ENVIRONMENTAL IMPACT AND RECOVERY OF A HIGH MARSH PIPELINE OIL SPILL AND BURN SITE, UPPER COPANO BAY, TEXAS

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On January 7, 1992, a rupture in an underground oil transfer pipeline resulted in a spill of about 2,950 bbl (469 m^3) of crude oil into a high marsh community near Chiltipin Creek, San Patricio County, Texas. Authorization for burning the oil, as a cleanup method, was given by the Texas General Land Office (the designated state on-scene coordinator). The environmental impact of the spill and ensuing burn on this high marsh has been assessed by monitoring changes in the total petroleum hydrocarbon (TPH) content of the associated floral community and soil over time. Ultimately 6.5 ha of oil and vegetation of the 15.5 ha surrounded by sorbent booms were burned, causing them to become barren. These bare patches produced by the burn were rapidly colonized by grasses, mainly Distichlis spicata. Secondary succession by perennial climax species is slow, resulting in significantly lower species diversity and biomass in the oiled and burned area even after 30 months. Significant changes within, and interactions between, impacted and control areas were determined using repeated measures MANOVA. TPH measurements made in December 1992 and repeated in July 1993 show consistent decreases. The obvious disadvantages of burning as a cleanup method in this high marsh area are the substantial initial damage to plants and the high residual hydrocarbon levels in the sediment.

A rupture in a 40-cm diameter underground oil transfer pipeline on January 7, 1992, resulted in a spill of about 2,950 bbls (469 m^3) of API gravity 37 south Texas light crude oil into 15.5 ha of a high marsh community near Chiltipin Creek, San Patricio County, Texas.[23] This high marsh area acts as a natural drainage basin, flowing towards the confluence of Chiltipin Creek and the Aransas River, approximately 0.8 km to the northeast. Final estimates indicate that, of the 2,950 bbl that leaked from the pipeline, 1,250 bbl (198.7 m^3) were recovered from the blowout hole, 500 bbl (79.5 m^3) were recovered by pumping, 50 bbl (8 m^3) were recovered in sorbent booms, pads, and pom poms, and 1,150 bbl (183 m^3) remained unaccounted for. The designated state on-scene coordinator, the Texas General Land Office, authorized burning off the remaining oil after consultation with the Texas Natural Resource Conservation Commission, Texas Railroad Commission, Texas Parks and Wildlife

Department, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, and U.S. Coast Guard. Their rationale was based on the conclusion that continued mechanical removal might result in the total loss of the existing marsh and that leaving the oil in place might pose a continuing threat to the adjacent marsh and Aransas River. It was also concluded that the below-ground root and rhizome systems of the marsh vegetation would be effectively protected against burn injury by the water-saturated condition of the soil at the time of the spill, resulting from recent heavy rainfalls, allowing subsequent regrowth in the spring.

Prior to the burn, at the request of U.S. Fish and Wildlife Service personnel, two areas of oiled dense vegetation were staked out and designated not to be burned. These oiled and unburned areas were to be used as additional treatments for comparison of marsh plant recovery with oiled and burned areas. Unfortunately, both staked sites were inadvertently burned two days later.[23] All areas that were oiled sufficiently to burn were apparently burned. Ultimately 6.5 ha of oil and vegetation of the 15.5 ha surrounded by sorbent booms were burned, causing them to become barren.

Saltmarshes receive the highest priority for protection in oil spill contingency and response plans for coastal areas because of their important ecologic and economic value.[13,20] However, despite their environmental sensitivity and priority for protection, saltmarshes are still occasionally affected by oil from accidental discharges by barge traffic,[4,14,16,22,25] oil transfer pipelines,[3,11,17] and oil storage tanks.[21]

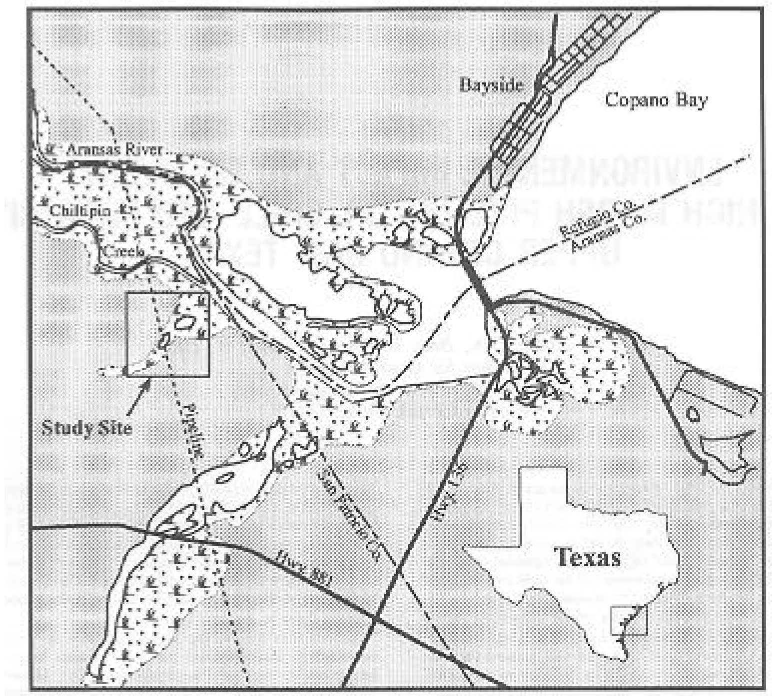
After oil enters a marsh, the cleanup methods must be determined, and the environmental impacts assessed. Kiesling and colleagues and Alexander and Webb have thoroughly reviewed oil spill cleanup techniques and their impacts on saltmarshes along the upper Texas coast.[1,2,19] Their field work on actual oil spills and experimental test plots, as well as a careful review of the literature, show that multiple cleanup technologies are available and results are varied, depending on the ecological setting and the type and volume of oil spilled. Of the cleanup methods, including absorption, flushing, clipping, burning, or doing nothing, any could be chosen as appropriate, depending on the spill scenario.

In situ burning is viewed with growing interest as a response tool and has distinct advantages over other countermeasures. It offers the potential to rapidly convert large quantities of oil into its primary combustion products, carbon dioxide and water, with small percentages of other unburned and residue by-products.[12] The removal of oil by burning from environmentally sensitive areas, such as high marshes, is rapid and may prove less damaging to vegetation (in the long term) than physical removal techniques, where trampling of plants is inevitable.

The purpose of this study is to assess the environmental impact of the spill and ensuing burn on this high marsh by monitoring changes in the associated floral community and by measuring changes in the soil total petroleum hydrocarbon (TPH) content over time.

Study area

The study area, in San Patricio County, Texas, 2 km west of Copano Bay at approximate coordinates of 28 °04′09″ N, 97 °16′01″ W, is characterized by typical south Texas middle and high marsh plant species, small unvegetated areas usually covered by blue-green algal mats, and several ephemeral brackish water ponds (Figure 1).



1.

Location of the Chiltipin Creek marsh study site on the Texas coast

The climate is considered semi-arid, with about 89 cm of precipitation annually. Average temperatures range from 8.3 °C in the winter to 33 °C in the summer.[10] Persistent southeasterly winds occur from March through September, while northeasterly winds occur with frontal passages from October through February.[5]

Methods

Methodology included a study of marsh plant impact and recovery as well as soil petroleum hydrocarbon analysis. Because the two areas of oiled dense vegetation set up by the U.S. Fish and Wildlife Service were inadvertently burned in the cleanup effort, only two sampling areas for study are located in the marsh, one impacted (oiled and burned) and the other unimpacted (unoiled and unburned). The adjacent unimpacted site served as an unoiled baseline and was used as the control area for this study. Although the oil spill and ensuing burn occurred in January 1992, field investigations by the Center for Coastal Studies on this Texas GLO funded project did not begin until October 1992.

Vegetation study

Species diversity.

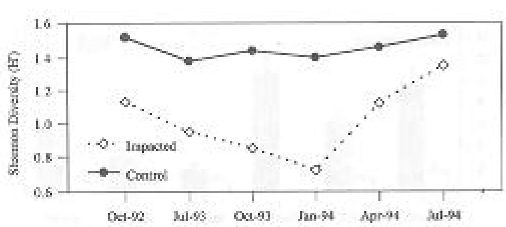
To determine the frequency of plants in the marsh community, a line-point intercept transect technique was used. Twenty 30-m transects were systematically located in both the impacted and control areas of the marsh, with points examined every 0.5 m. The plant species touching or immediately below the point being examined was recorded. The frequency of plant species was determined by totaling the number of times a given species was recorded for each transect, yielding a maximum mean frequency of 60. Marsh plant frequency sampling was initiated in October 1992, and transects were repeated once in July 1993, during the first year of the study, after which sampling was conducted quarterly (October 1993, January 1994, April 1994, and July 1994). Independent t-test analyses were used to test for differences in frequencies of individual plant species between the impacted and control areas. Repeated measures MANOVA analysis using joint-Bonferroni contrast were used to test for significant changes within, and interactions between, control and impacted areas. Shannon species diversity (H'), and t-tests on species diversity were calculated from frequency distributions.

Vegetation biomass.

Marsh plant biomass was obtained by clipping all above-ground tissue without regard to species composition from 100 randomly located 25-cm^2 quadrats in each area. All plant tissue removed from the quadrats was placed in marked brown paper bags and returned to the laboratory. The aggregate plant samples were dried for 72 hours in a drying oven before being weighed to the nearest milligram. Plant biomass samples were collected in March, April, and May for cool season plants and June, July, September, and October for warm season plants during the first year of the study (October 1992 - October 1993).[24] After the first year, biomass was collected quarterly, along with the plant frequency sampling. Mean dry weight biomass for the impacted and control areas was compared by independent t-test analysis.

Hydrocarbon study.

Soil for TPH analysis was collected in December 1992 and again one year later in December 1993. Initially, 70 core samples (8 cm length X 5 cm diameter), 50 from the impacted area and 20 from the control, were randomly collected using lexan cores and sent to the Texas Parks and Wildlife Contaminants Laboratory in San Marcos, Texas, for analysis. Areas found to have TPH values higher than 100 ppt were resampled in the subsequent sampling period. Because spiked recovery rates were different (91.6% in 1992 compared to 81.0% in 1993) results were normalized to 100% spiked recoveries and then analyzed using a paired-samples t-test.



2.

Shannon Diversity (base e) for the control and impacted sites in the Chiltipin Creek marsh

Results and discussion

Explanatory notes and general observations.

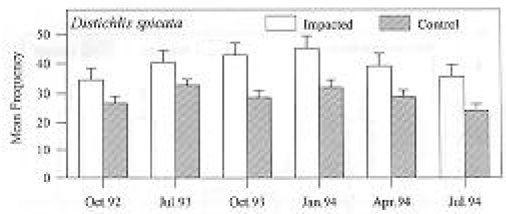
At the time of the spill the study area was in a period of above-normal precipitation, which continued through June 1993. In addition to rainfall, tropical storm Arlene in June 1993 caused local coastal flooding from high tides. These unusually high tides caused the Aransas River to back up into the marsh, inundating it with as much as 1 m of brackish water.

Initial examination of the spill site in August 1992 revealed that the impacted area segregated by sorbent booms was not equally affected within its confines by either the oil spill or the ensuing burn. The severity of the disturbance varied considerably across the impacted area, resulting in variable plant responses. Plant colonies in slightly elevated areas, along berms and hummocks, which were probably less impacted, appeared to be least affected. In many of these areas and other small patches, where fire intensity was not as great, the root mass probably survived, and regrowth to original conditions occurred within two growing seasons. However, in the majority of areas, where heavy oiling caused the fire to be intense, both the above-ground and below-ground plant parts may have been killed, allowing invasion by fugitive species and bare patches to persist. Regrowth of the impacted area was nearly complete by the end of the first year of study (two growing seasons). However, the species composition is much different than it was prior to the spill and burn, based on examination of burned shoot material and comparison with adjacent areas. The difference in species composition is largely due to the lack of perennial species that before the spill contributed to the diversity in the impacted area. The area is now colonized primarily by *Distichlis spicata*, while the frequency of other perennial climax species remains low. Despite the burning, a year of above-normal precipitation, and a marsh-flushing flooding event, oil can still be observed in many unvegetated areas simply by scraping the soil surface.[24] It is also interesting to note that in areas where burned stubble is still present and plants have not yet recovered, oil is usually visible just beneath the soil surface.

Vegetative study

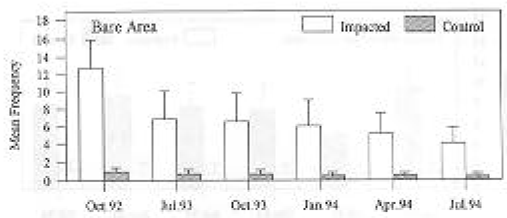
Species diversity.

Thirteen species of plants were identified inhabiting the marsh area: *Distichlis spicata* L., *Monanthochloe littoralis* Engelm., *Salicornia virginica* L., *Salicornia bigelovii* Torr., *Borrichia frutescens* (L.) DC., *Suaeda linearis* (Ell.) Moq., *Limonium nashii* Small, *Scirpus maritimus* L., *Batis maritima* L., *Lycium carolinianum* Walt., *Spartina spartinae* (Trin.) Hitche., *Ruppia maritima* L., and *Sporobolus virginicus* (L.) Kunth. All of these species were encountered in both the impacted and control areas at some period during the study. Shannon diversity indices values (H′), calculated from frequency distributions, were significantly lower ($P < 0.001$) in the impacted area throughout the study by t-test analysis (Figure 2). In the impacted area, as *Distichlis* colonized bare patches, the overall dominance was shifted to one species, and the diversity index value decreased. The increase in the diversity values observed in the last two sampling periods is attributed to succession by more climactic species.



3.

Comparison of monthly mean frequency for Distichlis spicata between impacted and control sites

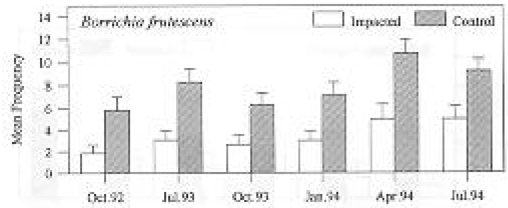


4.

Comparison of monthly mean frequencies for bare area between impacted and control sites

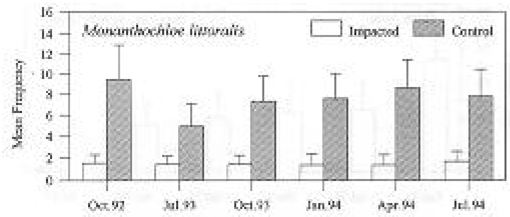
Distichlis spicata was the dominant plant of both the impacted and control areas throughout the study, accounting for averages of 73.8% and 48.5%, respectively. The frequency of *Distichlis spicata* was significantly higher ($P < .05$) in the impacted area during the last four of the six sampling periods (Figure 3). Significant interaction between the impacted and control areas was detected from October 1992 through January 1994 by repeated measures MANOVA. From January 1994 through July 1994 no significant interaction was found. *Distichlis spicata* significantly increased its frequency in the impacted area along transects, from 68.7% in October 1992 to a high of 83.6% in January 1993, by recolonizing bare patches which decreased from 16.3% to 10.1% over the same time period (Figures 3 and 4). The increase by *Distichlis spicata* is not unexpected, considering that it is regarded as a disturbance-dependent species whose success is a product of its ability to tolerate and recover from disturbance in high saltmarsh habitats.[8,9,15] Frequency of *Distichlis spicata* decreased in the impacted area after peaking in January 1994, to 63.5% in July 1994. Because bare area continuously declined in the impacted site, the decrease in *Distichlis spicata* over the last two sampling periods is attributed to succession by perennial climax vegetation species. *Distichlis spicata* continuously invaded bare areas, while being outcompeted in established areas by slower colonizing climax species.

Perennial climax species such as *Borrichia frutescens, Monanthochloe littoralis, Salicornia virginica*, and *Batis maritima* are major contributors to the plant community of the control area, and dominance is shared equally among them, averaging 10.7%, 12.8%, 10.8%, and 9.8%, respectively. In the impacted area, only minor contributions are made by these four species, averaging 6.6%, 3.4%, 3.1%, and 3.1%, respectively. Examination of burned stubble and root material in the soil of the impacted site indicates that all these species were common plants of the area before the spill and burn.



5.

Comparison of monthly mean frequencies for Borrichia frutescens between impacted and control sites



6.

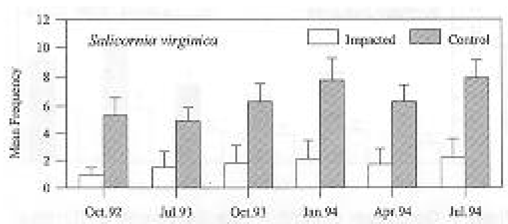
Comparison of monthly mean frequencies for Monanthochloe littoralis between impacted and control sites

The frequency of *Borrichia frutescens* was significantly higher ($P < .05$) in the control area during all sampling periods by independent t-test analysis (Figure 5). The frequency of *Borrichia frutescens* significantly increased along transects in both the control and impacted areas, and no interaction was statistically detectible, indicating similar colonization rates. The simultaneous increases of *Borrichia frutescens* in both areas are probably due to seasonal and annual fluctuations of environmental factors such as precipitation.

The frequency of *Monanthochloe littoralis* was significantly higher in the control area during all months sampled by independent t-test analysis (Figure 6). There was no significant change in the frequency of *Monanthochloe littoralis* in the impacted area over time. The significant decrease, observed in mean frequency in the control area in July 1993, may be due to seasonal variation as well as increased precipitation for the months of April, May, and June 1993. *Monanthochloe littoralis* may have been directly affected by standing water, which was observed to cover much of the marsh during this period. More likely, robust species took advantage of the increase in fresh water, obscuring *Monanthochloe littoralis* from view along transects. Because perennial climax species have much lower frequencies in the impacted area, competition was not as great, and consequently no species was able to overshadow *Monanthochloe littoralis*, so that its frequency remained unchanged in the impacted area.

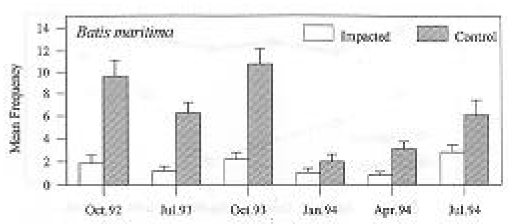
Frequency of *Salicornia virginica* was significantly higher in the control area throughout the study (Figure 7). The observed slow increase in the frequency of *Salicornia virginica* along transects in the impacted area was not significant, and no interaction was detected by repeated measures MANOVA between the areas, indicating that both areas are changing at approximately the same rate.

The frequency of *Batis maritima* was significantly higher in the control area in five of the six sampling periods (Figure 8). Repeated measures MANOVA indicate significant interaction between impacted and control areas. Throughout the study *Batis maritima* was found to be much more dynamic in the control area, exhibiting notable seasonal variation, while in the impacted area seasonal variation was not as apparent. *Batis maritima* is a dioecious, semideciduous perennial that normally flowers between April and June and sometimes later.[18] The semideciduous characteristic of *Batis maritima* makes seasonal changes easily observed, but because the frequency of *Batis maritima* was low in the impacted area as compared to the control area and the plants were severely stressed by the oil and burn, possibly causing plant growth to be retarded, seasonal effects may have been masked. The interaction observed between the study sites may be a combination of the slowed growth in the impacted area and the low frequency of occurrence by other species, which could obscure *Batis maritima* during seasonal lows if they were present.



7.

Comparison of monthly mean frequencies for Salicornia virginica between impacted and control sites



8.

Comparison of monthly mean frequencies for Batis maritima between impacted and control sites

Frequency of *Scirpus maritimus* was consistently higher in the impacted area (Figure 9). *Scirpus maritimus* thrives in standing water, the condition that was predominant throughout the first growing season. The bare areas produced by the burn made ideal habitat for *Scirpus maritimus*, whose only competition was from *Distichlis spicata.*

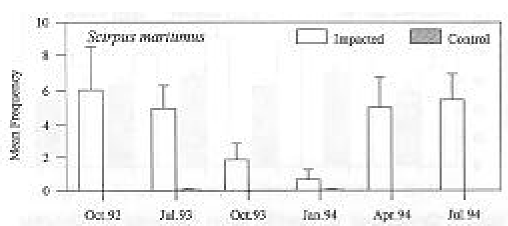
Individual perennial climax plant species, encountered in the impacted area, were not found to significantly increase in frequency over time, independent of the control area. By combining the mean frequencies of individual perennial climax plant species in a stacked bar arrangement and then comparing impacted and control areas an increasing trend in the impacted area is observed (Figures 10). This increasing trend is not apparent in the control area, where mean frequency values have remained fairly consistent over time.

Vegetation biomass.

Biomass in the control area was significantly higher for all months sampled by independent t-tests analyses (Figure 11). The significant differences observed between the two areas are likely due to differences in the composition of plant species. Woody-stemmed perennials such as *Borrichia frutescens*, *Salicornia virginica*, *Lycium carolinianum*, and *Batis maritima* would be expected to contribute more to the biomass per given area than the grasses that overwhelmingly dominate the impacted area. *Distichlis spicata* was shown to reach its original biomass level after three years following experimental disturbance in New England.[6] Throughout the study seasonal biomass variations were apparent in the control area, but in the impacted area seasonal variation was masked by the consistently increasing biomass until June 1993.

Hydrocarbon study.

TPH values for the 20 samples collected from the control area in December 1992 ranged from 16.4 to 72.0 ppm (;XX = 50.5, SE = 2.9). Of the 50 TPH samples randomly collected in the impacted area, 20 were found to have TPH values greater than 100 ppm. These 20 ranged from 108.0 to 4538.51 ppm (;XX = 1064.3, SE = 256.7) The 20 impacted site samples were repeated in December 1993. TPH values for the repeated samples ranged from 29.38 to 4440.4 ppm (;XX = 897.1, SE = 258.1) The overall decrease, in mean TPH values, was not significant by paired-sample t-test analysis. Although the TPH values have remained much higher than those of the control area (;XX = 50.5), it is not clear if they are at a level that would be detrimental to plant recovery. Levels of TPH < 5 ppt were found to have little effect on *Spartina alterniflora* marshes in Texas.[2]



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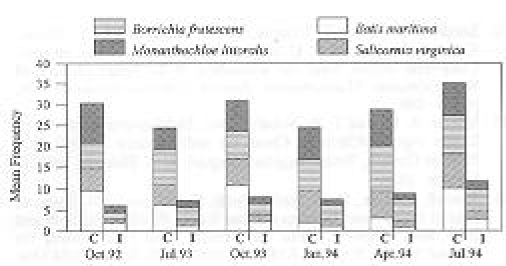
Comparison of monthly mean frequencies for Scirpus maritimus between impacted and control sites



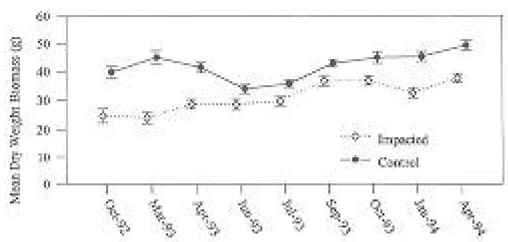
10.____
Comparison of combined perennial climax vegetation species between impacted and control sites (C = Control site, I = Impacted site)

Conclusions

Unfortunately, oiled marsh habitats are adversely affected by all cleanup methods. The obvious disadvantages of burning as a cleanup method in this high marsh area are the substantial initial damage to plants and the high residual hydrocarbon levels in the sediment.

Plant species distributions in high marshes are dictated by physical disturbance and competitive relations.[7,8] The observed primary recolonization of bare patches by *Distichlis spicata* is consistent with the literature, as is the slow secondary succession being observed by more climactic perennial species such as *Borrichia frutescens*, *Monanthochloe littoralis*, *Salicornia virginica*, and *Batis maritima*.[7,9,15] The loss of these climactic perennial species was probably a result of the intensity and long duration of the oil burning, and not simply oiling of the plants. No individual perennial climax plant species encountered in the impacted area was found to significantly increase over time. By combining the mean frequencies of perennial climax plant species in the control area and comparing it with the combined mean frequencies of plant species in the impacted area, a slow but steadily increasing trend over time is observed in the impacted area. This trend is not apparent in the control area.

The values of TPH measurements are decreasing over time, but the decrease was not significant in paired-sample t-test analysis.



11.

Comparison of vegetation dry weight biomass between impacted and control sites

Acknowledgments

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