fingas, 1992; Tennyson, 1993). Aerosol production is typically the dominant burn product component. As stated above, the primary component of aerosol release is carbon dioxide, with carbon monoxide, organic compounds, and sulphur-based compounds as relatively minor components.

### 3.2.3 Wetland Responses to *In situ* Burning

#### 3.2.3.1 Vegetative Responses

When evaluating the success of burning in a wetland, it is necessary to consider the removal efficiencies and resulting chemistry associated with the burning procedure, as well as the impacts on wetland ecosystem ecology. An obvious effect of burning on the marsh is the removal of vegetation from the system due to the destructive nature of fire. Of greater importance than this short-term consequence is the system's recovery from the disturbance. Vegetative response may be measured using any one of a number of parameters, with standing crop, productivity and diversity indices among the most useful.

While plant growth responses to *in situ* burning are often negative in the short-term, in general long-term responses are favorable. For example, the biomass of *Spartina alterniflora* initially decreased following burning, but after 12 months biomass did not differ from unburned controls that were exposed to either No. 2 fuel oil or various concentrations of South Texas Light Crude (Kiesling *et al.* 1988). Stem density of *Spartina anglica* did not differ from the oiled controls two months following application of Kuwaiti Crude and burning (Baker, 1973). Plant cover was representative of unaffected marshes one year after the burning of an oiled freshwater marsh in Maine (Metzger, 1995). In contrast, plant cover was significantly lower in burned plots compared to unburned plots seven months after the spill of a light Arabian Crude onto a Texas brackish *Spartina patens* marsh (McCauley and Harrel, 1981). Also, biomass in unburned plots of an oiled *Spartina patens* marsh was greater than either burned unoiled or burned oiled plots seven months after the spill (McCauley and Harrel, 1981). Oiled and burned plots in a *Spartina* *alterniflora* marsh in Texas had a significantly lower biomass than control plots (unoiled and unburned) six months after being subjected to a pipeline rupture of South Texas Light Crude (Holt *et al.* 1978). However, there was no oiled and unburned treatment in that study, and therefore the utility of burning as a cleanup method cannot be fully evaluated. Burned and oiled plots had lower biomass than unoiled controls after one year in a Minnesota pond (Zischke, 1993) and two years after the burning of a Texas high salt marsh (Tunnel *et al.* 1995).

Prescribed burning commonly results in an alteration of the diversity structure in marshes, and this appears to hold for oil spill response burning. Burning within a heavily oiled freshwater marsh in Maine led to a trend of increased dominance by *Sparganium americanum* at the expense of *Typha latifolia* one year following the burn. This result was considered beneficial given increased wildlife use of bur-reed over that of cattail (Metzger, 1995). Species richness decreased following the burning of an oiled Texas salt marsh, and *Distichilis spicata* became the dominant species according to Tunnel *et al.* (1995), who suggested that it may take 10 years for the site to recover in terms of species diversity. Burning may result in differential responses dependent upon species even if they do not contribute to an altered species diversity. Although *Avicennia germinans* was shown to recover more completely from heavy oiling than *Spartina alterniflora* if the spill was not treated, burning was extremely detrimental to *Avicennia*, while *Spartina* was able to recover from the burn (Holt *et al.* 1978). In general, woody species are less likely to recover from a fire than graminoid species (Castle, 1975; Moir and Erskin, 1994; Obot *et al.* 1992). This is also true for herbaceous species that lack sufficient belowground development for regrowth following destruction of aboveground tissues during a fire (Getter *et al.* 1984; Westree, 1977). While it may be argued that any alteration of the diversity structure is detrimental to a community given that it represents a departure from normality, we consider either an increase or no change in diversity to be beneficial over a decrease.

### 3.2.3.2 Substrate Effects

Burning may affect both vegetation and soil conditions of a particular site, with implications for plant recovery success. The use of burning to clean an experimental application of No. 2 fuel oil in a Texas salt marsh was found to increase sediment hydrocarbon content over other response options, including no treatment of the spilled oil (Kiesling *et al.* 1988). Residual elevated hydrocarbon levels were noted both for an impacted freshwater marsh in Maine after one year (Metzger, 1995) and for an oiled Texas high salt marsh after two years of recovery (Tunnnel *et al.* 1995). However, without an oiled and unburned treatment for the Maine burn, it is not possible to judge removal efficiency due to burning. Castle (1976) suggested that the loss of woody species due to oil, brine, and burning induced mortality in a Louisiana brackish marsh may cause increased erosion, particularly along fringe areas.

Soil disturbances may not originate from the actual burn event but in other response activities (Holt *et al.* 1978; Moir and Erskin, 1994). Due to a lack of available data on the effectiveness of burning as a response option, other techniques that may be more destructive to the marsh substrate but are more commonly accepted have been employed prior to burn approval (Eufemia, 1993). The recovery of a Texas high salt marsh to oiling may have been complicated by the post-burn disturbance of the marsh by response personnel seeking to light secondary burns and clean burn residue using pom-poms (Tunnel *et al.* 1995). Mechanical disturbance may also occur when response equipment must be brought in for facility repairs. Following the 1995 burn response to a pipeline rupture in a brackish marsh in Louisiana, heavy equipment was utilized to excavate soil around the pipeline, which was buried several feet below the marsh surface (Pahl, pers. obs.). Response options must be well thought out before implementation proceeds in order to reduce damage to the marsh substrate and vegetation. (Dunford *et al.* 1991; Lindstedt-Siva, 1979; Westree, 1977).

### 3.2.3.3 Faunal Recovery

It is difficult to generalize about the ability of faunal communities to recover from a burning event because different conditions and faunal groups respond differently to this situation. Burning an oiled Louisiana brackish marsh was believed to have produced minimal impact on marsh fauna due to the lack of surface evidence and the observation that heat from the burn did not penetrate more than a few inches into the marsh substrate (Castle, 1975). There were no data to suggest that any of the faunal communities associated with a Maine freshwater marsh were influenced by an oil spill and burn treatment after either a short-term or long-term recovery period (Metzger, 1995). Bird utilization of burned areas of a Texas high salt marsh was higher than unburned areas one year after the spill and burn treatment, but was not significantly different after two years. Tunnel *et al*. (1995) suggested that this was a result of revegetation of preferred open areas that resulted from the burn event. Invertebrate abundance and taxa from an oiled and burned pond in Minnesota were greater than those measured in an unoiled pond, and midge species richness was also significantly higher in the treated pond (Zischke, 1993). Infaunal populations appeared to only be affected in the short-term following an *in situ* burn in a Texas salt marsh, with numbers rising six months after the spill and species richness staying constant throughout (Holt *et al.* 1978). However, total macroinvertebrate numbers were lower in burned treatments (oiled or unoiled) compared to the unburned controls and the cut treatments (both either oiled or unoiled) in a Texas brackish marsh, with no significant differences in diversity between treatments (McCauley and Harrel, 1981).

### 3.2.3.4 Contributing Factors

Each spill has its own unique set of conditions and complications. For example, McCauley and Harrel (1981) demonstrated that the burning of a *Spartina patens* marsh in Texas following the 1979 Esso Bayway spill resulted in a drastic decrease of plant biomass as compared to plots that were oiled but untreated. However, recovery from this burn was complicated by high rainfall and resulting high water levels that never receded from the marsh during the six month recovery period following the spill. The recovering vegetation therefore not only had to cope with more flooded conditions, but also ambient water that was fresher than normal. These are not optimal conditions for *S. patens* growth, particularly from belowground rhizomes (Teal and Teal, 1969), as evidenced by the poor regrowth of both oiled and unoiled plots that were clipped to ground level but not burned (McCauley and Harrel, 1981). The response of a *Spartina alterniflora* salt marsh in Texas following a crude oil pipeline rupture (Holt *et al.* 1978) may have been complicated by the on site burning of oil soaked sorbent pads in areas of heaviest spill contamination. Castle (1975) reported that *Spartina spp*. appeared to recover rapidly from the burning of a Louisiana brackish marsh following a well blowout. The released oil was highly paraffinic and existed in a solid state for much of the response. This had the effect of matting the upper portions of the vegetation with a heavy coat of oil, while the lower portions were generally not exposed. Many of the lower portions were not consumed in the fire, and the residue formation was minimal, creating favorable conditions for regrowth. Recovery may have been hampered by the release of a large volume of hypersaline brine associated with the subterranean oil. The overlying water that existed when a Texas high salt marsh was burned in response to a pipeline rupture in 1992 may not have been enough to prevent the baking of the root zone by the fire as suggested by Tunnel *et al.* (1994) and hence the slow recovery of some species in this marsh.

This situational dependence suggests that some of the generalizations governing the successful use of prescribed burning for marsh management may not always apply to *in situ* burning. In particular, season did not seem to play a role in determining whether burning accomplishes an ecologically safe wetland oil spill cleanup. The amount of water overlying the wetland does appear to govern success here as it does for managed burns, with a lower water table increasing the risk of peat and root zone damage. These conclusions are based on a limited data set, however, and further testing of *in situ* burning in wetlands may aid in reaching definitive conclusions.

#### 3.2.3.5 Summary

Our literature review identified 11 wetland *in situ* burn sites for which published papers and reports describe recovery (Table 3.4). In two instances (Holt *et al*. 1978; Obot *et al.* 1992) appropriate controls were not used so that the effect of the burn, beyond that of the oil spill, cannot be determined. A third study (Overton, 1981) did not investigate recovery per se. Although recovery occurred at different rates depending upon the particular event, of the seven *in situ* burn sites that have adequate controls to draw valid conclusions six exhibited good to moderate recovery. The one instance where vegetative recovery was poor (McCauley and Harrel, 1981) was not due to burning but rather to the high post-burn water levels that continuously inundated the marsh for the six month recovery period. Plots where the vegetation was cut to simulate burning had the same poor regrowth. Thus, we conclude from this review of the *in situ* burn literature that recovery of herbaceous wetlands from *in situ* burning is likely to occur although recovery rates will vary. Substantial recovery can and often does take place within a few growing seasons although complete recovery may take as long as 8 to 10 years (Tunnel *et al.* 1995).

## 3.3 Field Sampling

### 3.3.1 Pass-a-Loutre, Louisiana

Sampling of a fresh water *Phragmites* marsh four years after a burn at Pass-a-Loutre, Louisiana, showed substantial recovery in both TPH and plant biomass compared to the controls. Total petroleum hydrocarbon levels in the soil were not significantly different between the oiled and burned marsh site and the two unoiled control marsh sites, which were located on either side of the burned area (Figure 3.1). Inspection of Figure 3.1 shows that the TPH levels of the oiled and burned marsh site (13.8 mg $g^{-1}$) were actually intermediate to those of the two controls (2.5 mg $g^{-1}$ and 24.6 mg $g^{-1}$ for control A and B, respectively), but none were significantly different from each other. The relatively high TPH level at control site B is believed to be due to past oil leakage from an oil well located adjacent to this control. Inspection of GC/MS data indicated that the oil at control site B was of more recent origin than the oil at control site A.

Both live biomass (2,167 g $m^{-2}$) and total biomass (3,431 g $m^{-2}$) of the oiled and burned marsh site were slightly elevated above control values (range of 1,030 ) 1,170 g $m^{-2}$ live biomass and 1,892 ) 1,974 g $m^{-2}$ total biomass) (Figure 3.2 top panel). Similarly, the live to dead biomass ratio of the oiled and burned marsh site showed no significant differences from the controls, although the live to dead biomass ratio of the oiled and burned marsh site was 2.6 compared to live to dead biomass ratios of about 1.7 at the control marsh sites (Figure 3.2 bottom panel). Although plant biomass recovery appears complete, aerial photography of the site shows that the vegetative cover is not yet uniform.

**Table 3.4** A summary of literature-derived marsh *in situ* burns and extent of recovery

| Reference | Location | Marsh Type | Recovery[1] |
|---|---|---|---|
| Baker, 1973 | United Kingdom | Salt | Good |
| Holt *et al.* 1978 | Texas | Salt | 2 |
| Kiesling *et al.* 1988 | Texas | Salt | Good |
| Tunnel *et al.* 1994 | Texas | Salt | Moderate |
| Castle, 1975,76 | Louisiana | Brackish | Good |
| McCauley & Harrell, 1981 | Texas | Brackish | Poor |
| Overton, 1981 | Louisiana | Brackish | No data |
| Obot *et al.* 1992 | Nigeria | Freshwater | 3 |
| Metzger, 1995 | Maine | Freshwater | Good |
| Zischke, 1993 | Minnesota | Freshwater | Moderate |
| Moir and Erskin, 1994 | Canada | Freshwater | Good |

[1] Recovery is defined as no significant difference in response variables between burned and control marshes or between pre- and post burn condition depending on the reference. Good = biotic responses and residual oil concentrations similar to controls or pre-burn condition; Moderate = biotic responses and/or residual oil concentrations approaching control levels or pre-burn condition. Poor = biotic responses and/or residual oil concentrations dramatically different from controls or pre-burn condition.

[2] Although the marsh recovered from the effects of fire without oil, recovery was very poor for the treatment receiving both oil and burning. Unfortunately, an oiled and unburned treatment was not included in the study. As a result, the effect of the oil could not be separated from the effect of the burning (i.e. poor recovery in the oiled and burned treatment could have been due just to the oil).

[3] The lack of appropriate controls made valid interpretation of the results relative to *in situ* burning precarious at best.

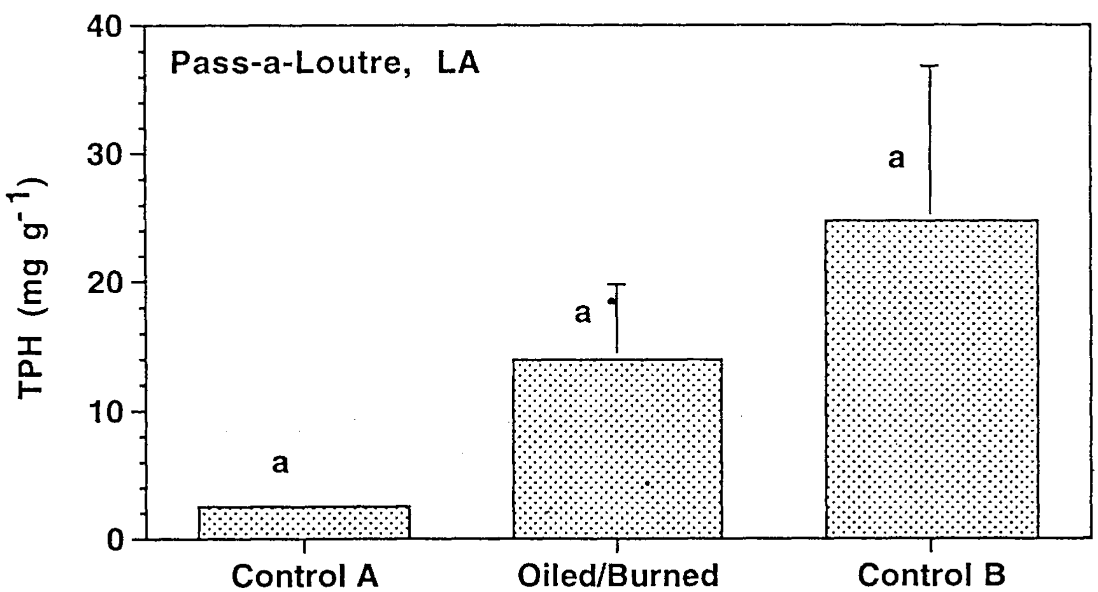



***Figure 3.1*** *Mean (± std err) total petroleum hydrocarbon levels in marsh soils sampled over a depth of 0 to 12 cm at the two control sites and the in situ burn site at Pass-a-Loutre, Louisiana. Treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

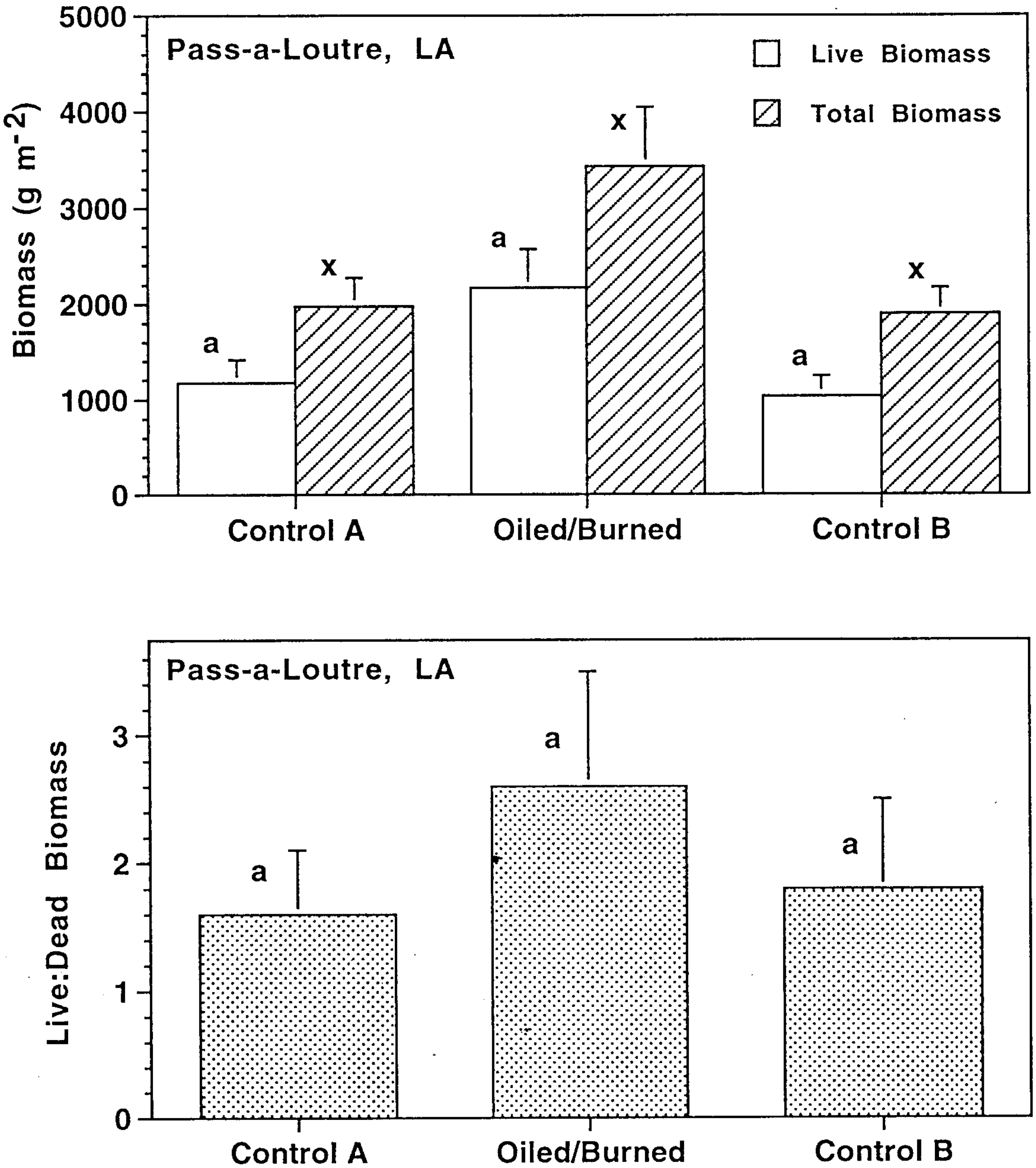



*Figure 3.2* *Mean (± std err) live and total plant biomass (top panel) and live to dead aboveground biomass ratio (bottom panel) at the two control sites and the in situ burn site at Pass-a-Loutre, Louisiana. Within each variable, treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

### 3.3.2 Chiltipin Creek, Texas

Sampling of this brackish/saline marsh 32 months after burning showed no significant differences in soil total petroleum hydrocarbon levels between oiled and burned sites and the unoiled controls (Figure 3.3). Although no significant differences in TPH levels were detected due to relatively high variation within treatments, on the average the oiled/pooled and burned marsh site had TPH levels of 9.3 mg $g^{-1}$ compared to 26.7 mg $g^{-1}$ at the oiled and burned marsh and 0.4 mg $g^{-1}$ at the control marsh site (Figure 3.3). This indication of still higher TPH levels in the burned marsh compared to the control is in agreement with the findings of Tunnel *et al.* (1995).

Total plant biomass values were similar and not significantly different between the control marsh site (92.2 g $m^{-2}$) and the oiled and burned marsh site (91.2 g $m^{-2}$, Figure 3.4). However, total plant biomass of the oiled/pooled and burned marsh site (24.5 g $m^{-2}$) was still significantly depressed compared to either the control site or the oiled and burned site. Although total plant biomass has shown good recovery at the oiled and burned site relative to the control site, it should be noted that the plant composition of the oiled and burned site and the oiled/pooled and burned site has shifted to a less diverse community dominated by *Distichlis spicata*. We encountered only two species at the oiled and burned marsh site: *Distichlis spicata* and *Borrichia frutescens*. Only three species were encountered at the oiled/pooled and burn marsh site*: Distichlis spicata, Suaeda maritima*, and *Salicornia sp*. Six species were encountered during our sampling of the control marsh site; *Monanthochloe littoralis*, *Batis maritima* and *Lycium carolinianum* missing. Species richness was significantly lower in the oiled and burned marsh site (1.6 species per plot) and the oiled/pooled and burned marsh site (1.0 species per plot) than the control marsh site (3.2 species per plot). However, it has been reported that species diversity (H'-Shannon Diversity) has been slowly increasing during the 32 months following the burn (Tunnel *et al.* 1995) and, therefore, may reach comparable levels to the control marsh over the next several years.

### 3.3.3 Meire Grove, Minnesota

There were no significant differences in soil TPH between the oiled and burned pond and the control pond in this northern prairie pothole freshwater marsh two years after *in situ* burning (Figure 3.5). The TPH levels of the oiled and burned pond (2.8 mg $g^{-1}$) and the control pond (0.7 mg $g^{-1}$) were both relatively low.

Plant biomass remained significantly depressed in the oiled and burned marsh two years after burning (Figure 3.6 top panel). Live biomass of the control marsh (262 g $m^{-2}$) was significantly greater than the average of 7.5 g $m^{-2}$ in the oiled and burned marsh. Differences between the oiled and burned marsh and the control marsh were even greater in terms of total plant biomass, which averaged 536 g $m^{-2}$ in the control marsh compared to 10 g $m^{-2}$ in the oiled and burned marsh (Figure 3.6 top panel). Both the control pond and the oiled and burn pond were dominated by *Typha latifolia*. In the control pond *Carex sp*. (a sedge) was present as a second species, comprising about 20% of the total biomass, whereas the oiled and burned pond lacked *Carex sp.*, but had about 14% *Phalaris sp*. (canary grass).

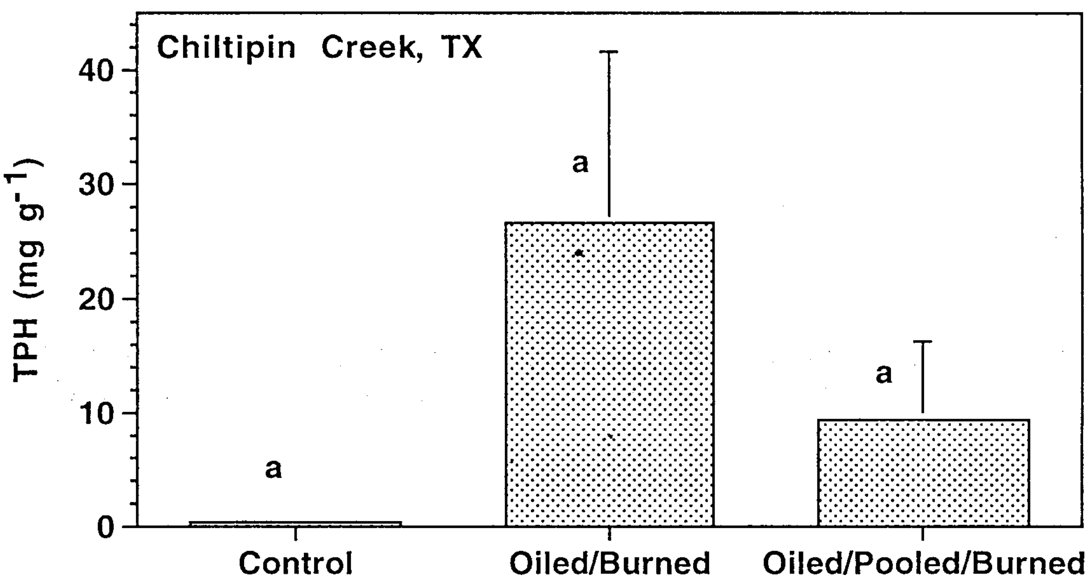



***Figure 3.3*** *Mean (± std err) total petroleum hydrocarbon levels in marsh soils sampled over a depth of 0 to12 cm at the control site, the in situ burn site, and the pooled oil in situ burn site at Chiltipin Creek, Texas. Treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

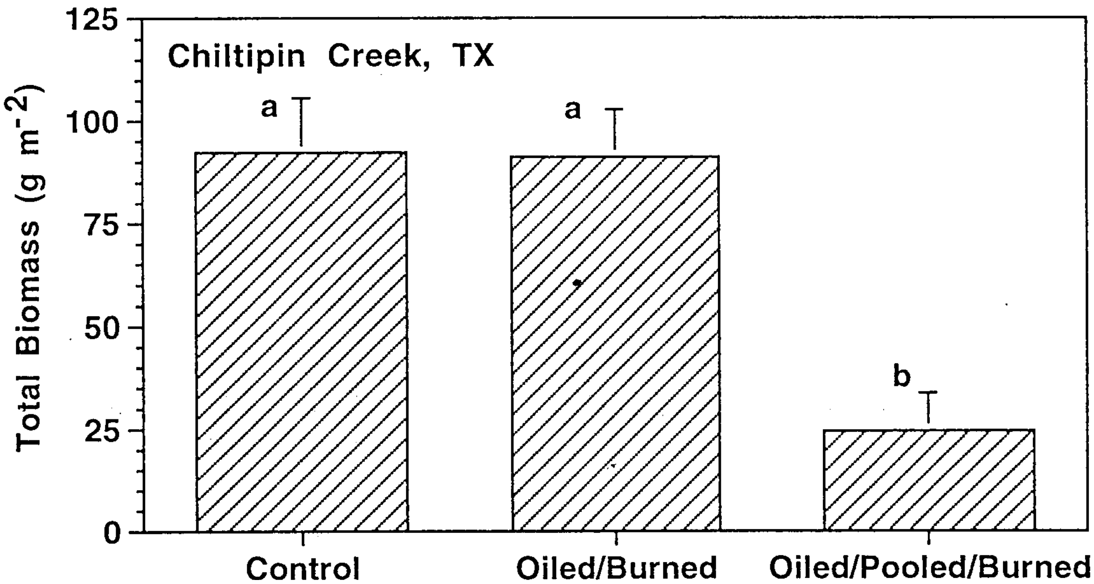



***Figure 3.4*** *Mean (± std err) total plant biomass at the control site, the in situ burn site, and the in situ burn site where oil pooled at Chiltipin Creek, Texas. Treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

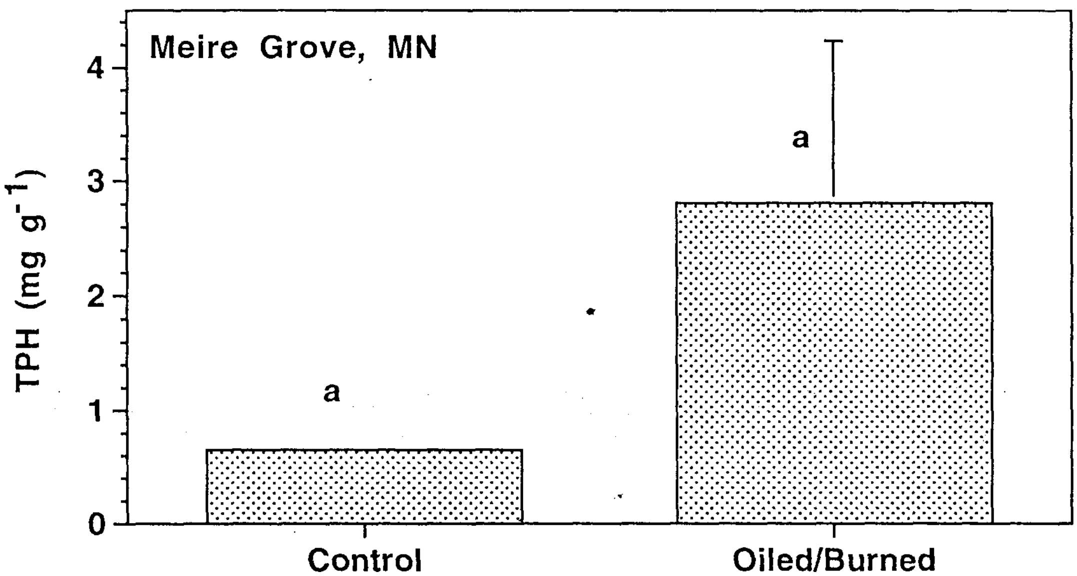



***Figure 3.5*** *Mean (± std err) total petroleum hydrocarbon levels in marsh soils sampled over a depth of 0 to 12 cm at the control site and the in situ burn site at Meire Grove, Minnesota. Treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

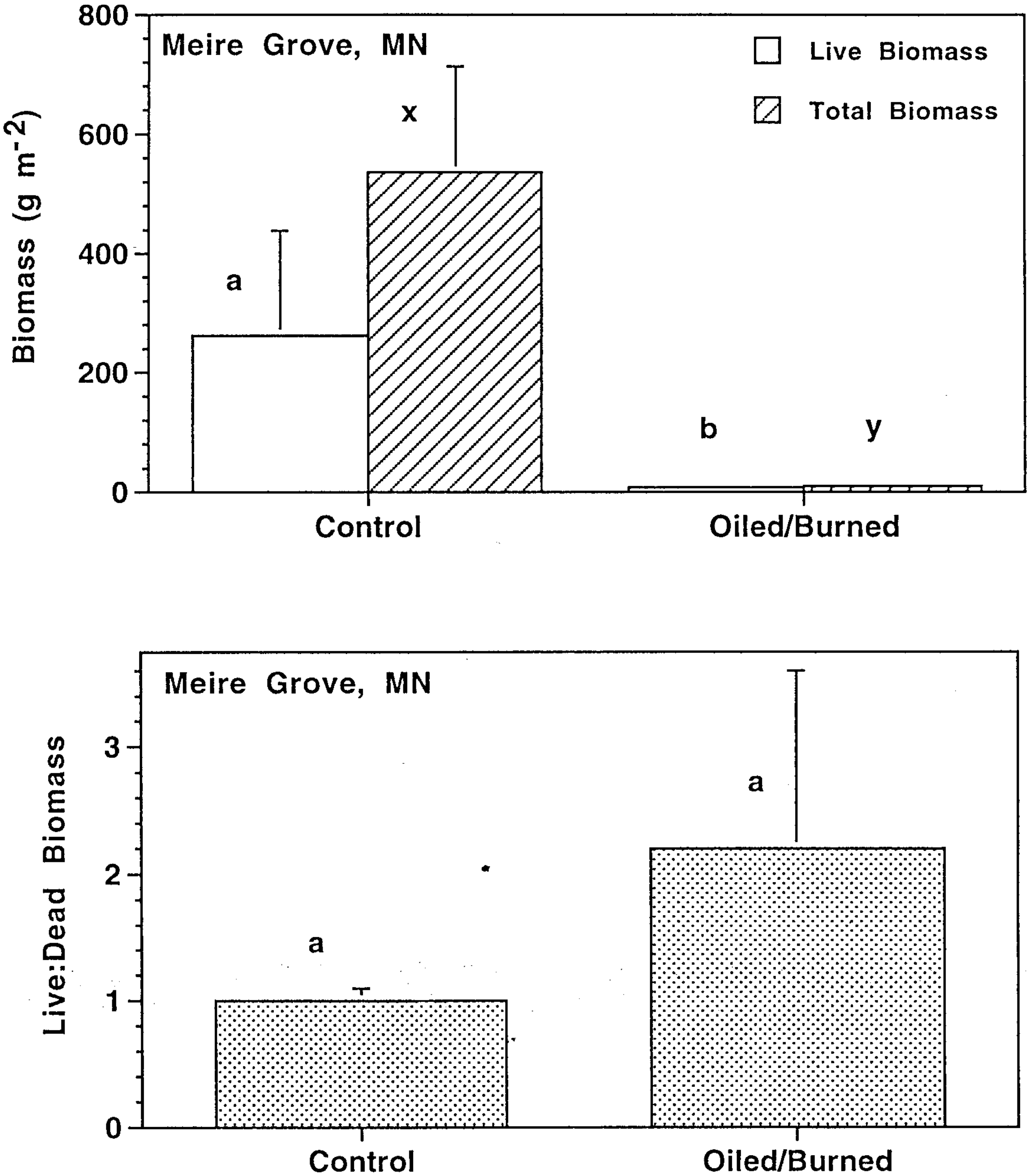



***Figure 3.6*** *Mean (±std err) live and total plant biomass (top panel) and live-to-dead aboveground biomass ratio (bottom panel) at the control site and the in-situ burn site at Meire Grove, Minnesota. Within each variable, treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

### 3.3.4 Lafitte Oil Field, Louisiana Station 1

There were no significant differences in soil TPH values between the oiled and burned site (4.5 mg $g^{-1}$) and the control site (3.9 mg $g^{-1}$) of this brackish marsh 29 months after burning (Figure 3.7).

Although the control site tended to have greater live and total plant biomass than the oiled and burned site, these differences were not statistically significant (Figure 3.8 top panel). Control marsh live biomass averaged 1,085 g $m^{-2}$ compared to 579 g $m^{-2}$ in the oiled and burned marsh. Total plant biomass values were greater, averaging 2,102 g $m^{-2}$ in the control marsh and 710 g $m^{-2}$ in the oiled and burned marsh (Figure 3.8 top panel). The plant communities of the control marsh site and the *in situ* burn marsh site were both dominated by *Spartina patens* and *Distichlis spicata*, with lesser amounts of *Juncus roemerianus*, and some *Spartina alterniflora*. There were no significant differences in species richness between the control and *in situ* burn marsh sites. The oiled and burned marsh site had an averaged species richness of 4.0 species per plot compared to 4.4 species per plot at the control marsh site.

Live to dead biomass ratio was significantly greater at the oiled and burned marsh (ratio of 5.0) than in the control marsh (ratio of 1.1), indicating that the oiled and burned marsh still had not accumulated as much standing dead biomass as the control marsh 29 months after burning (Figure 3.8 bottom panel).

### 3.3.5 Lafitte Oil Field, Louisiana Station 2

Eleven years following the oil spill and burn in this brackish marsh there were no significant differences in soil TPH between the control marsh site and the oiled and burned marsh site (Figure 3.9). The control marsh soil TPH in this oil field was somewhat elevated (10.7 mg $g^{-1}$) compared to more pristine controls (e.g., Figure 3.11) and is probably indicative of a past oil spill or leakage from the oil related activities in the area. The soil TPH of the oiled and burned marsh site averaged 18.1 mg $g^{-1}$ (Figure 3.9).

Live plant biomass of the control marsh (876 g $m^{-2}$) was not significantly greater than the live plant biomass of the oiled and burned marsh (554 g $m^{-2}$; Figure 3.10 top panel). Similarly, total plant biomass showed no significant differences between the control site (1,845 g $m^{-2}$) and the oiled and burned site (1,222 g $m^{-2}$; Figure 3.10 top panel). Plant community composition differed slightly between the control and *in situ* burn marsh sites. The oiled and burned marsh site was dominated by *Spartina patens*, with a fair amount of *Distichlis spicata* and some *Spartina alterniflora*, whereas the control marsh site was dominated by *Juncus roemerianus* and *Spartina patens*. Species richness in the oiled and burned marsh tended to be greater (average of 7.6 species per plot), but not significantly different from that of the control marsh site (average of 4.8 species per plot).

Live to dead biomass ratios were very similar between the control marsh (ratio of 0.97) and the oiled and burned marsh (ratio of 0.90) and reflected the longer time period (11 years) following the burn. This amount of time had allowed the oiled and burned marsh site to accumulate proportionately nearly as much standing dead biomass as the control marsh site (Figure 3.10 bottom panel).

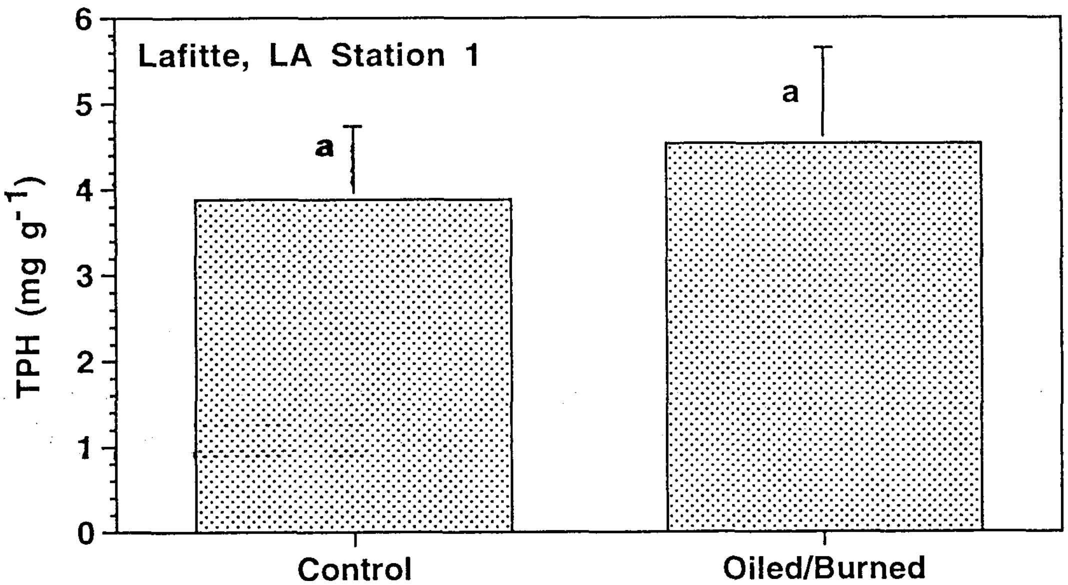



***Figure 3.7*** *Mean (± std err) total petroleum hydrocarbon levels in marsh soils sampled over a depth of 0 to 12 cm at the control site and the in situ burn site at Station 1 of the Lafitte oil field, Louisiana. Treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

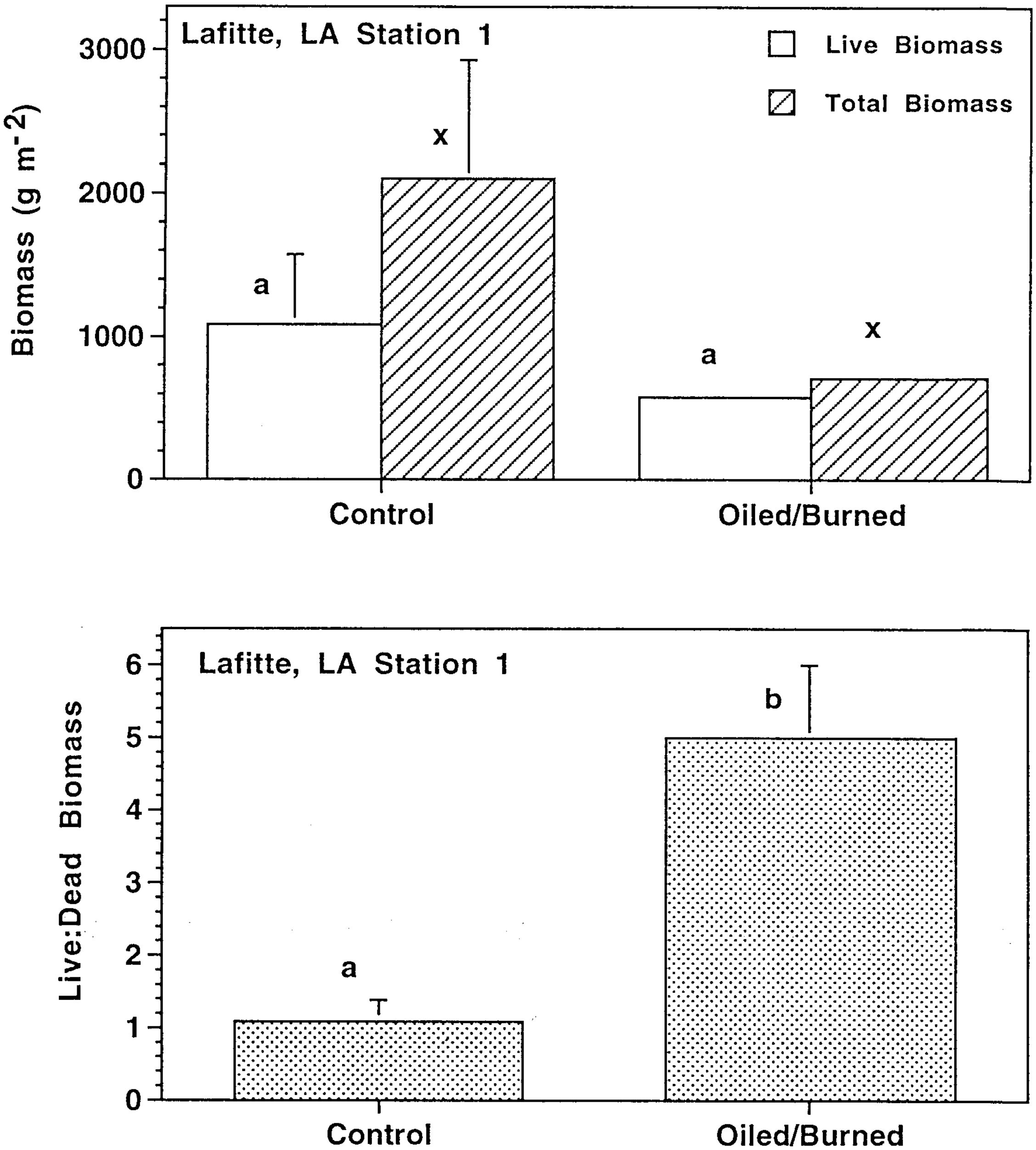



***Figure 3.8*** *Mean (± std err) live and total plant biomass (top panel) and live to dead aboveground biomass ratio (bottom panel) at the control site and the in situ burn site at Station 1 of the Lafitte oil field, Louisiana. Within each variable, treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

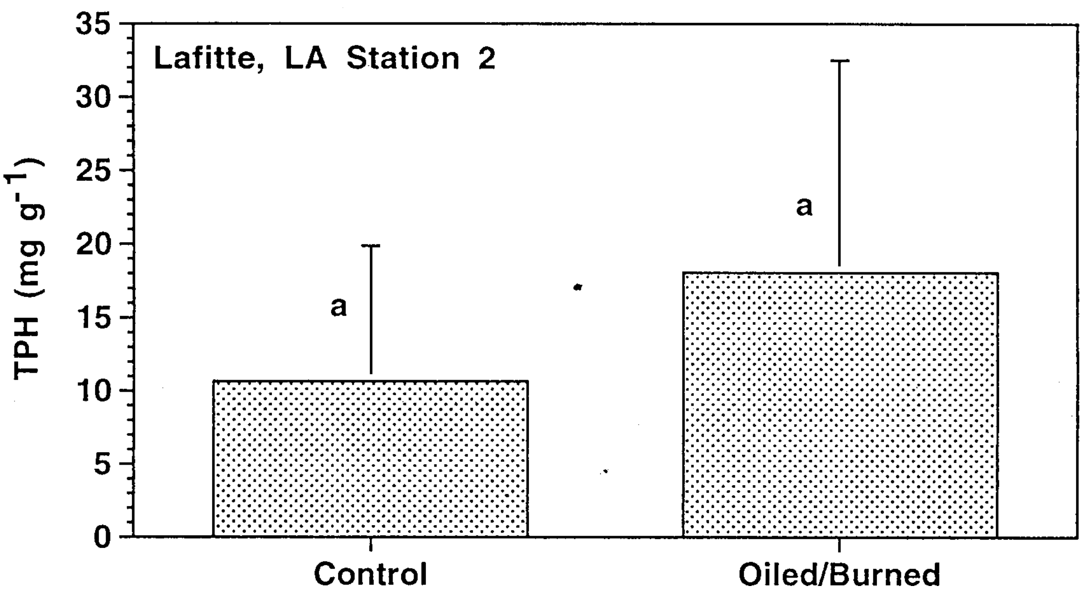



***Figure 3.9*** *Mean (± std err) total petroleum hydrocarbon levels in marsh soils sampled over a depth of 0 to 12 cm at the control site and the in situ burn site at Station 2 of the Lafitte oil field, Louisiana. Treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

### 3.3.6 Lafitte Oil Field, Louisiana Station 3

Eight years following the spill and burn in this brackish marsh plant community, soil TPH levels remained significantly elevated in the oiled and burned marsh (162 mg $g^{-1}$) compared to the control (less than 2 mg $g^{-1}$; Figure 3.11). It is not known how much, if any, of this relatively high soil TPH level in the oiled and burned site may be due to post-burn oil spills or leakage. However, inspection of GC/MS data and an FFPI (Fossil Fuel Petroleum Index) of 0.88 indicate that some of the oil at this *in situ* burn site is of post-burn origin.

Vegetation recovery in this marsh was excellent and essentially complete, showing no significant differences between the control marsh site and the oiled and burned marsh site. Both live and total biomass values were nearly identical between the control marsh and the oiled and burned marsh, with the oiled and burned site actually tending to slightly higher values (Figure 3.12 top panel). Live plant biomass averaged 665 g $m^{-2}$ at the control marsh site and 799 g $m^{-2}$ at the oiled and burned marsh site (Figure 3.12 top panel). Total plant biomass values were greater, averaging 1,423 g $m^{-2}$ at the control site and 1,484 g $m^{-2}$ at the oiled and burned site (Figure 3.12 top panel).

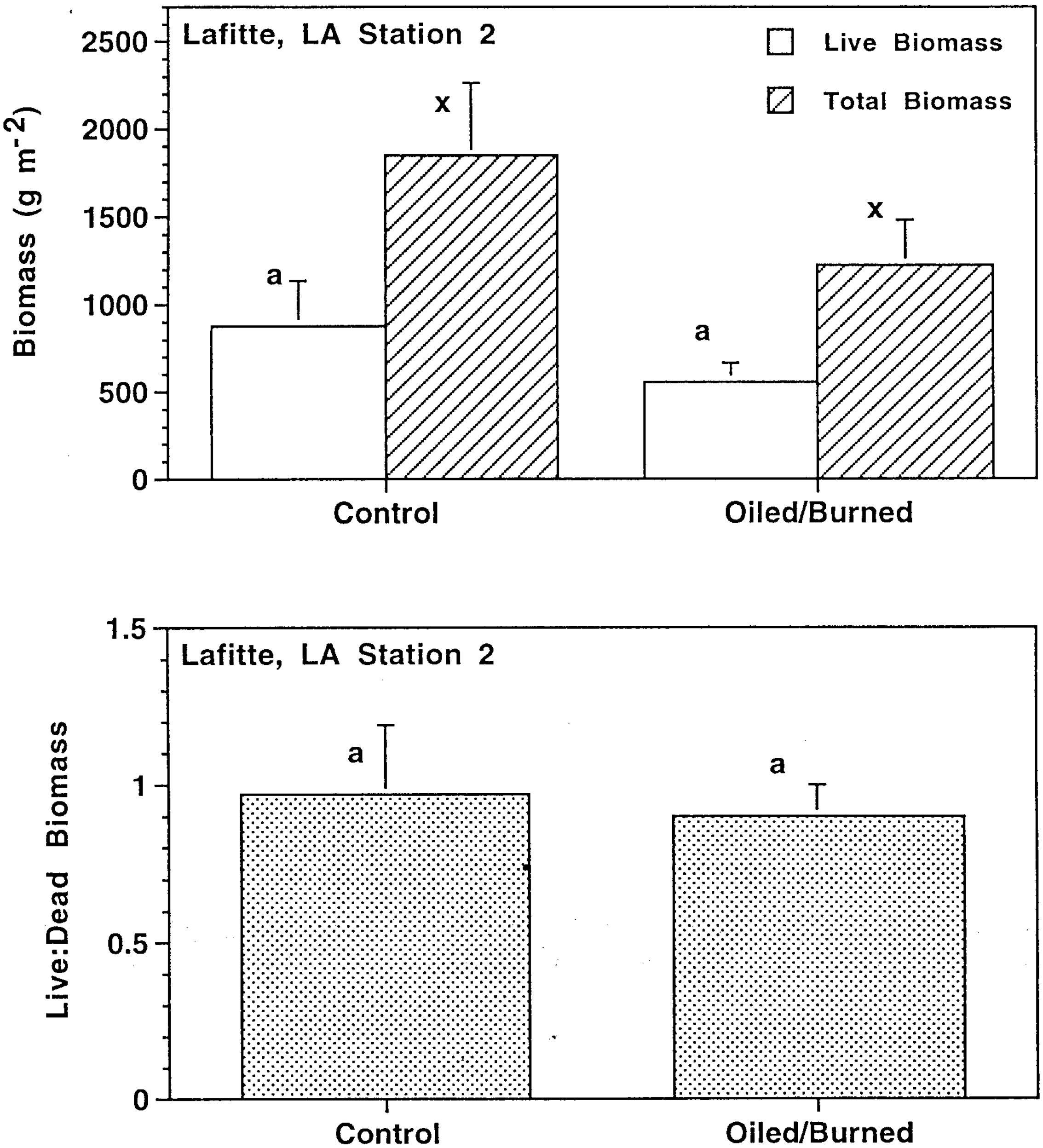



***Figure 3.10*** *Mean (± std err) live and total plant biomass (top panel) and live to dead aboveground biomass ratio (bottom panel) at the control site and the in situ burn site at Station 2 of the Lafitte oil field, Louisiana. Within each variable, treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

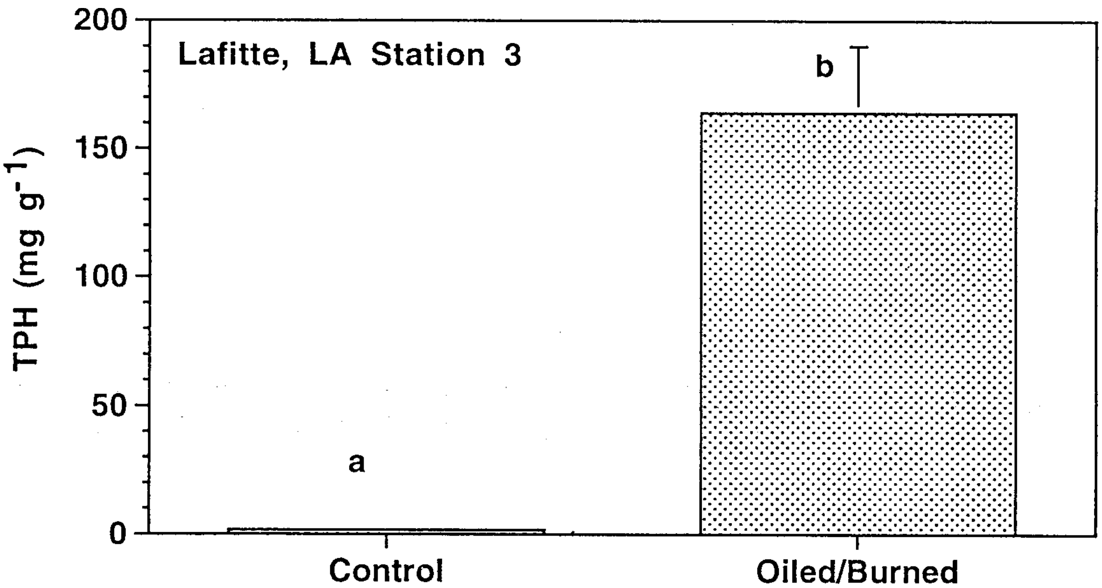
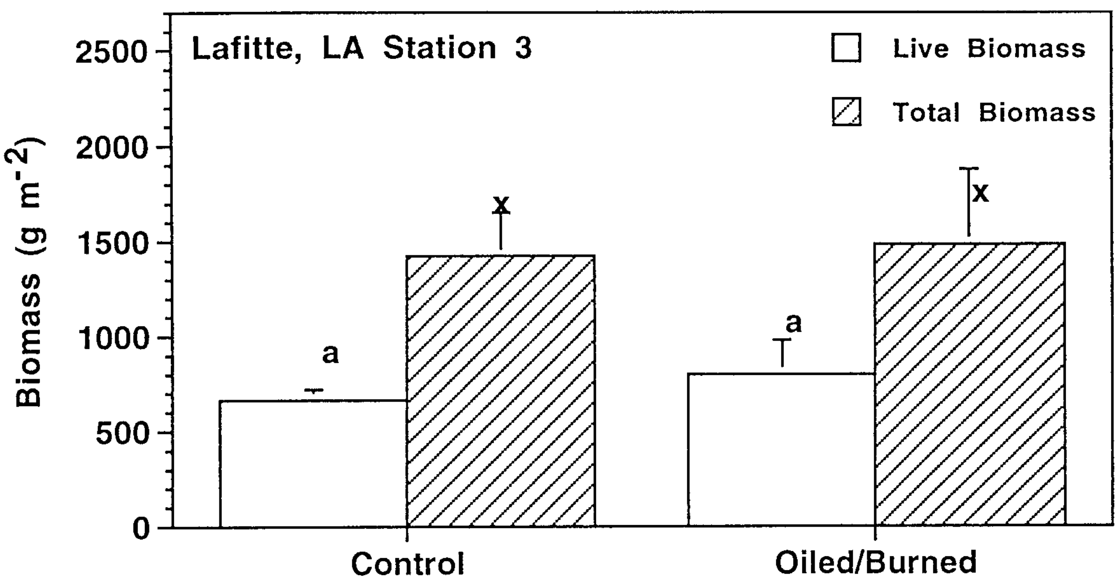



***Figure 3.11*** *Mean (± std err) total petroleum hydrocarbon levels in marsh soils sampled over a depth of 0 to 12 cm at the control site and the in situ burn site at Station 3 of the Lafitte oil field, Louisiana. Treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*



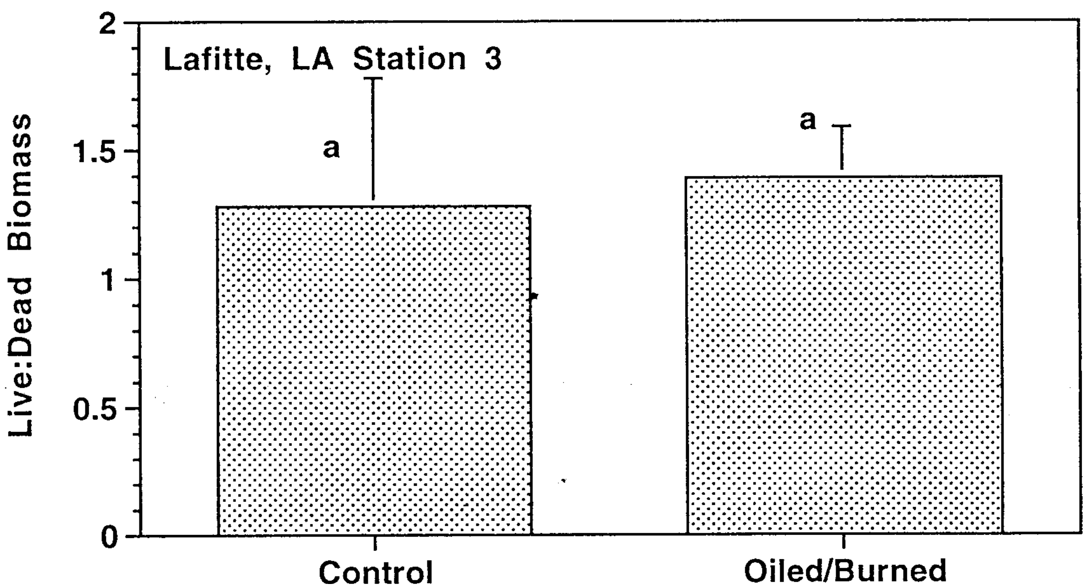




***Figure 3.12*** *Mean (± std err) live and total plant biomass (top panel) and live to dead aboveground biomass ratio (bottom panel) at the control site and the in situ burn site at Station 3 of the Lafitte oil field, Louisiana. Within each variable, treatment means that are significantly different (P#0.05) are indicated by different letters above the histogram bars (n=5).*

Plant community composition was different between the control and oiled and burned marsh sites, with the control marsh site having a significantly (P#0.05) higher species richness (average of 6.6 species per plot) than the *in situ* burn marsh site (average of 2.8 species per plot). The dominant species at both marsh sites was *Spartina alterniflora*, with *Distichlis spicata* also present. The control marsh site also had considerable *Spartina patens*, but no *Juncus roemerianus*, whereas the *in situ* burn marsh site had considerable *Juncus roemerianus* but no *Spartina patens*.

Live to dead biomass ratios also showed no significant differences between the control marsh (ratio of 1.3) and the oiled and burned marsh (ratio of 1.4; Figure 3.12 bottom panel), indicating adequate post-burn time for the accumulation of standing dead plant material.

### 3.3.7 Summary

Table 3.5 summarizes the findings from the sampling of the field *in situ* burn sites. Overall vegetative recovery was good with five of the six *in situ* burn sites exhibiting moderate to complete recovery. The freshwater marsh at Meire Grove, Minnesota is recovering slowly. It should be noted that conclusions based on such a small sample size (six *in situ* burn sites) comprising highly different types of wetland ecosystems and over different recovery periods must be viewed with some caution. Nonetheless, the field sampling results agree with those from the *in situ* burn literature discussed previously and suggest that *in situ* burning should be considered as a potential oil spill cleanup technology that may be used in the wetland environment, depending on the specific circumstances of the event.

**Table 3.5** Location and extent of recovery for sampled *in situ* burn sites

| Marsh Type | Location | Recovery Time (yr) | Recovery |
|---|---|---|---|
| Salt Marsh | Chiltipin Creek, TX | 2 | Moderate-Good[1] |
| Brackish Marsh | Lafitte Site 1, LA | 2.5 | Moderate-Good[2] |
| Brackish Marsh | Lafitte Site 2, LA | 11 | Good[3] |
| Brackish Marsh | Lafitte Site 3, LA | 8 | Good[4] |
| Fresh Marsh | Pass-a-Loutre, LA | 4 | Moderate-Good[5] |
| Fresh Marsh | Meire Grove, MN | 2 | Poor[6] |

[1]Biomass recovering and approaching controls, but species composition slower to recover.

[2]Biomass in oiled and burned marsh not significantly different from control marsh; however, a tendency still exists for lower biomass in oiled and burned site.

[3]Biomass and species composition completely recovered.

[4]Biomass recovered, but species richness still lower in oiled and burned marsh.

[5]Biomass has recovered, but the total vegetative cover of the oiled and burned marsh is less than the control marshes.

[6]Only minor vegetative recovery, possibly due to the initial impact of light fuel oils.

# 4.0 Conclusions

We have reviewed the marsh burning literature and the *in situ* burn literature and have sampled *in situ* burn sites in Louisiana, Texas, and Minnesota in order to develop a better understanding of the effectiveness and ecological safety of this potential oil spill cleanup technique in wetlands. Our basic premise was that the existing scientific literature contains information that when analyzed and integrated with empirical data from *in situ* burn sites would allow us to formulate some overall conclusions concerning the appropriateness of *in situ* burning in the wetland environment. This proved to be the case.

Based on the marsh burning literature, *in situ* burning generally causes few long-term negative impacts as long as root and peat burns are avoided. Marsh recovery from non-peat burns can occur in as little as one or two growing seasons. The exception to this short recovery time are forested or shrub wetlands, which take much longer to recover their original community structure. If we apply the lessons learned from prescribed burns to *in situ* burning for oil spill cleanup, it appears that *in situ* burning would be most effective and compatible with the wetland ecology when: (1) summer burns are avoided, (2) the wetland is dominated by rhizomatous herbaceous species, not shrub or tree species, (3) water covers the marsh surface, or at least the soil is saturated at the time of the burn, and (4) no long-term increase in water level is expected after the burn. The marsh management literature documents that burning generally either increases or has no effect on vegetative species richness. *In situ* burning may not always have the same effect (e.g. Lafitte Site 3).

Reviews of the *in situ* burn literature and field sampling of *in situ* burn sites indicate that *in situ* burning can be successfully used to enhance oil removal while allowing for recovery. However, rates of recovery for both plants and animals will vary depending on the specifics of the event and cleanup. Complete recovery may require as little as one or two years or as long as a decade. As for prescribed burns, burning when the soil surface is exposed and when post-burn water levels are expected to rise and remain high for periods of several weeks should be avoided.

*In situ* burning thus represents a suitable alternative to other oil spill cleanup techniques in wetlands under some circumstances. *In situ* burning for wetland oil spill cleanup should be evaluated on a case by case basis before a final decision to burn is made.

## 5.0 Recommendations

This research has been the first effort to synthesize our present understanding of both prescribed burning for management purposes and *in situ* burning for oil spill cleanup in wetlands. However, our ability to draw more specific and far reaching conclusions is impaired by the lack of well designed studies, both experimental and spills of opportunity, from which to assess the influence of the variables that control successful *in situ* burning in wetlands. We will only be able to further our knowledge of this subject through a concerted monitoring and research effort. We highly recommend an experimental evaluation of the effects of *in situ* burns in a variety of wetland habitats (salt, brackish, intermediate, and freshwater marshes) and under different environmental conditions (season, water level, low versus high marsh, etc.). These investigations should assess more than just the response of the vegetation and the changes in oil chemistry to the *in situ* burn. The wetland fauna and air quality during the burn should also be evaluated.

Because spills of opportunity will occur more often than will the chance to conduct manipulative field experiments, we should take advantage of these spills in wetlands to determine the best cleanup procedure for the particular situation. For both scientific and regulatory reasons, not all spills of opportunity will easily lend themselves to this type of monitoring. However, for the subset of wetland spills that are compatible with spill of opportunity testing of cleanup procedures, including *in situ* burning, trustee agencies should be mandated and provided the funds to conduct statistically valid monitoring for recovery. The funding might come from both the responsible party and the trustee agencies (e.g. in Louisiana, the Louisiana Oil Spill Coordinator's Office). Funds must be available at the time of spill response, and the amount should be dependent on the intensity of sampling required within the bounds of the available funds.

We further recommend that the trustee agencies (in Louisiana, the Department of Environmental Quality and the Louisiana Oil Spill Coordinator's Office) should work together to provide a central location where reports, data, and photographs would be archived for each spill and subsequent monitoring activities. In addition, the agencies or their delegates should evaluate and synthesize this information on a yearly basis and provide cumulative reports describing current knowledge of oil spill cleanup technology in wetlands. This important process will document in writing the institutional knowledge concerning oil spill cleanup in wetlands that has been gained over years of practical experience, field monitoring, and experimentation. Too often this knowledge base within institutions is lost soon after the pertinent individuals retire from their jobs or move on to other employment. A written document that annually summarizes the changes to the current state of knowledge relative to oil spill cleanup in wetlands would serve as a guide for trustee agency personnel when responding to spills. The document will also help to reduce the need for agency personnel to reinvent the wheel each time an oil spill cleanup is needed.

# 6.0 References

Allen, A.A. 1991. Controlled burning of crude oil on water following the grounding of the Exxon Valdez. Proceedings of the 1991 Oil Spill Conference. API: Washington, D.C.

Allen, A.A., and R.J. Ferek. 1993. Advantages and disadvantages of burning spilled oil. Proceedings of the 1993 Oil Spill Conference. API: Washington, D.C. pp. 765-772.

APHA (American Public Health Association). 1989. Standard methods for the examination of water and wastewater, Standard Method 5520F. 17th Edition, New York. pp. 5.41 - 5.50.

Babcock, K. M. 1967. The influence of water depth and salinity on wiregrass and salt marsh grass. M.S., Louisiana State University, Baton Rouge. 109 pp.

Baker, J. M. 1970. Oil pollution in salt marsh communities. Marine Pollution Bulletin. 1:27-28.

Baker, J.M. 1973. Effects of cleaning. In: E.B. Cowell (ed.), Ecological effects of oil pollution on littoral communities. Applied Science Publ. Ltd.: England. pp. 52-57.

Benner, B.A., Jr., N.P. Bryner, S.A. Wise, G.W. Mulholland, R.C. Lao, M.F. Fingas. 1990. Polycyclic aromatic hydrocarbon emissions from the combustion of crude oil on water. Environ. Sci. Technol. 24: 1418-1427.

Castle, R.W. 1975. Observations of the Intracoastal City, Louisiana, gas well blowout and oil spill. URS Research Company, San Mateo. 41 pp.

Castle, R.W. 1976. Observations of the Intracoastal City, Louisiana, gas well blowout and oil spill: Supplement. URS Research Company, San Mateo. 11 pp.

Chabreck, R.H. 1975. Management of wetlands for wildlife habitat improvement. Presented at Third Biennial Conference, Estuarine Research Federation, Galveston, Texas. October 1975.

Chabreck, R. H. 1981. Effect of burn date on regrowth rate of *Scirpus olneyi* and *Spartina patens*. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 35: 201-210.

Cofer, W. R. III, R.K. Stevens, E. L. Winstead, J.P. Pinto, D. I. Sebacher, M. Y. Abdulraheem, M. Al-Sahafi, M. A. Mazurek, R. A. Rasmussen, D. R. Cahoon, and J. S. Levine. 1992. Kuwaiti oil fires: Compositions of source smoke. Journal of Geophysical Research. 97(D13): 14521-14525.

Day, T., D. Mackay, S. Nadeau, and R. Thurier. 1979. Emission from *in situ* burning of crude oil in the arctic. Water, Air, and Soil Pollution. 11: 139-152.

Davison, K. L., and S. P. Bratton. 1988. Vegetation response and regrowth after fire on Cumberland Island National Seashore, Georgia. Castanea. 53: 47-65.

Delaune, R.D., C.J. Smith, W.H. Patrick, Jr., J.W. Fleeger, and M.T. Tolley. 1984. Effect of oil on salt marsh biota: Methods for restoration. Environmental Pollution (Series A). 36:207-227.

Diiro, B. W. 1982. Effects of burning and mowing on seasonal whitetop ponds in southern Manitoba. M.S., Iowa State University, Ames, 48 pp.

Dunford, R.W., S.P. Hudson, W.H. Desvousges. 1991. Linkages between oil spill removal activities and natural resource damages. Proceedings of the 1991 Oil Spill Conferences. API: Washington, D.C. pp. 377-383.

Eufemia, S.J. 1993. Brunswick Naval Air Station JP-5 aviation fuel discharge: *In situ* burn of fuel remaining in fresh water marsh: April 6-8, 1993.

Evans, D. D., W.D. Walton, H. R. Baum, K. A. Notarianni, E. J. Tennyson, P. A. Tebeau. 1993. Mesoscale experiments help to evaluate *in situ* burning of oil spills. Proceedings of the 1993 Oil Spill Conference. API: Washington, D.C. pp. 775-760.

Faulkner, S. P., and A. A. de la Cruz. 1982. Nutrient mobilization following winter fires in an irregularly flooded marsh. Journal of Environmental Quality. 11: 129-133.

Fingas, M. 1992. *In situ* burning of oil spills: Review and research properties. Proceedings from the First International Oil Spill R&D Forum. pp. 247-252.

Forthman, C. A. 1973. The effects of prescribed burning on sawgrass *Cladium jamaicense* Crantz, in south Florida. M.S., University of Miami, Coral Gables, 83 pp.

Foster, D. R., and P. H. Glaser. 1986. The raised bogs of southeastern Labrador, Canada: Classification, distribution, vegetation and recent dynamics. J. Ecol. 74: 47-71.

Furnis, O. C. 1938. The 1937 waterfowl season in the Prince Albert District, central Saskatchewan. Wilson Bull. 50: 17-27.

Garren, K. H. 1943. Effects of fire on vegetation of the southeastern United States. Bot. Rev. 9: 617-654.

Getter, C. D., G. Cintron, B. Dicks, R. R. Lewis III, E. D. Seneca. 1984. The recovery and restoration of salt marshes and mangroves following an oil spill. In: Cairns, J., Jr., and A.L. Bukema Jr. (eds.), Restoration of habitats impacted by oil spills. Butterworth Publ.: Boston. pp. 65-113.

Gonzalez, M. F., and G. A. Lugo**.** undated**.** Texas marsh burn: Removing oil from a salt marsh using *in situ* burning. Unpublished manuscript.

Griffith, R. W. 1941. Waterfowl management on Atlantic coast refuges. Trans. N. Am. Wild. Conf. 5: 373-377.

Gunderson, L. H. 1984. Regeneration of cypress in logged and burned stands at Corkscrew Swamp Sanctuary, Florida. In: K. C. E. and H. T. Odum (eds.), Cypress swamps. Gainesville, University of Florida, pp. 349-357.

Hackney, C. T., and A. A. de la Cruz. 1977. The ecology of a Mississippi tidal marsh: Part 1A: The effects of fire on the vegetation of a tidal marsh in St. Louis Bay, Mississippi. Mississippi Marine Resources Council No. GR-76-033 Part 1A. 30 pp.

Hackney, C. T., and A. A. de la Cruz. 1981. Effects of fire on brackish marsh communities: Management implications. Wetlands. 1: 75-86.

Hackney, C.T., and A. A. de la Cruz. 1983. Effects of winter fire on the productivity and species composition of two brackish marsh communities in Mississippi. Intern. J. of Ecol. and Environ. Sci. 9:185-208.

Hess, T. J. 1975. An evaluation of methods for managing stands of *Scirpus olneyi*. M.S., Louisiana State University, Baton Rouge, 98 pp.

Hess, T. J. Jr., R. H. Chabreck, and T. Joanen. 1975. The establishment of *Scirpus olneyi* under controlled water levels and salinities. Proc. 29th Ann. Conf. SE Assoc. Game and Fish Comm. 548-554.

Hobbs, P. V., and L. F. Radke. 1992. Airborne studies of the smoke from the Kuwait oil fires. Science. 256: 987-991.

Hoffpauir, C. M. 1961. Methods of measuring and determining the effects of marsh fires. Proc. Annual Conf. of Southeast Assoc. Game and Fish Comm. 15: 142-161.

Holt, S., S. Rabalais, N. Rabalais, S. Cornelius, J. S. Holland. 1978. Effects of an oil spill on salt marshes at Harbor Island, Texas. I. Biology. Proceedings of the 1978 Conference on Assessment of Ecological Impacts of Oil Spills. pp. 345-352.

Imperial Oil Limited Emergency Response Newletter. 1988. Spill clean-up in action. June 1988.

Ivester, M. S., and C. J. Harp. 1978. Effects of marsh fires on meiofaunal community structure. Am. Zool. 18: 661 (Abstr. only).

Jordan, T. E., and D. F. Whigham. 1988. The importance of standing dead stems of the narrow-leaved cattail, *Typha angustifolia.* L. Aquat. Bot. 29: 319-328.

Kiesling, R. W., S. K. Alexander, and J. W. Webb. 1988. Evaluation of alternative oil spill cleanup techniques in a *Spartina alterniflora* salt marsh. Environmental Pollution. 55: 221-23.

Kirby, R. E., S. J. Lewis, and T. N. Sexson 1988. Fire in North American Wetland Ecosystems and Fire-Wildlife Relations: An Annotated Bibliography [Biological Report No. 88(1)], U.S. Fish and Wildlife Service.

Kirkman, L. K., and R. R. Sharitz. 1994. Vegetation disturbance and maintenance of diversity in intermittently flooded Carolina bays in South Carolina. Ecological Applications. 4: 177-188.

Lay, D.W., and T. O'Neil. 1942. Muskrats on the Texas coast. J. Wildl. Manage. 6: 301-311.

Lindstedt Siva, J. 1979. Ecological impacts of oil spill cleanup: Are they significant? Proceedings of the 1979 Oil Spill Conference. API: Washington, D.C. pp. 521-524.

Louisiana Applied Oil Spill Research and Development Program. 1995. Selected abstracts and bibliography of international oil spill research. Prepared by the Louisiana Oil Spill Coordinator, Office of the Governor, Baton Rouge: Louisiana Applied Oil Spill Research and Development Program. pp. 578.

Lynch, J. J. 1941. The place of burning in management of Gulf Coast wildlife refuges. J. Widl. Manage. 5:454-457.

Mallik, A. U. 1990. Microscale succession and vegetation management by fire in a freshwater marsh of Atlantic Canada. Tasks for Vegetation Science. 25: 19-29.

Mallik, A.U., and Ross W. Wein. 1986. Response of a *Typha* marsh community to draining, flooding, and seasonal burning. Canadian Journal of Botany. 64: 2136-2143.

Matta, J. F., and C. L. Clouse. 1972. The effect of periodic burning on marshland insect populations. Va. J. Sci. 23:(113) Abstr. only.

McCauley, C.A., and R.C. Harrel. 1981. Effects of oil spill cleanup techniques on a salt marsh. Proceedings of the 1981 Oil Spill Conference. API: Washington, D.C. pp. 401-407.

McGlone, M. S., C. S. Nelson, and A. J. Todd 1984. Vegetation history and environmental significance of pre-peat and surficial peat deposits at Ohinewai, Lower Waikato lowland. J. Royal Soc. of New Zealand. 14: 233-244.

Messinger, R. D. 1974. Effects of controlled burning on waterfowl nesting habitat in northwest Iowa. Iowa State University, Ames. 43 pp.

Metzger, R.S. 1995. 1994 Ecological assessment, Naval Air Station Brunswick, Brunswick, Maine. Halliburton NUS Corp., Pennsylvania.

Moir, M. E., and B. Erskin. 1994. *In situ* burning of oil spills on land: A case study. Proceedings of the Seventeenth Arctic and Marine Oil Spill Program (AMOP) Technical Seminar. Environment Canada. pp. 651-655.

Mook, J. H., and J. van der Toorn. 1982. The influence of environmental factors and management on stands of *Phragmites australis*. II. Effects on yield and its relationships with shoot density. J. of Appl.Ecol. 19: 501-517.

Neckles, H. A., J. W. Nelson, and R. L. Pedersen 1985. Management of whitetop (*Scolochloa festucacea*) marshes for livestock forage and wildlife.Tech. Bull. No. 1. Delta Waterfowl Research Station. 12 pp.

Obot, E.A., A. Chinda, and S. Braid. 1992. Vegetation recovery and herbaceous production in a freshwater wetland 19 years after a major oil spill. African J. of Ecol. 30: 149-156.

Oil and Gas Journal. 1993. Oil spill burn test slated off east Canada. 91(30): 28 (2).

Overton, E.B., J.A. McFall, S.W. Mascarella, C.F. Steele, S.A. Antoine, I.R. Politze, and J. L. Laseter. 1981. Identification of petroleum residue sources after a fire and oil spill. Proceedings of the 1981 Oil Spill Conference. API, Washington, D.C. pp. 541-546.

Roques, D. E., E. B. Overton, and C. B. Henry. 1994. Using gas chromatography/mass spectroscopy fingerprint analyses to document process and progress of oil degradation. J. of Environ. Quality. 23:851-855.

Schmalzer, P. A., C. R. Hinkle, and J. L. Mailander. 1991. Changes in community composition and biomass in *Juncus roemerianus* Scheele and *Spartina bakeri* Merr. marshes one year after a fire. Wetlands. 11: 67-86.

Shay, J. M., D. J. Thompson, and C.T. Shay. 1987. Post-fire performance of *Phragmites australis* (Cav.) Trin. in the Delta Marsh, Manitoba, Canada. Arch. Hydrobiol. Beih. 27: 95-103.

Smith, L. M., and J. A. Kadlec. 1985. Fire and herbivory in a Great Salt Lake marsh. Ecology. 66: 259-265.

Smith, N. K., and A. Diaz. 1985. In place burning of Prudhoe Bay oil in broken ice. Proceedings of the 1985 Oil Spill Conference. API: Washington, D.C. pp. 405-410.

Smith, R. H. 1942. Management of salt marshes on the Atlantic coast of the United States. Trans. N. Am. Wildl. Conf. 7: 272-277.

Steward, K. K., and W. H. Ornes. 1975. The autecology of sawgrass in the Florida Everglades. Ecology. 56: 162-171.

Taylor, K. L., J. B. Grace, G. R. Guntenspergen, and A. L. Foote. 1994. The interactive effects of herbivory and fire on an oligohaline marsh, Little Lake, Louisiana, USA. Wetlands. 14: 82-87.

Teal, J., and M. Teal. 1969. Life and death of the salt marsh. Little Brown and Company: Boston, Massachusetts.

Tennyson, E. J. 1993. Results from oil spill response research: An update. Proceedings of the 1993 Oil Spill Conference. API: Washington, D.C. pp. 541-544.

Tewes, M. E. 1982. Response of selected vetebrate populations to burning of gulf cordgrass. M.S., Texas A & M University, College Station. 131 pp.

Thompson, D. J., and J. M. Shay. 1989. First-year response of a *Phragmites* marsh community to seasonal burning. Canadian Journal of Botany. 67: 1448-1455.

Timmins, S. M. 1992. Wetland vegetation recovery after fire: Ewebum, Te Anau, New Zealand. New Zealand J. of Botany. 30: 383-399.

Tunnel, J. W., D. W. Hicks, and B. Hardegree. 1994. Environmental impact and recovery of the Exxon pipeline oil spill and burn site, Upper Copano Bay, Texas: Year One. Center for Coastal Studies, Texas A&M University-Corpus Christi. 75 pp.

Tunnel, J. W., B. Hardegree, K. Withers, and D. W. Hicks. 1995. Environmental impact and recovery of the Exxon pipeline oil spill and burn site, Upper Copano Bay, Texas: Year Two. Center for Coastal Studies, Texas A&M University-Corpus Christi. 42 pp.

Turner, M. G. 1987. Effects of grazing by feral horses, clipping, trampling and burning on a Georgia salt marsh. Estuaries. 10:54-60.

Turner, M. G. 1988. Multiple disturbances in a *Spartina alterniflora* salt marsh: Are they additive? Bulletin of the Torrey Botanical Club. 115: 196-202.

VanArman, J., and R. Goodrick. 1979. Effects of fire on a Kissimmee River marsh (wetland plant communities). Florida Scientist. 42:183-195.

van der Toorn, J., and J.H. Mook. 1982. The influence of environmental factors and management on stands of *Phragmites australis*. I. Effects of burning, frost, and insect damage on shoot density and shoot size. J. Appl. Ecol. 19:477-499.

Vogl, R. J. 1973. Effects of fire on the plants and animals of a Florida wetland. American Midland Naturalist. 89: 334-347.

Ward, E. 1942. *Phragmites* management. Trans. N. Am. Wildl. Conf. 7: 294-298.

Wells, B. W. 1942. Ecological problems of the southeastern United States coastal plain. Bot. Rev. 8: 533-561.

Westree, B. 1977. Biological criteria for the selection of cleanup techniques in salt marshes. Proceedings of the 1977 Oil Spill Conference. API: Washington, D.C. pp. 231-235.

Whipple, S.A., and D. White. 1977. The effects of fire on two Louisiana marshes. Assoc. Southeast Biol. Bull. 24:95.

Young, R. P. 1986. Fire ecology and management in plant communities of Malheur National Wildlife Refuge, Oregon. Ph.D., Oregon State University, Corvallis. 183 pp.

Zischke, J.A. 1993. Benthic invertebrate survey: Meire Grove Pipeline Project. Report for Delta Environmental Consultants, Inc. 7 pp. + figures and tables.