

Amelioration of Freshwater, Peat-based Marshes after Oil Contamination
Part I. A Field Experiment
Part II. An Historic Spill Site Assessment

Report No. _____

OSRADP Logo

**Amelioration of Freshwater, Peat-based Marshes after Oil Contamination:
Part I. A Field Experiment
Part II. An Historic Spill Site Assessment**

by

Guerry O. Holm, Jr. and Charles E. Sasser
School of the Coast and Environment
Coastal Ecology Institute
Louisiana State University
Baton Rouge, LA 70803

and

Patrick J. Bergeron
Environmental Safety and Health Consulting Services, Inc.
Houma, LA 70364

Prepared for
Louisiana Applied and Educational Oil Spill Research and Development Program
258A Military Science Bldg.
Baton Rouge, LA 70803
Report No. _____

DISCLAIMER

This report was prepared under a contract between Louisiana State University and the Louisiana Applied and Educational Oil Spill Research and Development Program (OSRADP). The contents of this document do not necessarily reflect the views and policies of the Louisiana Oil Spill Coordinator's Office—Office of the Governor or those of the Louisiana Applied and Educational Oil Spill Research and Development Program, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use by the state of Louisiana.

Report Availability

Additional copies of this report may be obtained by writing to:

Louisiana Applied and Educational Oil Spill Research and Development Program
Room 258 Military Sciences Bldg.
Baton Rouge, LA 70803
Telephone Number: 225.578.3477 FAX number 225.578.0403

or

Louisiana Oil Spill Coordinator/Office of the Governor

Natural Resources Bldg.
Baton Rouge, LA 70806
Telephone Number: 225.219.5800 FAX Number 225.219.5802

Citation

Holm, G. O., Jr., C. E. Sasser, and P. J. Bergeron. 2003. Amelioration of freshwater, peat-based marshes after oil contamination: I. A Field Experiment; II. An Historic Spill Site Assessment. Louisiana State University, School of the Coast and Environment. Louisiana Applied and Educational Oil Spill Research and Development Program, OSRADP Technical Report Series 28p.

TABLE OF CONTENTS

1. General Introduction.....	2
Part I. A Field Experiment	
2.0 Introduction.....	3
3.0 Methods.....	4
4.0 Results.....	5
5.0 Discussion.....	6
6.0 Literature Cited.....	8
Part II. An Historic Spill Site Assessment	
7.0 Introduction.....	14
8.0 Methods.....	15
9.0 Results.....	17
10.0 Discussion.....	18
11.0 Literature Cited.....	20

Acknowledgements

We thank the Louisiana Applied and Educational Oil Spill Research Program (OSRADP) for their support of this project. Forest Oil Corporation and their subcontractor, ES&H Consulting and Training Group, provided assistance with logistical support, project implementation, and field data collection. Forest Oil also funded the hydrocarbon analyses of the soil samples collected at the 2001 spill site. We extend special thanks to: B. Ashton, C. Henry, D. Isham, R. Jacob, S. Miles, E. Peterson, H. Pitre, and J. Sasser.

List of Figures

1.1	Total petroleum hydrocarbon reduction or increase among different treatments.....	10
1.2	Stem counts and stem heights of plants.....	11
1.3	The difference in the number of plant stems between October and May compared to the average TPH concentration (Oct. TPH+May TPH/2) in each experimental plot.....	12
2.1	Aboveground biomass comparison between the Control and Exxon sites.....	23
2.2	Belowground biomass comparison between Control and Exxon sites.....	24
2.3	Soil shear strength comparison among the Exxon spill site and a Control site.....	25
2.4	Soil carbon to nitrogen content between the Exxon and Control sites.....	26

List of Tables

1.1	Louisiana coastal marsh distribution.....	13
1.2	Stem density comparisons for May 2002 and October 2002.....	14
2.1	A list of plant species harvested from Control and Exxon sites.....	27
2.2	Concentration of total petroleum hydrocarbons (TPH), alkanes, and total polycyclic aromatic hydrocarbons in soil cores taken from each of five plots at the Exxon and Control study marshes.....	28
2.3	Comparison of historical data (Wong 1994) from the Paradis-Exxon site to the measurements made for this study.....	29

Amelioration of Freshwater, Peat-based Marshes after Oil Contamination: I. A Field Experiment; II. An Historical Spill Site Assessment

Abstract

This report includes two discrete but complementary field studies pertaining to oil spills in freshwater peat-based marshes. Our objectives were: (1) to compare the success of marsh recovery by either transplanting or natural plant reestablishment; and (2) to compare the ecological status (plant/soil characteristics) of an oil-impacted versus un-impacted marsh, 10 years following a spill. In the first experiment, we found that the process of plant reestablishment is slow in peat soils with moderate to high oil concentrations. However, transplant survivorship and growth of *Panicum hemitomon* and

Sagittaria lancifolia is positive in peat soils with fresh crude oil conditions. Whether the growth of transplants accelerated oil breakdown is uncertain. In the second study, we found that the oil-impacted marsh fell short of the target conditions, which were defined by an un-impacted Control marsh. Nonetheless, the oil-impacted marsh has become fully re-vegetated within 10 years and exhibits comparable species richness to that of the un-impacted marsh. Transplantation may be useful in accelerating plant coverage of crude oil impacted marshes, thereby facilitating the natural recovery process.

1.0 General Introduction

Louisiana's coastal marsh landscape has been heavily used by the oil and gas industry. Pipelines connecting various components of production and storage facilities are widespread. Occasionally, these pipelines are damaged or broken, causing spillage of oil products. Studies designed to provide scientific information on the most effective response to oil spills and restoration of oil-impacted wetlands have focused largely on saline marshes. Little information adequately addresses cleanup and restoration after spills in freshwater, peat-based wetlands.

This report describes a "spill of opportunity" research project we conducted to address some of the pertinent questions related to ecological recovery of freshwater peat marshes. The project was initiated in spring 2002. The results of this project are presented in two sections that describe the transplant and fertilization study at the recent (2001) spill site and the natural plant colonization study at the older (1993) spill site.

The objective of this research is to test and evaluate methods to ameliorate oil contamination and to restore dominant natural vegetation in freshwater peat-based marshes impacted by spilled crude oil. The research uses two time scales: short-term (<2 years) and long-term (10 years). Specific objectives were to evaluate marsh recovery following transplantation of natural vegetation (maidencane and bulltongue) into the recently contaminated site, determine the effects of applying inorganic fertilizer on maidencane, and evaluate the subsequent oil degradation. The study also evaluated the long-term (~10 years) marsh recovery without transplantation of natural vegetation. This objective used a separate but similar marsh site in the study region contaminated by oil and brine during 1993. The main objectives of both study components were to: (1.)

understand how initial remedial approaches to small oil spills may enhance marsh stability soon after a spill, and (2.) contrast how the effect of time, without initial restoration efforts (i.e. transplanting and fertilization), influences the freshwater wetland recovery process.

2.0 Introduction Part I. A Field Experiment

Given the breadth of freshwater marshes (Table 1) and the oil production occurring within this coastal habitat, there is a need to find multiple ways of reducing oil contamination and enhance the recovery process. We lack information about different methods of plant restoration and site amelioration in these habitats (Henry et al. 2003). Although greenhouse studies have addressed the question of plant species performance and oil concentration (Lin and Mendelsohn 1997; Dowty et al. 2001), to our knowledge no studies have tested plant growth in freshwater peat-based marshes.

In order to begin addressing this data gap, the field experiment's goal was to determine the success of native plant restoration in an oil contaminated peat marsh after a recent (~1 yr) oil spill. We measured the growth of maidencane (*Panicum hemitomon*) and bulltongue (*Sagittaria lancifolia*) after transplantation into an oil contaminated freshwater floating marsh. We also measured the rate of natural plant colonization into Control plots that received no treatment. The results of this study comprise one growing season (May–Oct. 2002).

The oil spill occurred between the winter and spring of 2001, and it impacted approximately 1.0 ac of floating marsh located in the Paradis Oil Field (N 29° 51' 35" W

90° 28' 11"). There was no evidence of brine contamination with the oil spill. One year following the spill, very little plant colonization had occurred.

3.0 Methods

The transplantation of *Panicum* and *Sagittaria* sods took place on May 24, 2002. We collected sods (10 cm diameter X 15 cm depth) from an un-impacted donor marsh near the oil spill site. Five sods were planted in each plot (except for Controls); the stems in each sod were then counted, recorded, and clipped. The purpose of clipping was to measure new stem growth over time. Each plot was protected from mammal herbivory with 1.0 m² enclosures made of galvanized wire.

The four treatments—*Panicum* (P), *Panicum*-fertilized (PF), *Sagittaria* (S), and Control (C)—were randomly assigned to four plots in each of 10 locations that covered the heavily impacted zone of the oil spill. Thus, there were 10 replicates of each treatment, resulting in 40 plots. The locations were chosen along a transect that bisected the heavily oiled area. We avoided locations that had received traffic from prior cleanup efforts. We were unable to add another treatment to test *Sagittaria* with fertilization.

Plant growth was measured by change in live stem production and change in stem heights. Tiller production (in the case of *Panicum*) were recorded along with the general condition of the plants (stressed or vigorous).

Soil sampling for oil concentration was done prior to transplanting (May 2002) and at the end of the growing season (Oct. 2002). Soil cores (10 cm diameter X 15 cm depth) were excavated from each plot close to the center. Sampling equipment was cleaned with soap and water between samples to eliminate sample cross contamination. Individual plot samples (40) were analyzed for total petroleum hydrocarbon

concentration (EPA method 8270; GC/FID). The samples were analyzed by Sherry Laboratories (Lafayette, LA).

4.0 Results

Oil concentrations were unequal among the four treatments at the beginning of the experiment (Fig. 1.1). The *Panicum* treatment contained twice the oil content of the *Sagittaria* and Control treatments—84 versus 36 and 40 g/kg, respectively. Oil reduction in the *Panicum* and *Panicum*-fertilized treatments, after five months, was proportionate to the initial concentrations (Fig. 1.1). No reduction in oil was observed in the *Sagittaria* or Control treatments.

The variability of the initial stem densities of transplanted sods among plots within each treatment was low (<4 stems; Table 1.1). Average stem production was highest in fertilized *Panicum*, where an almost five-fold increase over initial stem density was observed (Fig. 1.2; Table 1.2). *Sagittaria* only had a 1.5 fold increase in stems from the initial density (Table 1.2). Stem heights were relatively even among all treatments. *Panicum* stems reached their maximum height in August and declined slightly in October (Fig. 1.2).

No signs of plant establishment in Control treatments occurred throughout the first growing season or at the beginning of the second season (April 2003). Although we recorded the presence of young shoots or seedlings (unknown dicots) in Control plots, their presence was ephemeral. Colonization of plants other than *Sagittaria* and *Panicum* (in the transplanted plots) was limited over the length of this study. The other species that colonized the transplanted plots included: *Alternanthera philoxeroides*, *Carex* spp., *Eleocharis* spp., *Hydrocotyle* spp., *Leersia oryzoides*, *Polygonum punctatum*, *Sapium*

sebiferum, unknown vines, and unknown dicots. At the treatment level, the total amount of coverage for all of these species was less than 5%. Outside of the study plots, colonization of some annuals (*Cyperus* spp.) and perennials (*Eleocharis* spp.) was observed, especially, in disturbed areas.

The average change in growth (positive, negative, or static) of transplants with respect to average soil TPH and treatment is shown in Fig. 1.3. In general, *Panicum* exhibited a stronger positive growth response than *Sagittaria*. At relatively high oil concentrations, *Panicum* appeared to have greater aboveground production, even without fertilization.

5.0 Discussion

Plant colonization or expansion into Control plots from May 2002 to April 2003 was practically nonexistent. Given this lack of seed germination or vegetative growth, it is apparent that the process of natural plant establishment is slow following an oil spill. Indeed, a similar oil spill site (see Part II of this report) showed negligible natural plant establishment two years following an oil spill of similar magnitude (pers. comm. P. Bergeron ES&H; Mendelssohn 1997). The positive growth response of transplants indicates that oil spill amelioration may occur more rapidly with transplanting perennials such as *Panicum* or *Sagittaria*.

Growth response was greater for *Panicum* than *Sagittaria*, and fertilization of *Panicum* stimulated aboveground biomass. These results are consistent with mesocosm studies (Dowty et al. 2001) of these two species. After 18 months, *Panicum* exhibited greater productivity and photosynthetic rates compared to *Sagittaria*. However,

Sagittaria was the dominant plant that remained after the spill; its presence was limited to the fringes of the moderately impacted spill site areas.

Prior to our experiment, *Panicum* establishment has not been observed in heavily or moderately oiled areas. Even though *Panicum* exhibited positive growth in experimental plots with high oil concentrations ($>100 \text{ g kg}^{-1}$), this plant was negatively affected by some phytotoxic component of fresh oil contamination (other than brine) at the spill site. From experimental and visual observations and other literature (Dowty et al. 2001; Lin and Mendelsohn 1997), we recognize *Sagittaria* as a plant with a high tolerance to oil contamination. But it appears that the process of transplanting *Sagittaria*—especially in the spring months—may limit its ability to expand, at least initially.

Other studies have tested the role of plants in stimulating oil degradation (Venosa et al. 2000). We observed a decrease of oil concentration in *Panicum* and *Panicum*-fertilized treatments; oil concentration in *Sagittaria* and Control treatments remained the same over time. Whether the decrease in oil concentration in *Panicum* treatments was plant-mediated is uncertain.

The results of this study indicate that transplantation of *Panicum hemitomon* into an oil degraded freshwater floating marsh has the potential to produce immediate restoration benefits. At least in the short-term (one year) as documented in this study, transplanted *Panicum hemitomon* plants have performed well. The reestablishment of this plant species is important to the maintenance and sustainability of the flotant marsh mat, and should be implemented in response to future oil spills whenever possible.

6.0 Literature Cited

- Dowty, R.A., G.P. Shaffer, M.W. Hester, G.W. Childers, F.M. Campo, and M.C. Greene. 2001. Phytoremediation of small-scale oil spills in fresh marsh environments: A mesocosm simulation. *Marine Environmental Research*. 52:195-211.
- Henry, C., C. E. Sasser, G. O. Holm, Jr., K. Lynn, J. Brodin, P. Bergeron, and D. Isham. 2003. Responding to oil spills in Louisiana's coastal floating marshes: Ecology, oil impact, and response alternatives. Proceedings of the International Oil Spill Conference. Vancouver, British Columbia, Canada. April 2003.
- Lin, Q., I.A. Mendelssohn. 1996. A comparative investigation of the effects of Louisiana crude oil on the vegetation of fresh, brackish, and salt marsh. *Marine Pollution Bulletin*. 32:202-209.
- Mendelssohn, I. A. 1997. Vegetation recovery from the Paradis oil spill. Final report to Exxon Co., USA. New Orleans, LA. 105 p.
- Sasser, C.E. and J.G. Gosselink. 1984. Vegetation and primary production in a floating freshwater marsh in Louisiana. *Aquatic Botany*. 20:245-255.
- Sasser, C.E. 1994. Vegetation dynamics in relation to nutrients in floating marshes in Louisiana, USA. PhD. Dissertation, University of Utrecht, Netherlands. 193 p.
- Venosa, A.D., M.T. Suidan, B.A. Wrenn, K.L. Strohmeier, J. R. Haines, B.L. Eberhart, D. King, and E. Holder. 1996. Bioremediation of an experimental oil spill on the shoreline of Delaware Bay. *Environmental Science and Technology*. 30(5):1764-1775.

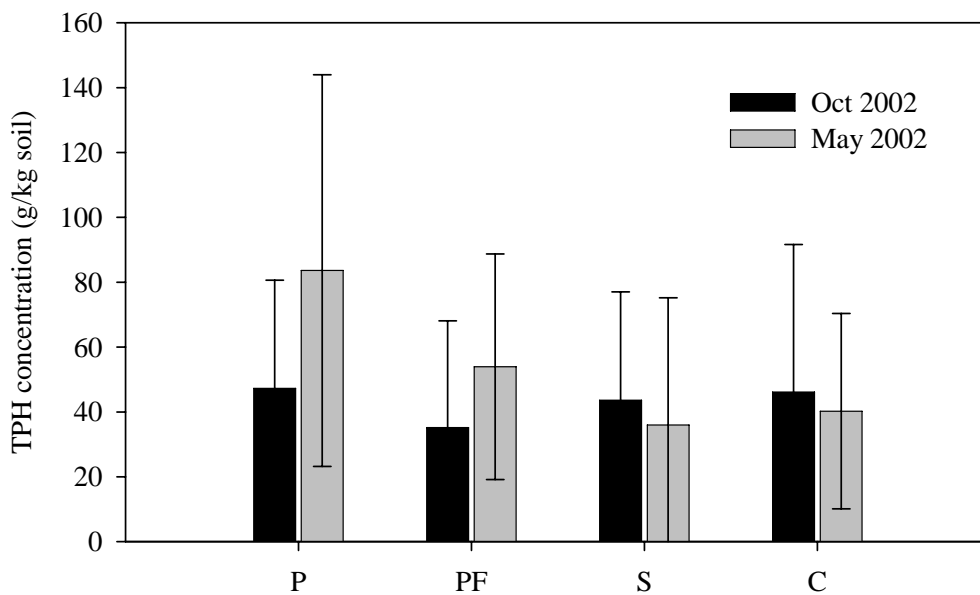
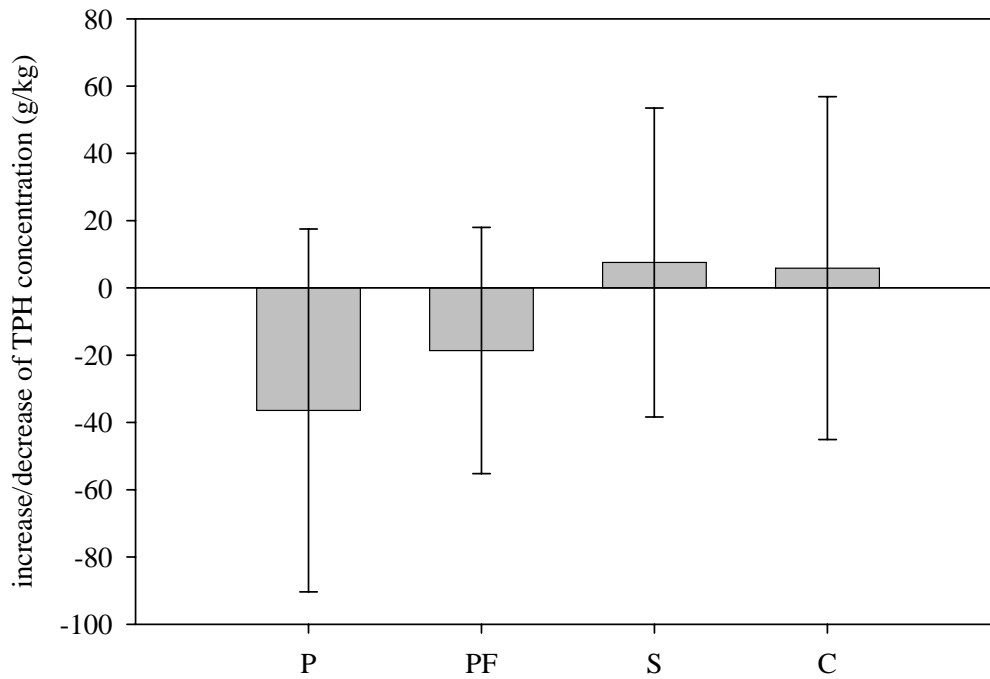


Figure 1.1. Total petroleum hydrocarbon reduction or increase among different treatments. The upper graph shows the amount of TPH reduction or increase based on the difference between the beginning (May 2002) and ending (October 2002) soil concentrations. The lower graph shows the absolute change in concentrations for May and October sampling periods. Both of the treatments containing *Panicum* showed

decreases in mean TPH concentrations; however, this reduction is proportionate to high initial concentrations.

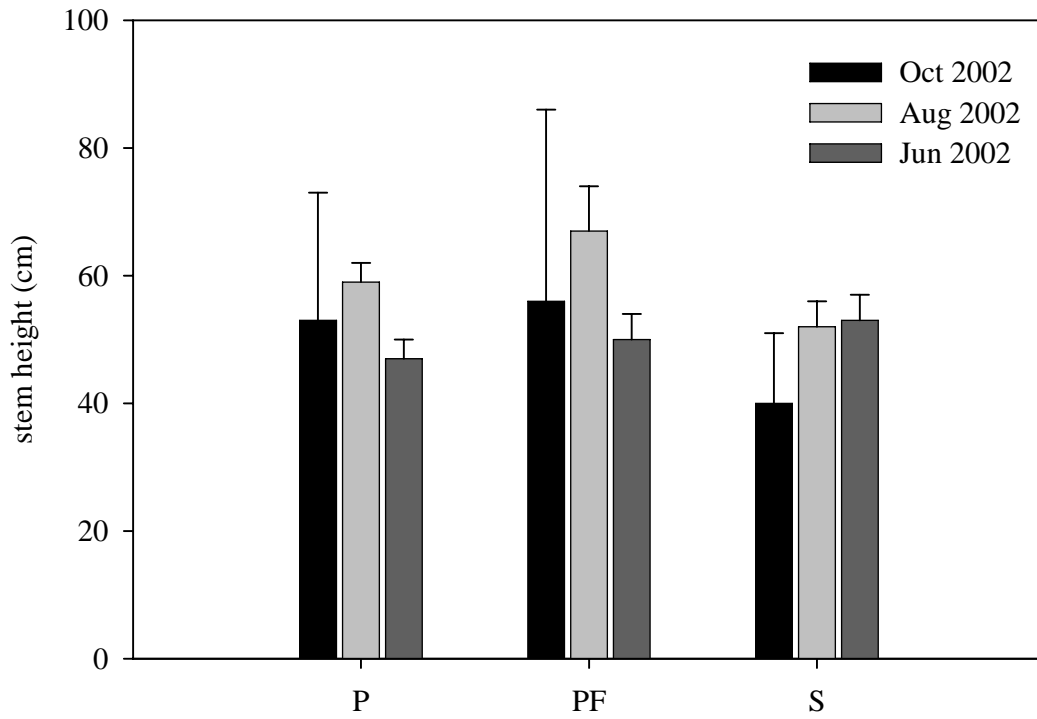
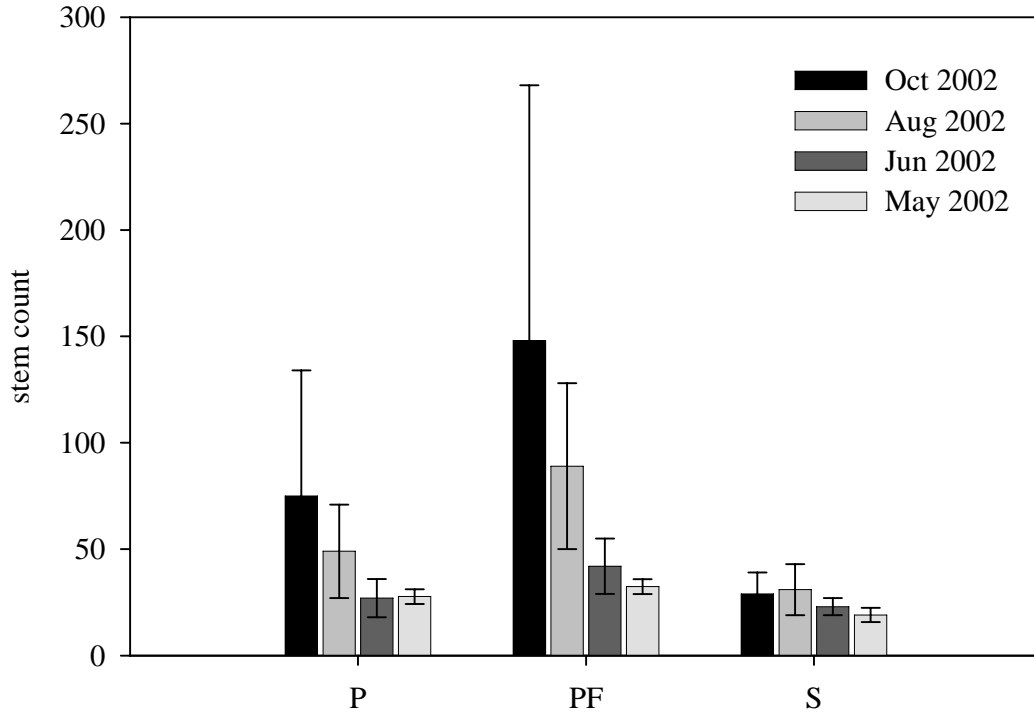


Figure 1.2. Stem counts and stem heights of plants. May through October stem counts of the three species studied (upper graph). The lower graph shows the average stem heights, which represent new growth after the plants were clipped and transplanted in May.

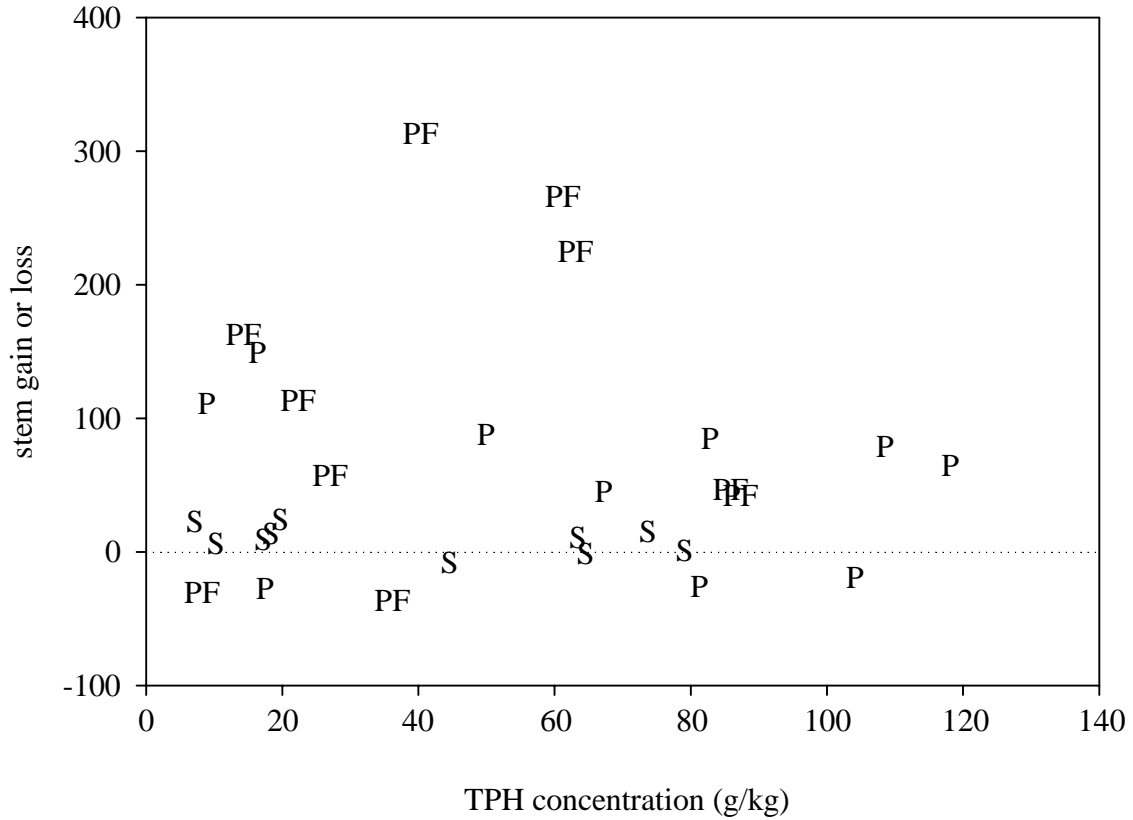


Figure 1.3. The difference in the number of plant stems between October and May compared to the average TPH concentration (Oct. TPH+May TPH/2) in each experimental plot. *Sagittaria* stem gain was low across a wide range of oil concentrations, while *Panicum* stem gain was stable at relatively higher oil concentrations.

Table 1.1. Louisiana coastal marsh distribution (Coast 2050). Approximately 40% of the coastal marsh landscape is composed of marshes in the freshwater zone. Except for active deltaic areas, most freshwater marshes are peat-based.

marsh type	acreage
freshwater	908,000
intermediate	365,000
brackish	765,000
salt	404,000
total	2.4 million

Table 1.2. Stem density comparisons for May 2002 and October 2002. Final plot stem density represents newly produced stems. The initial stem density represents the number of stems that were clipped prior to transplanting the sods.

treatment	initial live stem density (May)	final live stem density (Oct)	factor of increase of stems*
P	28±3.4	75±59	3.2
PF	32±3.4	148±120	4.8
S	19±3.3	29±10	1.5

*This factor of increase is the minimum, as stem turnover was not measured. In the case of *Sagittaria*, complete stem turnover can occur in less than three weeks

7.0 Introduction Part II. An Historic Spill Site Assessment

The purpose of this study was to evaluate the recovery of a coastal freshwater marsh that was impacted by an oil and brine spill. Ten years had passed from the time that the oil spill occurred to the time of our study. The specific measurements we made between a reference marsh and the impacted marsh were: aboveground biomass, belowground biomass, plant composition, oil concentration, soil strength, and soil carbon to nitrogen content. We compared these parameters between the impacted and reference marshes to provide a recovery trajectory that can be expected in the absence of a large-scale site restoration following an oil spill.

The Paradis-Exxon oil and brine spill occurred in January 1993. It impacted 2.4 acres of floating marsh. Approximately 800 barrels of oil contaminated material were physically removed from the site. Although the salt stress to plants was ephemeral, the remaining unweathered oil, trapped in the anaerobic peat matrix, caused poor plant regeneration.

An experimental study was initiated in 1996 by the Louisiana Department of Environmental Quality (LDEQ) to determine whether the removal of oiled surface litter would stimulate seed germination and vegetative productivity. The results of LDEQ's experiment (Bergeron and St. Pe, unpublished data) showed significant increases in plant biomass in raked plots versus untreated plots (no litter removal).

In an assessment (Mendelssohn 1997) for the oil company, vegetation recovery was visually estimated on the ground and from a series of aerial photographs. Mendelssohn (1997) found that the area of dead and stressed vegetation from 1994 to 1996 had been reduced by 60% (1.57 to 0.63 acres). However, he reported that the

vegetation of the impacted marsh was different from the adjacent reference marsh. He predicted that with time, competitive grasses (*Panicum hemitomon* and *Leersia oryzoides*) would out-compete the early successional community of plants (*Cyperus* sp.).

8.0 Methods

The reference marsh we selected for comparison to the Paradis site is located at Lake Bouef, which is in the same hydrologic basin (Barataria Basin) as the Paradis site. The Lake Bouef site (hereafter referred to as the Control site) is a long-term site where vegetation and soil parameters have been measured since the 1980s (Sasser 1984; Sasser et al. 1994).

The vegetation at the Control site is similar to marshes in the general area of the Paradis oil field. Vegetation composition is usually diverse, dominated by *Panicum hemitomon*, in association with *Leersia oryzoides* and *Sagittaria lancifolia*. Other plants that usually are found in this community are the ferns, *Thelypteris palustris* and *Osmunda regalis*, and the vines, *Vigna luteola*, *Impomoea sagittata*, and *Polygonum sagittatum*. *Myrica cerifera* (wax myrtles) are frequently a major part of the maidencane floating marsh vegetation assemblage.

Both the Paradis and Control sites are floating marshes. Floating marshes have peat-based soils that are formed by densely intertwined roots and rhizomes. The maintenance or accretion of the peat mat is controlled by live root production; mineral sedimentation is rare. Approximately 30 cm below the marsh mat surface, the root matrix grades into fine organic detritus. Depending on water levels, the buoyant root zone may

be separated from an underlying organic ooze or clay pan by a free water layer (Sasser et al. 1994).

At the Paradis site we used five preexisting plots (those used in the earlier study by LDEQ) to estimate above and belowground biomass, oil concentration, soil strength and soil C:N. These five plots represent a gradient of oil impact with distance from the source. However, all of these plots were within a zone where vegetation had initially died from oil exposure.

We used 0.25 m² clip plots to estimate aboveground live and dead standing crop and species composition. Vegetation was harvested in the study plots in mid-November 2002 at both sites. Although this is late in the average growing season, both sites were sampled in the same time period. Furthermore, mild weather in October and November extended the 2003 growing season. At the Paradis site, four soil cores (10 cm diameter X 15 cm depth) were collected at each of the five clip plots. One core was bisected, with one half used for a C:N ratio and the other half used for TPH and GC-MS analyses.

The remaining three cores were bisected in the lab, where soil strength measurements were taken on each half-face at three depths (0-5, 6-10, 11-15 cm). The three split cores were then rinsed through a sieve (#35 mesh; 0.5 mm) and separated by live and dead belowground biomass. All live and dead biomass was dried to a constant weight at 60°C and weighed to the nearest 0.01 g.

The only difference in sampling design was the collection of cores from the Control site, where cores were collected from a preexisting study of soil and vegetation parameters. Thus, averages from the Control site have a different number of

replicates/cores in these cases: there were 17 cores for belowground biomass, seven cores for soil strength and nine cores for C:N ratio.

Soil samples were dried and ground through a Wiley Mill with a #40 mesh screen. Soil C:N ratios were measured with a Perkin-Elmer CHN analyzer, and the standard was ground pine needles, which matched the organic nature of the soil samples. Duplicate samples (1 mg) were run for each core. Soil strength was measured as the force (kg cm^{-2}) required to cause soil failure or shear, and the instrument used was a Trodden Torvane Soil Strength Tester (ELE Inc.).

Five cores from the Control and impacted sites were analyzed for TPH content; a detailed GC-MS analysis was also performed. These cores were taken in the proximity of plots that were sampled in February 1993, May 1993, and September 1994. Historical GC/MS data were provided to us by P. Bergeron (ES&H, Houma, LA) and K. St. Pe' (BTNEP, Thibodaux, LA). These data were provided to the Exxon Co. USA (New Orleans, LA) by LSU (R. Wong 1994). The GC/FID and GC/MS analytical techniques used in our study are described in EPA Method 8270. Method 8270 is used to determine the concentration of semi-volatile organic compounds in extracts prepared from many types of solid waste matrices, soils, air sampling media, and water samples. Analyses were performed by the LSU Environmental Studies Department.

9.0 Results

Dominant vegetation composition of the impacted oil spill site differed from the Control site. *Panicum hemitomon* (maidencane) was the dominant species at the Control site, and *Sagittaria lancifolia* (bulltongue) was dominant at the impacted site (Table 2.1).

There was a total of 12 and 13 species harvested in clip plots from impacted and Control sites, respectively. There was no significant difference between the average numbers of species in each plot between impacted (5.5 ± 2.2 species) and Control (6 ± 1.8 species).

There were five species in common between both sites, but they were present in different proportions (Table 2.1).

The average live aboveground biomass was higher in the Control plots (580 ± 182 g m⁻²) than in impacted plots (329 ± 111 g m⁻²) (Figure 2.1). Likewise, dead biomass was greater in the Control (370 ± 72 g m⁻²) compared to the impacted sites (161 ± 59 g m⁻²).

Live belowground biomass was comparable between the Control ($1,565 \pm 360$ g m⁻²) and impacted ($1,144 \pm 752$ g m⁻²) sites; however, the impacted site had much greater dead belowground material than the Control site (impacted $2,656 \pm 736$ versus Control $1,187 \pm 344$ g m⁻²; Figure 2.2). The measurements for dead belowground material may have been slightly inflated from the residual oil that could not be removed by sorting, washing, and drying the dead material.

Soil strength was greater in the Control marsh (0.48 ± 0.05) than in the impacted marsh (0.32 ± 0.08) (Figure 2.3). The proportion of carbon-to-nitrogen was high (30 ± 4) in the impacted site; while the Control site exhibited a balanced ratio (23 ± 2) (Figure 2.4).

Total petroleum hydrocarbons, alkanes, and polycyclic aromatic hydrocarbons were at least three orders of magnitude higher at the impacted site than at the Control site (Table 2.2). Overall, there was a limited reduction in PAHs from historical numbers. In 1994, average PAH concentrations were 189 ± 152 mg kg⁻¹, compared to 108 ± 111 mg kg⁻¹ in 2002 (Table 2.3).

10.0 Discussion

Of the parameters that we measured, the oiled site fell short of an unimpacted target. We assume that our Control marsh represented a reasonable target condition. This indicates that the Paradis-Exxon marsh is operating at a reduced, but stable equilibrium compared to that of the Control marsh. Nonetheless, the Paradis-Exxon site has become fully vegetated since the last comprehensive survey (Mendelssohn 1997). The plants at the impacted site were visibly healthy, yet less productive than the Control marsh.

Both sites had diverse assemblages, but the differences we saw in plant community structure may help explain the relatively low and highly variable live belowground biomass at the Paradis site. The dominant belowground biomass at the oil spill site comprised *Sagittaria lancifolia* basal rosettes. These structures are massive but weak in terms of peat-binding capacity. The rosettes do not produce a network of dendritic, fine roots and rhizomes, which are typical of grasses (i.e. *Panicum hemitomon*). Instead, fine roots and rhizomes from *S. lancifolia* are aerenchymatous (air-filled) and poorly branched. Our soil strength measurements corroborate these observations; in that the *Panicum*-dominated control site had significantly greater soil strength than the *Sagittaria*-dominated oiled site. In organic marsh soils, McGinnis (1997) showed that the shear stress of a soil was positively correlated with the live root biomass of a sample.

The reduced productivity of the Paradis site can be explained partially by the surplus of carbon relative to nitrogen. Nitrogen immobilization occurs when C:N ratios >20 (Kulshreshtha and Gopal 1982). The Control site was balanced (< 25) more so than the impacted site, where C:N values approached 30-35. If excess carbon associated with

the residual oil retards soil decomposition, rates of nitrogen mineralization may decrease concomitantly.

There is an apparent limitation on the establishment of grasses such as *Panicum* and *Leersia* at the Paradis-Exxon site, even though ten years have lapsed since the spill. The results from a field experiment conducted at a new oil spill site (Paradis-Forest, see Part I) show that *Panicum* exhibits positive growth even at relatively high concentrations of fresh oil; the *Panicum* at this site was transplanted. Since *Panicum* produces few viable seeds, its establishment occurs by clonal rhizome growth. Other species such as *Eleocharis* and *Sagittaria* at the Paradis-Exxon site have inhibited the clonal expansion of *Panicum* or *Leersia*. Moreover *Eleocharis* has been shown to have allelopathic effects on other plants (Wooten and Elakovich 1991).

A successional sequence is implied in the case of floating marsh development, but this phenomenon has not been observed or recorded (but see O'Neil 1949). It is conceivable, however, that in the absence of flooding or other strong abiotic stress (which would create zonation of plant communities; Neiring 1987), the high diversity observed in many floating marshes is a product of high interspecific competition among species. This diversity arises under a relatively stable environment (Sanders 1968). The presence of *Panicum hemitomon* as a dominant component of the floating marsh association seems to confer a high biotic integrity to the development of freshwater peat-based marshes in Louisiana's deltaic plain.

11.0 Literature Cited

- Dowty, R.A., G.P. Shaffer, M.W. Hester, G.W. Childers, F.M. Campo, and M.C. Greene. 2001. Phytoremediation of small-scale oil spills in fresh marsh environments: A mesocosm simulation. *Marine Environmental Research*. 52:195-211.
- Kulshreshtha, M. and B. Gopal. 1982. Decomposition of freshwater wetlands vegetation. I. Submerged and free-floating macrophytes. In: B. Gopal, R.E. Turner, R.G. Wetzel, and D.F. Whigham (eds.), *Wetlands Ecology and Management*. National Institute of Ecology: Jaipur, India. pp. 259-278.
- Lin, Q., I.A. Mendelssohn. 1996. A comparative investigation of the effects of Louisiana crude oil on the vegetation of fresh, brackish, and salt marsh. *Marine Pollution Bulletin*. 32:202-209.
- Mendelssohn, I. A. 1997. Vegetation recovery from the Paradis oil spill. Final report to Exxon Co., USA. New Orleans, LA. 105 p.
- McGinnis, T.E., III. 1997. Factors of soil strength and shoreline movement in a Louisiana coastal marsh. MS Thesis. University of Louisiana, Lafayette. Lafayette, LA.
- Neiring, W.A. 1987. Vegetation dynamics (succession and climax) in relation to plant community management. *Conservation Biology*. 1:287-295.
- O'Neil, T. 1949. The muskrat in Louisiana coastal marshes. Louisiana Department of Wildlife and Fisheries. 152 p.
- Sanders, H.L. 1968. Benthic marine diversity: A comparative study. *American Naturalist*. 102:243-82
- Sasser, C.E. and J.G. Gosselink. 1984. Vegetation and primary production in a floating freshwater marsh in Louisiana. *Aquatic Botany*. 20:245-255.
- Sasser, C.E. 1994. Vegetation dynamics in relation to nutrients in floating marshes in Louisiana, USA. PhD. Dissertation, University of Utrecht, Netherlands. 193 p.
- Wooten, J.W. and S.D. Elakovich. 1991. Comparisons of potential allelopathy of seven freshwater species of spikerushes (*Eleocharis*). *Journal of Aquatic Plant Management*. 29:12-15.

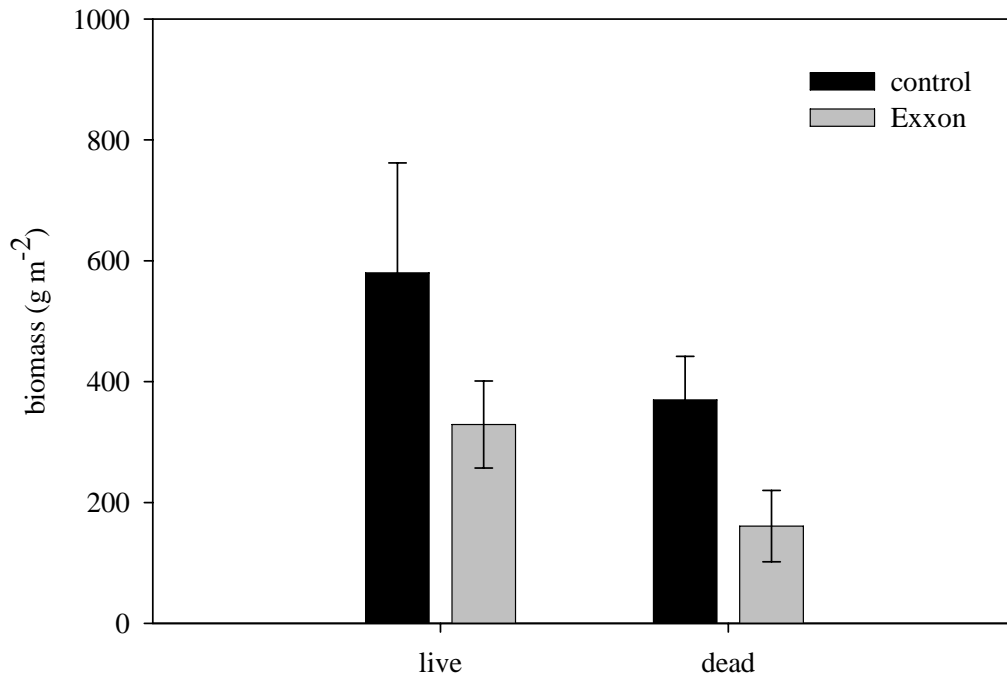


Figure 2.1. Aboveground biomass comparison between the Control and Exxon sites. Five 0.25 m⁻² clip plots were taken at each marsh.

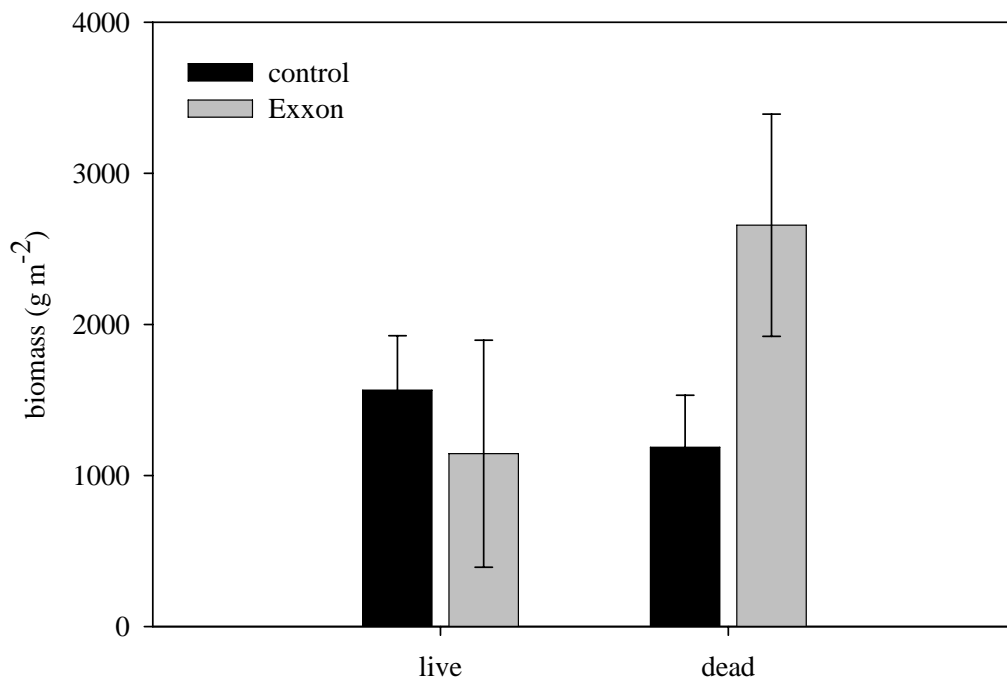


Figure 2.2. Belowground biomass comparison between Control and Exxon sites. There were five plots with three replicate cores taken at the Exxon site. Seventeen cores were taken at the Control marsh.

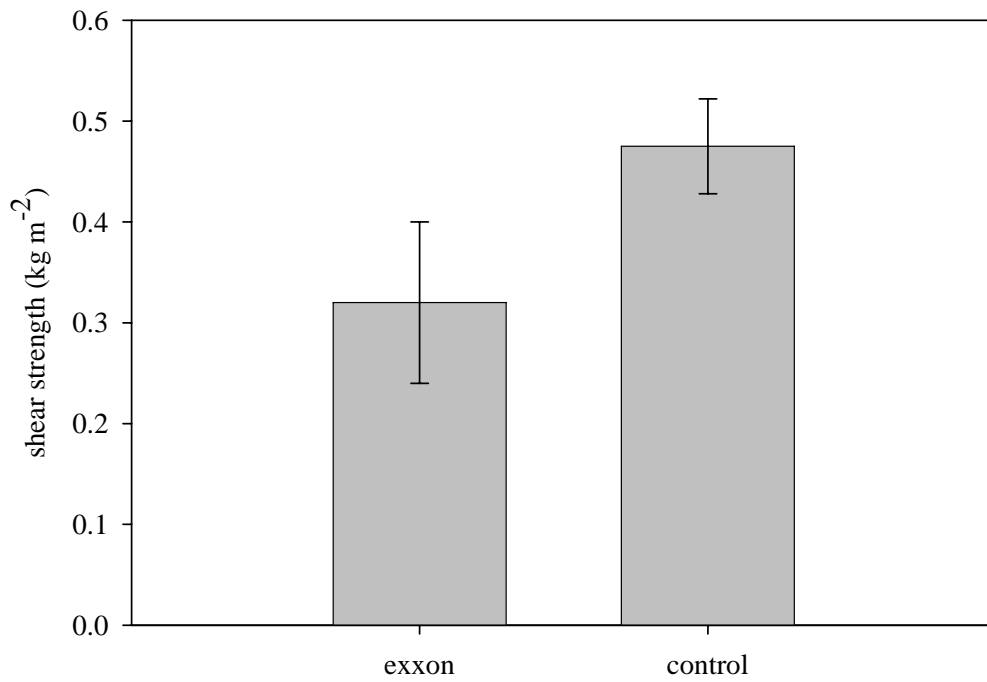


Figure 2.3. Soil shear strength comparison among the Exxon spill site and a Control site. The strength measurement is an average of duplicate measurements at three depths: 0-5, 6-10, and 11-15 cm. The Exxon average was based on three replicates at each of five plots; the Control average comprised seven plots.

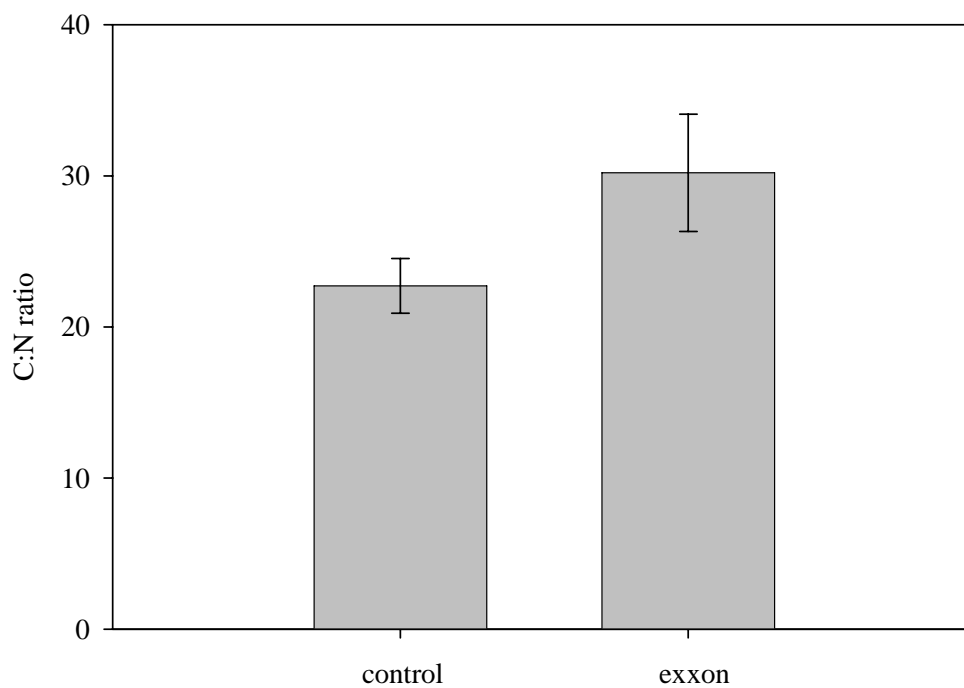


Figure 2.4. Soil carbon to nitrogen content between the Exxon and Control sites. The ratio is mass based with samples representing the upper 15 cm of the soil/peat matrix. The Exxon and Control sites were based on five and nine cores, respectively, with duplicate masses (mg g^{-1}) averaged for each core.

Table 2.1. A list of plant species harvested from Control and Exxon sites. The plants are ranked by their cumulative mass from five 0.25 m² plots.

Exxon Species	biomass (g)	Control species	biomass(g)
<i>Sagittaria lancifolia</i> *	185.9	<i>Panicum hemitomom</i> *	481.3
<i>Eleocharis sp.</i> *	178.6	<i>Solidago sempervirens</i> *	160.9
<i>Polygonum punctatum</i>	25.0	<i>Thelypteris palustris</i> *	49.6
Unknown sedge	6.7	<i>Leersia oryzoides</i> *	24.9
<i>Paspalum sp.</i>	4.9	<i>Hydrocotyle sp.</i>	1.5
<i>Panicum hemitomom</i>	4.1	<i>Myrica cerifera</i>	1.3
<i>Leersia oryzoides</i>	3.0	<i>Eleocharis sp.</i>	0.7
Unknown monocot	1.1	<i>Pluchea sp.</i>	0.7
<i>Sacciolepis striata</i>	0.7	<i>Sagittaria latifolia</i>	0.6
<i>Cyperus sp.</i>	0.6	<i>Bacopa monerii</i>	0.5
<i>Hydrocotyle sp.</i>	0.5	<i>Cyperus sp.</i>	0.4
<i>Salix nigra</i>	0.5	<i>Ipomoea sagittata</i>	0.3
		<i>Vigna luteola</i>	0.1
Total Live Biomass	412	Total Live Biomass	723

* represents a species that occurred in all five sample plots within a study site

Table 2.2. Concentration of total petroleum hydrocarbons (TPH), alkanes, and total polycyclic aromatic hydrocarbons in soil cores taken from each of five plots at the Exxon and Control study marshes. Values are based on wet-soil with no correction to hopane. Concentrations are in mg kg⁻¹.

site-plot	TPH	total alkanes	total PAH
Exxon A	2,157	20,002	110
Exxon B	3,523	2,193	67
Exxon C	5,743	2,895	58
Exxon D	12,064	15,959	494
Exxon E	2,255	2,039	48
Control A	2.00	1.90	0.03
Control B	1.82	0.61	ND
Control C	1.94	0.41	ND
Control D	2.18	0.72	ND
Control E	1.96	19.58	ND

Table 2.3. Comparison of historical data (Wong 1994) from the Paradis-Exxon site to the measurements made for this study. Our stations correspond closely to historical locations, which represent a gradient of distance from the spill source. Data presented here are not normalized to the hopane biomarker.

Station (Wong, Sep 1994)	Total PAH	Station (Nov 2002)	Total PAH range*
2	446	A	102-110
2 surface	182	B	53-67
3	117	C	39-58
4	52	D	302-494
7	146	E	45-48
Average	189	Average	108-155

*The lower range value does not include: C4 PHEN; C3,C4 PYR; C1-C3 NBT; C3,C4 CHRY. The higher range value does include these molecules.