THE APPLICATION OF IN-SITU BURNING TO A LOUISIANA COASTAL MARSH FOLLOWING A HYDROCARBON PRODUCT SPILL: PRELIMINARY ASSESSMENT OF SITE RECOVERY

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ABSTRACT: *The high degree of physical disturbance associated with conventional responses to oil spills in wetlands is driving the search for alternative cleanup methodologies. In March 1995, in southwestern Louisiana, a spill of gas condensate product into a brackish marsh at Rockefeller Wildlife Refuge was removed by in-situ burning. A monitoring program was established to examine the recovery of the marsh site. Three treatments were examined: (1) condensate-impacted and burned, (2) condensate-impacted and unburned, and (3) a reference that was neither exposed to the condensate nor burned. In March, July, and October 1995, vegetation plots were analyzed for biomass and stem density. Permanent quadrats were surveyed in July and October for total and species-specific percent cover. Although vegetation recovery was apparent 7 months after the burn, the burn treatment resulted in significantly lower biomass and stem density compared with both unburned treatments. In addition, burning led to conditions that favored initial recolonization by the sedge* Scirpus robustus *in a site previously dominated by the grasses* Distichilis spicata *and* Spartina patens*. However, biomass and stem density data suggest that* D. spicata *is regaining dominance. On the basis of these initial results, observations made in 1996 at the study site, and previous research, it is expected that in-situ burning will be successful at this site.*

The prolific nature of petroleum exploration, production, and transportation in the Gulf of Mexico coastal zone carries with it the inevitability of spill events and the necessity of developing adequate response options to such events. In particular, the widespread presence of petroleum-related activities in the marshes of the Gulf coastal zone require the development of response options that are both efficient in removing the spilled oil and effective in minimizing damage to the marsh ecosystem, while promoting the recovery of such systems from a spill event (Adams *et al.,* 1983).

Traditional methods of cleaning up oil spills have concentrated on the mechanical removal of the oil from the marsh. Examples of such methods include low-pressure flushing of the marsh, the use of sorbent pads, and the clipping and removal of oil-impacted vegetation from the site (Baker, 1973a; Holt *et al.,* 1978; Kiesling *et al.,* 1988; McCauley and Harrel, 1981; Owens *et al.,* 1993a). It is becoming increasingly clear that such methods of oil removal show only limited removal efficiency and may be deleterious to the long-term recovery of the impacted marsh system (Owens *et al.,* 1993b). Specifically, mechanical removal methods tend not to be particularly efficient at removing any product that may have been absorbed into the subsurface peat. Additionally, the use of these cleanup methodologies can result in physical damage to both the vegetation and the underlying substrate (Lindstedt-Siva, 1979), scarring the marsh landscape at best and accelerating marsh degradation at worst.

The recognition of these disadvantages has fueled interest in methodologies that are more efficient at removing the oil and less destructive to marsh structure (see review in Baker *et al.,* 1993; Owens *et al.,* 1993b). One of the novel response options under investigation is the addition of exogenous oil-degrading microbes to the site to augment or replace the activity of native microbial communities (Davies and Hughes, 1968). Also under investigation are the additions of fertilizers and soil oxidizers to an impacted marsh system, which improve the microenvironment for native oil-degrading microbes and thus enhance their activity. Dispersants have been in use in some environments to chemically degrade spilled oil (Owens *et al.,* 1993a). Finally, in-situ burning, often used in open-water spill response (Allen and Ferek, 1993; Benner *et al.,* 1990), has also been under investigation as a possible mechanism to remove spilled oil from a marsh while minimizing response personnel impact to the site (Holt *et al.,* 1978; Kiesling *et al.,* 1988; Mendelssohn *et al.,* 1995; Metzger, 1995; Tunnell *et al.,* 1994, 1995).

It has been difficult to evaluate the overall effectiveness of in-situ burning as a response option because of the limited application of experimental techniques to previous in-situ burning events. Specifically, the existing data are often lacking in adequate references, both spatial and temporal (Mendelssohn *et al.,* 1995). Spatially, there is seldom an adequate control to take into account the effect of burning per se, that is, where oil was spilled but not burned. This is not surprising, since the spiller is required to effect as complete a cleanup as possible. Although a large body of literature on the effects of oil on marsh vegetation points to certain assumptions about the effect of untreated oil on a marsh (Baker, 1973b; Gilfillan *et al.,* 1987; Hershner and Moore, 1977; Hoff *et al.,* 1993; Holt *et al.,* 1978, among others), it is becoming clear that, because of the variety of oil spill scenarios and coastal wetland community types, applying the results from a spill in one system to a spill in another may be an invalid procedure. The lack of temporal references also limits the ability to accurately assess whether a response is successful or not. Details of the structure of the marsh community prior to the burn are often absent, and although assumptions can be made from unburned references located near the impact zone, such assumptions can be risky given the heterogeneous nature of many marshes.

On March 13, 1995, a leak was detected in a gas pipeline submerged under a brackish marsh at the Rockefeller Wildlife Refuge in the Chenier Plain of Louisiana's southwest coast. On the morning of March 17, the decision was made to conduct an in-situ burn on the product spill, and an experimentally based response investigation was initiated. Pre- and postburn vegetation samples were taken to determine the effect of burning on the marsh vegetation community. The extent of recovery from the burn event was determined by comparing the impacted area with an untreated reference and using plant species composition, percent cover, stem density, and biomass as the criteria for comparison. The response of the marsh vegetation to the burn event after the first growing season is reported here. Hydrocarbon analysis for the project is reported elsewhere (Henry, 1996).

Materials and methods

Site description. A complete description of the product spill site within Rockefeller Wildlife Refuge (Figure 1) can be found in Hess *et al.* in these proceedings. The marsh at the impact site is dominated by salt grass [*Distichilis spicata* (L.) Greene] and wire grass [*Spartina patens* (Aiton) Muhl.], with inclusions of leafy three-square grass (*Scirpus robustus* Pursh) and common three-square grass (*Scirpus americanus*, formerly *S. olneyi*). At the time of the burn, there was low-stature, green vegetation at the site. The low stature was due to both newly emergent culms and the fact that the entire site had been burned following a lightning strike in August 1994.

Experimental design and sample collection. The experiment employed a completely randomized design with three treatments: (1) condensate-impacted and burned, (2) condensate-impacted and unburned, and (3) condensate-nonimpacted and unburned (reference). On the morning of the burn, March 17, 1995, a transect with 5 replicate sampling points was established in the impacted-and-burned marsh that would be burned later that day. Vegetation was sampled at these points prior to burn treatment. For all transects established at the study site, a 50-m line was placed within the treatment area and divided into 10-m subsegments, and a random point within each subsegment was established as a sampling point, giving 5 random points within each transect. Each sampling point was marked by placing a 2-m galvanized steel pipe into the marsh.

The day after the burn, March 18, 1995, two transects in the condensate-impacted and unburned area were established. It was necessary to wait until the burn occurred before delineating the impacted-and-unburned transects because of the unpredictability of the burn and the desire of the spill responder, LARCO Environmental Services, to effect as complete a cleanup as possible. These two transects were initially 30 m each, with 3 sampling points per transect, due to the relatively small size of the impacted-and-unburned treatment area. A reference marsh

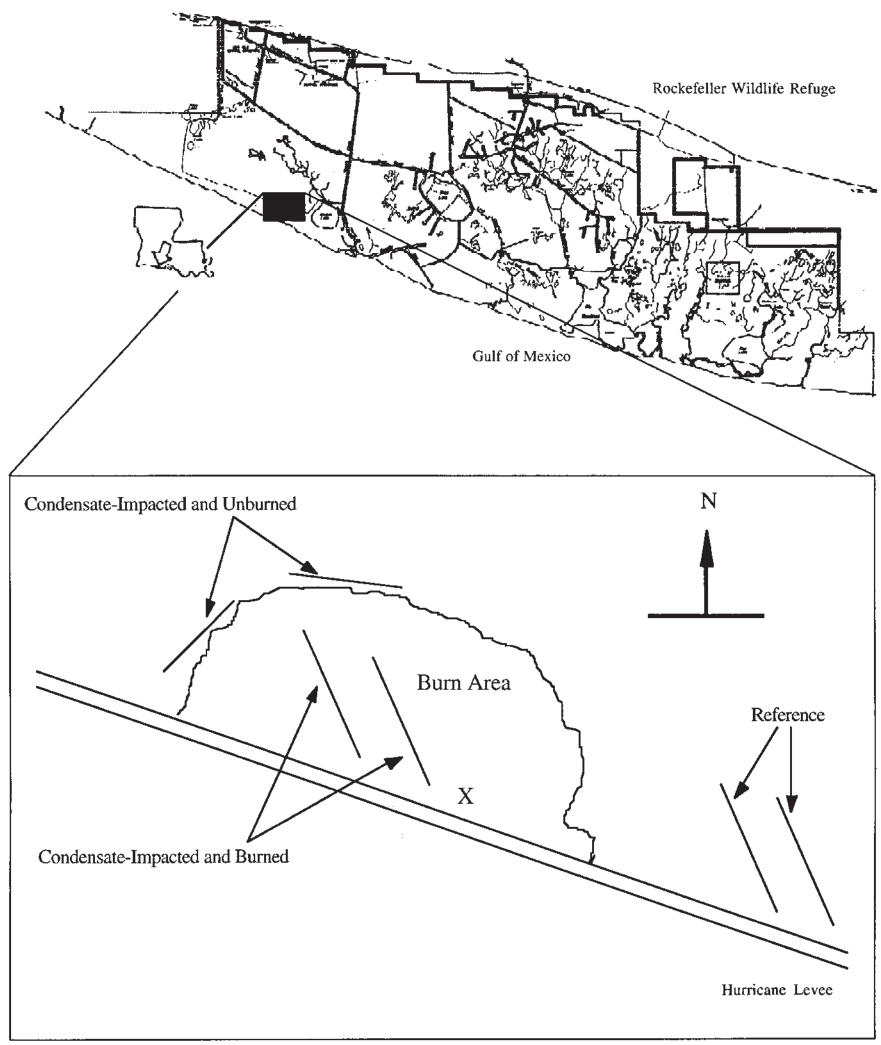

Figure 1. Location of the treatment assignments in relation to the pipeline rupture (X) and primary impact zone within the Price Lake Unit of Rockefeller Wildlife Refuge in southwest Louisiana. (Courtesy of Louisiana Department of Wildlife and Fisheries.)

within 0.5 km of the impacted marsh was also identified, and a 50-m control transect was established and sampled.

On July 22, 1995, vegetation and sediment samples were taken to represent mid-growing season response. Two additional transects were established and sampled, one in the impacted-and-burned treatment and one in the reference treatment, and the two impacted-and-unburned treatment transects were lengthened to 50 m, thereby adding 4 new sampling points to the two transects and resulting in a total of 10 sampling points for each treatment. Also, permanent 1-m^2 quadrats were established at each sampling point in all three treatments for tracking treatment response through total and species-specific changes in cover. Vegetation and sediment samples and coverage data were also taken on October 6, 1995, to represent the end of the growing season response.

Vegetative cover. Total and species-specific vegetative cover were determined within permanent 1-m^2 quadrats using a modification of the Braun-Blanquet Cover-Abundance Scale (Mueller-Dombois and Ellenberg, 1974). A numeric value was assigned for each coverage class of the Braun-Blanquet method as the midpoint for that class's range (i.e., Class 5: 75%–100% = 87.5; Class 4: 50%–75% = 62.5; Class 3: 25%–50% = 37.5; Class 2: 5%–25% = 15; Class 1: < 5% = 2.5). As an additional modification, the r and + components (solitary and few stems, respectively) were pooled and assigned a value of 0.5. The use of numeric data instead of categorical data allowed mean percent cover to be calculated for each treatment at each sampling date.

Vegetative stem density and biomass. Biomass response within each treatment was determined by clipping at ground level all vegetation within a 0.25-m^2 quadrat placed randomly around each sampling point. Upon return from the field, material from each quadrat was separated by species and by live and dead component, and the stems of each component were counted. All component material was dried at 65°C to a constant weight, and dry mass was taken.

Statistical analysis. The data were analyzed as a one-way analysis of variance with repeated measures of the following three treatments: impacted-and-burned, impacted-and-unburned, and reference, in spring, summer, and fall. Significant differences between treatment means were determined using least square means and contrasts in SuperANOVA (Abacus Concepts, 1991). Unless otherwise specified, significant differences are at $p = 0.05$.

Results

Vegetative cover. The impacted and burned treatment site had significantly less cover than the other sites following the burn because of the complete removal of all aboveground vegetation (Figure 2). The treatment effect was time dependent (significant treatment × time interaction). Percent cover increased significantly from summer to fall in the impacted-and-burned treatments, while there was no difference in cover between summer and fall in the other treatments. Still, by the end of the first growing season the impacted-and-burned treatment was significantly lower in cover than either the impacted-and-unburned or the control treatments.

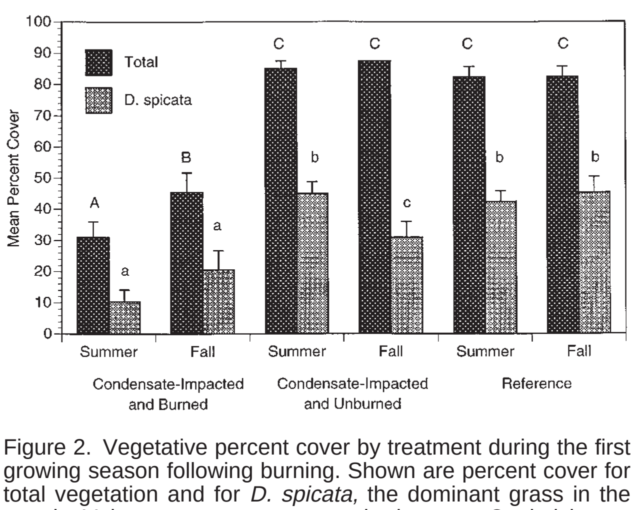

Figure 2. Vegetative percent cover by treatment during the first growing season following burning. Shown are percent cover for total vegetation and for *D. spicata,* the dominant grass in the marsh. Values are means ± standard errors. Capital letters denote significant differences between total cover values. Lowercase letters denote significant differences between *D. spicata* values. Treatment * season interaction for total coverage: $p = 0.0120$; for *D. spicata:* $p = 0.0096$.

Burning following the condensate impact resulted in significantly lower cover of the two major graminoid species on the site, *Distichilis spicata* and *Spartina patens,* but increased the cover of the sedge *Scirpus robustus.* For *D. spicata* (see Figure 2), the interaction between treatment and season was significant, with a lower cover in the fall compared to the summer in the impacted-and-unburned treatment but no seasonal effect for the other two treatments. Whereas there was no significant interaction between treatment and time in the cover of either *S. patens* or *S. robustus,* treatment was significant for both. Percent cover of *S. patens,* averaged over time, was significantly lower in the impacted-and-burned treatment (6% ± 2%) than in either the control (44% ± 3%) or the impacted-and-unburned treatment (45% ± 2%). In contrast, mean cover of *S. robustus* in the impacted-and-burned site (16% ± 1%) was significantly higher than in both the impacted-and-unburned (0.4% ± 0.0%) and reference sites (0.4% ± 0.1%).

Stem density. The response of total vegetative stem density (Figure 3) to burning was similar to that of vegetative cover. Burning significantly reduced total stem density below that of both the impacted-and-unburned and reference treatments. Although stem density increased throughout the growing season in the impacted-and-burned treatment, it never reached the level of the impacted-and-burned or reference treatments. Total stem density within the impacted-and-unburned treatment did not exhibit the gradual increase in stem density during the growing season seen in the reference marsh (significant treatment × time interaction), which may be evidence of an untreated condensate effect on the marsh.

The removal of aboveground material due to burning was only one of the reasons for the significantly lower stem density within the impacted-and-burned treatment compared to the other two treatments. The site was not immediately colonized by the dominant grasses, which exhibit high stem densities, but by *Scirpus robustus,* which has more robust stems and produces less dense stands. As a result, stem density was less than in the nonburned treatments. *S. robustus* contributed more to total stem density in both the summer and fall in the impacted-and-burned treatment than in either the impacted-and-unburned or reference treatments, which show trace contributions by *S. robustus* to total stem density during the growing season (Figure 4).

Distichilis spicata dominated both the impacted-and-unburned and reference treatments throughout the growing season, with *Spartina patens* as the subdominant species (see Figure 4). Within the impacted-and-burned treatment, the contribution of *D. spicata* to total stem density increased from summer to fall. *Spartina patens,* in contrast, decreased its share of the total stem density during the same time period.

Vegetative biomass. Total vegetative biomass also demonstrated a pattern of lower total biomass in the impacted-and-burned treatment (Figure 5) compared to the unburned treatments (treatment effect significant). The season was also significant in controlling total biomass response, with biomass over all treatments increasing from spring (124.3 ± 23.3 g/0.25 m^2) to fall (313.8 ± 28.3 g/0.25 m^2). Although total biomass production continued throughout the growing season, live biomass production appeared to stop in late summer, with no significant increase between summer (244.0 ± 24.4 g/0.25 m^2) and fall. Total live biomass (see Figure 5) also exhibited a significant treatment effect, with significantly lower total live biomass in the impacted-and-burned site than in both of the unburned sites. The interaction between treatment and time was not a significant factor in either total biomass or total live biomass response.

Discussion

The successful use of in-situ burning for oil spill cleanup is dependent upon the intrinsic characteristics of the wetland as well as on particular aspects of the spill (Mendelssohn *et al.,* 1995). In-situ burning is partic-

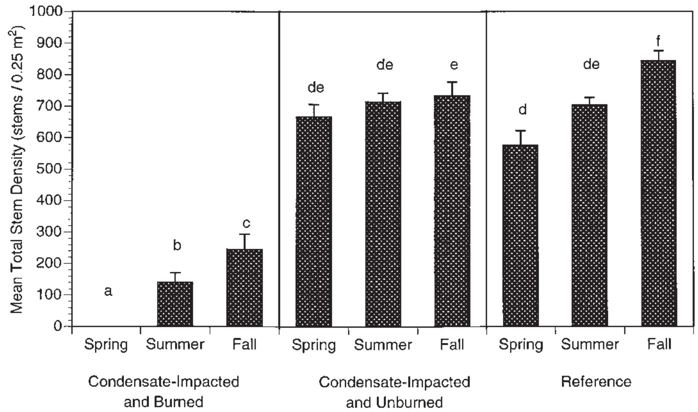

Figure 3. Total vegetative stem density by treatment during the first growing season of recovery following burning. Values are means ± standard errors. Different letters denote significant differences at $p = 0.05$. Treatment * season interaction: $p = 0.0001$.

ularly applicable for spills in wetlands where fire is a common occurrence. The long growing season for many coastal marsh species results in a rapid accumulation of biomass within the marsh, providing the fuel for fires resulting from lightning strikes. In addition, humans have historically burned marshes to promote those species of plants that serve as food for furbearing species and waterfowl, as well as for increasing access to the marsh (Furnis, 1938).

However, burning is not an applicable remediation technique for all marsh types (Westree, 1977). Wetlands dominated by shrubs or trees take longer to recover from burning. In these systems the majority of nutrient stocks are located in aboveground tissues, the removal of which can be catastrophic to the plant community (Obot *et al.,* 1992). Additionally, many tree species do not exhibit vegetative reproduction. Graminoid marshes, such as the site on Rockefeller Wildlife Refuge, show quick recovery times to fire in terms of plant biomass because of the potential for extensive belowground reserves and vegetative reproduction from rhizomes.

The season of the burn influences the status of these belowground reserves. In a review of the factors governing successful recovery from burning (Mendelssohn *et al.,* 1995), summer and early fall burns were found to result in less successful recoveries than burning in the spring or the winter. This particular in-situ burn occurred in mid-March, when plant regrowth was just beginning following winter dormancy and the majority of carbohydrate and nitrogen reserves within the plants were still in the belowground rhizomes. Removal of the aboveground portions of the plants by burning did not remove a large part of the reserve nutrient stock, and thus the plants could rather easily mobilize those remaining stocks for regrowth. This would not have been the case had the burn occurred later in the growing season. By summer or early fall the majority of nitrogen and carbohydrates are in the aboveground portions of the plant, and burning would lead to an irrecoverable loss of total nutrient stocks (Shay *et al.,* 1987) and thus a lower capacity for vegetative regrowth.

One of the most important preconditions to burning a wetland for the purpose of oil removal is that water should cover the surface of the marsh. Water on the surface will allow a successful burn of the aboveground vegetative component while absorbing heat produced by the fire (Hoffpauir, 1961) and preventing a root burn (Lynch, 1941). However, at the in-situ burn of a crude oil spill in Chiltipin Creek, Texas (Tunnell *et al.,* 1994, 1995), it was hypothesized that the heat transfer from the

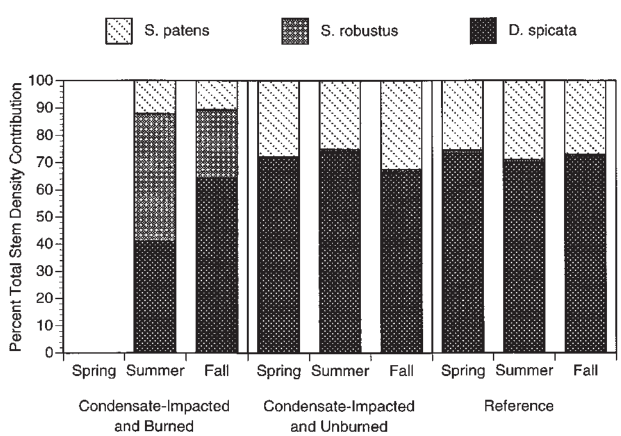

Figure 4. Species-specific contributions to total stem density by treatment during the first growing season of recovery following burning. Values are expressed as percent of total stem density.

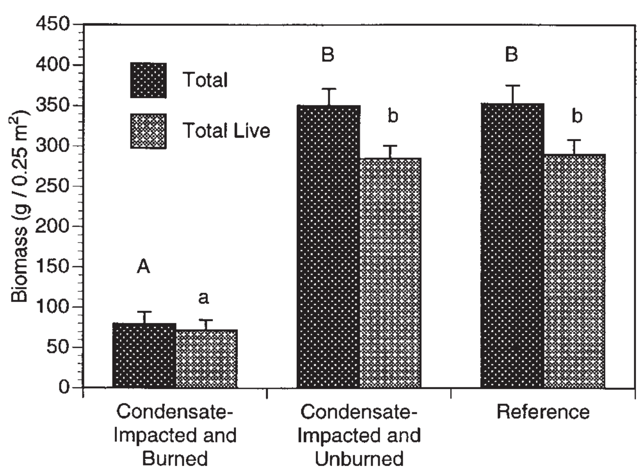

Figure 5. Total and total live biomass by treatment during the first growing season following burning. Shown are biomass for total and for total live vegetation. Values are means ± standard errors. Capital letters denote significant differences between total biomass values. Lowercase letters denote significant difference between total live biomass values. Treatment * season interaction for total biomass: $p = 0.0001$; for total live biomass: $p = 0.0001$.

fire through the water and to the root zone may have been the reason for a delayed return of preburn vegetation to the site. Water on the surface is also important in preventing the physical burning of the marsh peat, which can lead to the removal of the seed bank and rhizomes in the best case and the removal of the peat down to the clay underlay, and the formation of ponds (Lynch, 1941), in the worst case.

Lower water levels following a burn event are also necessary for vegetative recovery. For example, burning followed by flooding of the marsh resulted in decreased growth of both *Distichilis spicata* (Smith and Kadlec, 1985) and *Panicum hemitomon* (Kirkman and Sharitz, 1994). The postfire flooding presumably decreases the amount of oxygen that reaches the belowground portions of the plant, and thus forces the roots and rhizomes into anoxic conditions to the extent that recovery is not possible. Removal of the flood water from the Rockefeller marsh was then necessary to promote the regrowth of vegetation. This in-situ burn did accomplish some of the water removal itself. Heat transfer from the fire and burning oil to the underlying water resulted in water vaporization, which was evidenced during the burn as white smoke (brine steam) evolving from the marsh along with the thick black smoke associated with the burning oil.

Ecological theory predicts that subclimax species will initially colonize a disturbed site. The postburn increases in percent cover and stem density of the herbaceous species *Scirpus robustus* in a previously grass-dominated marsh demonstrate that this did indeed occur. However, this community shift did not occur in the subsequent regrowth of the clip plots on the site. *D. spicata* and *Spartina patens* were the only species seen returning to denuded clip plots, as opposed to the initial colonization of the burn site by *S. robustus.* This would suggest that the shift in the vegetation composition was due to a fire-related effect on plant regrowth over and above an increase in light reaching the soil surface. The burn may have resulted in an ash effect or a fire-induced seed break in addition to a heat shock of the graminoid rhizomes, as was hypothesized for the Chiltipin Creek in-situ burn (Tunnell *et al.,* 1994).

In the long term, ecological theory would predict the eventual return of a disturbed ecosystem to a climax community, which in the case of a brackish marsh in coastal Louisiana is graminoid-dominated. Such a return to the climax state would indicate that the marsh had fully recovered from the impact of the burning treatment. Tunnell *et al.* (1995) have defined the recovery of an oiled-and-burned marsh in Texas as occurring when the treated marsh exhibits the same frequency of climax vegetation species as the surrounding unimpacted marsh, and have predicted that such a recovery will occur 8.6 years following burning. For this project, we have used vegetative percent cover, stem density, and biomass as the basis of comparison between the burned and reference marshes. Using these criteria, it can be concluded that although this in-situ burn site appears to be on a return path to the reference state of a system dominated by the grasses *D. spicata* and *S. patens,* after the first growing season such a recovery has not yet occurred, and the site still shows an influence of the initial colonization by the sedge *S. robustus.* Of course, once full recovery does occur, the accumulation of dead biomass over time will eventually lead to a fire that will again reset succession to an earlier subclimax herbaceous species assemblage.

In general, the paucity of significant differences between the condensate impacted-and-unburned treatment and the reference treatment would suggest that the marsh community responded more to the burning treatment than to exposure to the condensate. This conclusion, however, is complicated by the method of establishing the impacted-and-unburned treatment. As stated previously, without an assurance of protection from burning by the spill responder of a designated area within the primary impact zone, the impacted-and-unburned treatment transects could not be established until the burn subsided. Although this treatment area was based on the presence of visible oil (primarily a sheen) on the surface, the postburn product concentrations within this treatment were much lower than within the preburn primary impact zone. Preburn sediment samples yielded a mean total petroleum hydrocarbon (TPH) content of 36.35 ± 13.45 mg hydrocarbon per gram of soil, whereas the highest mean TPH level achieved after the burn within any of the treatment areas was 5.53 ± 3.81 mg/g. Therefore, although the research does improve on some of the design deficiencies addressed in the introduction, without the ability and willingness of responders to provide mechanisms for proper treatment controls, some interpretation will be confounded.

Conclusions

Lindstedt-Siva (1979) stated that cleanup methods for oil spills should be chosen on the basis of their ecological impact, and specifically that those methods that demonstrate the least amount of impact on the environment should be used. In-situ burning has been and will continue to be relied upon as a response option for oil spills in marshes, although such factors as marsh type, season, and water level need to be taken into account to ensure successful recovery of the marsh. Results of monitoring following the in-situ burn of a petroleum condensate product spill at Rockefeller Wildlife Refuge in southwest Louisiana suggest that burning is an appropriate response option on the basis of Lindstedt-Siva's criteria. Although burning resulted in the complete removal of the aboveground vegetation initially, revegetation did rapidly occur throughout the site. After the first growing season, despite the fact that the burn site exhibited subclimax herbaceous vegetation with a lower biomass than the reference site, community structure of the impacted-and-burned treatment appears to be approaching the climax structure of the unburned marsh surrounding the site. Unpublished data from the 1996 growing season support this conclusion. Of equal importance, the use of in-situ burning precluded the need for foot-traffic through the site by response personnel, and thus minimized damage to the marsh substrate.

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Biography

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