Vegetation Recovery in an Oil-Impacted and Burned *Phragmites australis* Tidal Freshwater Marsh

Scott Zengel[a], Jennifer Weaver[a], Susan L. Wilder[b], Jeff Dauzat[c], Chris Sanfilippo[d], Martin S. Miles[e], Kyle Jellison[f1], Paige Doelling[f], Adam Davis[f], Barret K. Fortier[b], James Harris[b], James Panaccione[b], Steven Wall[f], Zachary Nixon[a]

[a]Research Planning, Inc. (RPI), 247 E. 7th Avenue, Suite 200, Tallahassee, FL 32303, USA. Emails: szengel@researchplanning.com; jweaver@researchplanning.com; znixon@researchplanning.com.

[b]U.S. Fish and Wildlife Service, 61389 Highway 434, Lacombe, LA 70445, USA. Emails: sue_wilder@fws.gov; barret_fortier@fws.gov; james_harris@fws.gov; james_panaccione@fws.gov.

[c]Louisiana Department of Environmental Quality, 201 Evans Road, Suite 420, New Orleans, LA, 70123, USA. Email: jeff.dauzat@la.gov.

[d]Texas Petroleum Investment Company, 207 Town Center Parkway, Suite 150, Lafayette, LA 70506, USA. Email: csanfilippo@txpetinv.com.

[e]Louisiana State University (LSU), Department of Environmental Sciences, Baton Rouge, Louisiana 70803, USA. Email: msmiles@lsu.edu.

[f]NOAA Emergency Response Division, Office of Response and Restoration, 500 Poydras Street, Suite 1213, New Orleans, LA 70130, USA. Emails: kyle.jellison@maine.gov; paige.doelling@noaa.gov; adam.davis@noaa.gov; steven.j.wall@noaa.gov.

[1]Present address: Maine Department Environmental Protection, 36 Mechanic Street, Bath, ME 04530, USA.

Corresponding author: Scott Zengel, szengel@researchplanning.com, (850) 329-2001.

Abstract

In-situ burning of oiled marshes is a cleanup method that can be more effective and less damaging than intrusive manual and mechanical methods. In-situ burning of oil spills has been examined for several coastal marsh types; however, few published data are available for *Phragmites australis* marshes. Following an estimated 4,200 gallon crude oil spill and in-situ burn in a *Phragmites* tidal freshwater marsh at Delta National Wildlife Refuge (Mississippi River Delta, Louisiana), we examined vegetation impacts and recovery across 3 years. Oil concentrations in marsh soils were initially elevated in the oiled-and-burned sites, but were below background levels within three months. Oiling and burning drastically affected the marsh vegetation; the formerly dominant *Phragmites*, a non-native variety in our study sites, had not fully recovered by the end of our study. However, overall vegetation recovery was rapid and local habitat quality in terms of native plants, particularly *Sagittaria* species, and wildlife value was enhanced by burning. In-situ burning appears to be a viable response option to consider for future spills in marshes with similar plant species composition, hydrogeomorphic settings, and oiling conditions. In addition, likely *Phragmites* stress from high water levels and/or non-native scale insect damage was also observed during our study and has recently been reported as causing widespread declines or loss of *Phragmites* stands in the Delta region. It remains an open question if these stressors could lead to a shift to more native vegetation, similar to what we observed following the oil spill and burn. Increased dominance by native plants may be desirable as local patches, but widespread loss of *Phragmites*, even if replaced by native species, could further acerbate coastal erosion and wetland loss, a major concern in the region.

Key words: *Phragmites australis*, *Sagittaria* spp., tidal freshwater marsh, oil spill, in-situ burning, ecological recovery, scale insect damage.

Introduction

Oil spills in marshes can have significant short and long-term impacts affecting marsh habitats and productivity, fish and wildlife resources, coastal storm and flood protection, and various other resources and ecosystem services (Michel and Rutherford, 2014; Baker et al., 2017). Emergency response and cleanup operations in oiled marshes involve a fine balance of removing oil, enhancing the degradation of remaining oil, protecting fish and wildlife, fostering habitat recovery, and not causing additional ecological damage (Michel and Rutherford, 2014; Zengel et al., 2015). Under the appropriate conditions, typically including free-floating oil and a protective layer of water over the marsh substrate, in-situ burning is a response method that can be more effective and less damaging to the marsh environment than more intrusive manual and mechanical methods (Mendelssohn et al., 1995; Zengel et al., 2003; Michel and Rutherford, 2014). Recent examples of effective in-situ burning in oiled marsh habitats with positive marsh recovery outcomes have included field cases and experiments involving salt, brackish, intermediate, and freshwater marshes in coastal Louisiana, though none of these involved *Phragmites australis* (common reed, Roseau cane; *Phragmites* hereafter) (Pahl et al., 2003; Lindau et al., 2003; Lin et al., 2005; Baustian et al., 2010). The only reported information on in-situ burning in oiled *Phragmites* marsh comes from a single sampling event 4-years post burn, where vegetative recovery was considered moderate to good, as soil oiling levels and aboveground plant biomass in oiled-and-burned sites were not different than controls (sites without oiling or burning); however, vegetative cover had not fully returned to the oiled and burned area (Mendelssohn et al., 1995).

In late May 2014, a pipeline spill occurred in Delta National Wildlife Refuge, roughly nine miles southeast of Venice, Louisiana. An estimated 4,200 gallons of South Louisiana crude oil were released and approximately 15 acres of marsh were oiled. The affected area was a semi-permanently flooded *Phragmites* tidal freshwater marsh located on the Mississippi River Delta. Both native and introduced (non-native) *Phragmites* occur in the Mississippi River Delta; however, *Phragmites* at the spill site is an introduced form which is also the dominant type across the delta, known as the "Delta type" (M1 haplotype) (Hauber et al., 2011; Lambertini et al., 2012; Kettenring et al., 2012). Due to the remote location, degree of oiling, and difficulty of oil removal in the dense vegetation, a marsh in-situ burn was conducted in early June 2014 while the marsh was flooded (water depth ~50 cm). Approximately five acres of oiled marsh were burned. The burn was successful at removing roughly 80-90% of the oil based on responder field observations. Following the burn, response operations included various combinations of oiled vegetation cutting and debris removal, low-pressure flushing and herding, sorbent use, and skimming over six weeks to remove residual oiling, both in the burned areas and in oiled areas that were not burned. Vegetation cutting was not widely applied, and was not used in the locations sampled.

In order to examine the effectiveness and environmental effects of in-situ burning in this marsh type and vegetation recovery over time, our study monitored oiling conditions and vegetation cover (by species and in total) over four sampling periods beginning in June 2014 (roughly one week after burning) and annually from September 2014-2016. We compared results among sites from three oiling/treatment classes: (a) reference (not oiled or burned), (b) oiled-and-not-burned, and (c) oiled-and-burned. The primary study questions were: (1) What were the effects of oiling and oiling combined with burning on the marsh; and (2) Did burning help or hinder vegetation recovery of the oiled marsh? The findings of this study support future oil spill response decisions in coastal marshes, particularly in tidal freshwater *Phragmites* marshes on the Mississippi River Delta and in similar hydrogeomorphic settings. The findings also contribute to the body of work on *Phragmites* marsh ecology and management in North America, where *Phragmites* is often considered an invasive/nuisance plant in natural areas (see Hazelton et al., 2014 for a recent review).

Methods

This study was conducted on the Mississippi River Delta at Goose Island, south of Octave Pass, within Delta National Wildlife Refuge, Louisiana (Figure S1). Sampling sites were randomly selected among three types of areas with similar airboat access: (a) an adjacent reference area (not oiled or burned), (b) areas that were oiled-and-not-burned, and (c) areas that were oiled-and-burned. Five sampling sites were established for each of the three oiling/treatment classes. Sampling was conducted in June 2014 and September 2014-2016 (four sampling periods).

Assessment of oiling conditions included recording observations of oiling on the water surface and on the vegetation at each site during each sampling period, based on standard shoreline oiling assessment methods and terminology (NOAA, 2013). Both oiling height and vertical oil cover on the vegetation were recorded within a 1-m^2 quadrat at each site. Oiling height was defined as the vertical extent of the oiling band on the vegetation that was visible above the water line (in this case extending from the water line to the maximum height of oiling on the stems). Vertical oil cover was defined as the percent cover of oil within the oiling band observed in each quadrat (side view, from the water surface to the height of oiling). The same cover classes used for the vegetation sampling were used for estimating oil cover (see following paragraph). Descriptive oiling thickness and character were also recorded for oil on the vegetation, and oiling character was recorded for oil on the water surface. In addition, marsh soil samples were collected for each site using a coring device (5 cm diameter) to a soil depth of 20 cm. Soil samples were collected over three sampling periods in 2014-2015, but not in 2016. Soil samples were analyzed for total polycyclic aromatic hydrocarbons (tPAH) using GC/MS-SIM (gas chromatography/mass spectrometry in selective ion monitoring mode) based on EPA Method 8270D. TPAH included the sum of 45 PAHs, including alkylated homologues, presented as mg/kg.

Vegetation data collected for each site included *Phragmites* cover and vegetation cover for all other plant species observed on a per species basis. Cover estimates were made within a 1-m^2 quadrat using the following modified Braun-Blanquet/Daubenmire cover classes (Mueller-Dombois and Ellenberg, 1974): 0 = absent, 0.1 = <5% cover (solitary shoot), 0.5 = <5% cover (sparse, few shoots), 1 = ≤5% cover (many shoots), 2 = 5-25% cover, 3 = 25-50% cover, 4 = 50-75% cover, 5 = 75-95% cover, and 6 = 95-100% cover. Additional calculated vegetation metrics included total vegetation cover (all species combined), species composition by relative cover (species cover/total vegetation cover), and total vegetation cover other than *Phragmites* (i.e., non-*Phragmites* cover). Calculated vegetation metrics were determined using the mid-points of the cover classes described above. All vegetation metrics were based on rooted emergent marsh species. Floating marsh species were also present, but were typically smaller components of the "understory" with distributions at least partly subject to variations in wind and current conditions, therefore, they were not included in the analyses (though one species is discussed briefly).

All parameters other than relative species composition were plotted by oiling/treatment class and sampling time period as means ± 1 standard error (SE). In some cases SE values were very small or were zero and were not visible in the figures. Cover values were calculated using the mid-points of each cover class (after Mueller-Dombois and Ellenberg, 1974; Pahl et al., 2003). Repeated measures ANOVA was used for all statistical analyses with p-values reported for the effects of oiling/treatment class, time, and the interaction of oiling/treatment class and time. We applied Greenhouse-Geisser corrections in cases where the sphericity assumption was violated according to Mauchly's test. Pairwise comparisons among oiling/treatment classes were made using Tukey's test. In a few specific cases we also tested for oiling/treatment class effects and differences among oiling/treatment classes within certain sampling periods for interpretive purposes. We defined statistical significance as $p \leq 0.10$ based on guidance designed to better balance type I and II errors during environmental impact studies (Mapstone, 1995). We reported all p-values to two decimal places. Cases where $p = 0.00$ due to rounding were reported as

$p < 0.01$. P-values are reported in the figure captions with the corresponding data figures; summary and test statistics are reported in Table S1.

Results and Discussion

Conditions at the beginning of sampling in June 2014 included widespread vegetation dominance by *Phragmites*, the presence of oil on the water and on plant stems in the oiled sites, and the obvious effects of burning on the vegetation, which removed much of the aboveground plant material (Figure S2).

Oiling on the water surface at the time of sampling in June 2014 included silver sheen, rainbow sheen, and emulsified crude oil (mousse) at the oiled sites. Some silver sheen was also observed in the reference site nearest the oiled area (see Figure S1). Oiling on the vegetation in June 2014 occurred in both the oiled-and-not-burned sites and the oiled-and-burned sites, consisting of an oil coat (≤ 0.1 cm oil thickness) of fresh crude oil and/or mousse on the lower plant stems (overall mean oiling height was 27 cm above the water line). This oil weathered to a stain by September 2014.

Vertical oil cover on the vegetation was greater for the oiled-and-not-burned sites (mean 85% ± 0 SE) compared to the oiled-and-burned sites (mean 36% ± 16 SE) in June 2014, indicating a positive influence of burning on oil removal, even for the vegetation that remained after burning (Figure 1, Table S1). Vegetation oiling declined over time in the oiled sites, with no vegetation oiling observed in September 2015 or 2016, indicating that visible oil on the vegetation likely persisted for less than a year. No vegetation oiling was observed for the reference sites during any sampling periods.

Elevated soil tPAH levels were observed in the oiled sites in June 2014, particularly in the oiled-and-burned sites (mean 6.391 mg/kg ± 1.707 SE) relative to the reference sites (mean 0.832 mg/kg ± 0.099 SE) (Figure 2, Table S1). In September 2014 and 2015, tPAH values were below reported minimum background levels for *Phragmites* marshes in the Delta region (1.211 mg/kg; Rouhani et al., 2017) across all oiling/treatment classes. No burn residues were observed on the water surface, but it is unknown if submerged burn residues could have contributed to soil tPAH levels in the burned sites. Higher tPAH values in the burned sites may have been due to initial heavier oiling in the burned areas as compared to the unburned sites, based on proximity to the release site, the area that ultimately burned, and our field observations. The degree of airboat traffic and follow-up response operations (low pressure water flushing and herding, etc.) in and around the release site and burn area may also have contributed to higher initial tPAH values in the surface soils through mixing of crude oil into the water column and oil contact with suspended sediments. Regardless, tPAH levels were similar to reference and below background levels within three months.

Total vegetation cover in the reference and oiled-and-not burned sites was similar throughout the study (means 25-41% ± 0-6 SE across sampling periods, Figure 3, Table S1). The oiled-and-burned sites had very little vegetation cover immediately after the burn (mean 1% ± 0 SE in June 2014), but total cover increased rapidly thereafter, being similar to reference conditions by September 2014 (mean 31% ± 12 SE) and exceeding the reference and oiled-and-not-burned sites by September 2016 (mean 77% ± 13 SE). Although no overall effect of oiling/treatment class was observed for total vegetation cover across the span of the study, there was a strong interaction between oiling/treatment class and time (Figure 3, Table S1), reflecting the initial impact of oiling and burning, the increase in cover in the oiled-and-burned sites with time, and recovery in the oiled-and-burned sites for this individual metric, though the exceedance of the reference and unburned cover values hints at other underlying changes in the burned marsh, discussed further below.

Phragmites was the dominant marsh plant throughout the study area at the time of the spill, based on field observations and the review of pre-burn ground and aerial photography (*Phragmites* dominance was 100% in the reference and oiled-and-not-burned sites in June 2014). Not surprisingly, similar to total vegetation cover, *Phragmites* cover values in the reference and oiled-and-not burned sites were also similar (means 24-38% ± 0-6 SE across sampling periods, Figure 4, Table S1). Also like total cover, the oiled-and-burned sites had greatly reduced *Phragmites* cover immediately after the burn (mean 1% ± 0 SE in June 2014), with steadily increasing values thereafter, indicating initial impact followed by the onset of recovery. However, in contrast to total cover, *Phragmites* cover in the burned sites in September 2016 (mean 18% ± 8 SE) had not reached typical levels (mean 38% ± 0 SE) observed in the reference and unburned sites. If the observed trend in *Phragmites* cover in the burned sites to date were to continue going forward, it could take another three to four years until *Phragmites* cover fully returns (a total of five to six years following the impact of oiling and burning). *Phragmites* stem density and plant height were also examined, stem density was recovering more slowly than *Phragmites* cover in the oiled-and-burned sites; however, *Phragmites* plant height had returned to reference levels by September 2015 (data not shown). Overall, across all metrics, *Phragmites* appeared to be recovering in the oiled-and-burned sites, but recovery for this species was not yet complete.

Phragmites across our study area (all oiling/treatment classes and sites) seemed atypically senescent or stressed in September 2016, with noticeably fewer green leaves and stems (Figure S3). This was also evident in the decreased *Phragmites* cover in the reference sites in September 2016 (mean 24% ± 6 SE, Figure 4). Stem density in both the reference and oiled-and-not-burned sites also declined steadily over September 2014-2016 (data not shown). We think these observations may have been caused by stress due to extended high water levels from the Mississippi River, non-native scale insect damage, and/or other unknown factors. A non-native scale insect (*Nipponaclerda biwakoensis*, Phragmites scale or Roseau cane mealy bug) has been recently reported (April 2017) to be causing widespread damage to *Phragmites* on the Mississippi River Delta (Louisiana Department of Wildlife and Fisheries and LSU AgCenter; see http://www.wlf.louisiana.gov/news/41050, http://www.nola.com/environment/index.ssf/2017/04/scientists_finally_identify_pe.html, accessed 18 August 2017). Phragmites scale insect appeared to be visible in some of our detailed quadrat photos from September 2016, and was confirmed in our study area in May 2017 by the authors (B. Fortier, pers. comm.). *Phragmites* continued to look stressed in our study area as of May 2017, but damage did not seem to be as severe as reported for other parts of the Delta. It remains to be seen if scale insect damage, or a combination of multiple stressors including the scale insect, will further affect *Phragmites* in our study area, including future *Phragmites* recovery in our burned sites.

Vegetation species composition indicated that the reference and oiled-and-not-burned sites were very similar, each strongly dominated by *Phragmites* in September 2016 (Figure 5). *Phragmites* also strongly dominated the reference and oiled-and-not-burned sites across all other sampling periods (not shown). In contrast, by September 2016, the oiled-and-burned sites were characterized by a relatively even distribution of *Sagittaria latifolia* (broadleaf arrowhead), *Sagittaria platyphylla* (delta arrowhead), *Zizania aquatica* (southern wild rice), *Pontederia cordata* (pickerelweed), and *Phragmites* (Figure 5). *Sagittaria lancifolia* (bulltongue arrowhead) may also have been present, but was not differentiated from *Sagittaria platyphylla*. Though overall cover was low, the oiled-and-burned sites were initially dominated by *Phragmites* in June 2014, but with a small contribution by *Sagittaria platyphylla* (a few sparse shoots at one site). This progressed to typical total cover values and near equal dominance by *Phragmites*, *Sagittaria latifolia*, and *Sagittaria platyphylla* in September 2014, followed by these same three species with sizeable contributions by *Pontederia cordata*, *Polygonum* sp. (smartweed), and *Zizania aquatica* in September 2015.

Although relative cover values indicated clear differences in species composition in the oiled-and-burned sites compared to the reference and unburned sites, individual species other than *Phragmites* did not show strong differences in absolute cover values among oiling/treatment classes when averaged across sites (e.g., means for *Sagittaria latifolia* cover were 20% ± 17 SE across all oiled-and-burned sites versus 0% ± 0 SE in the reference and unburned sites in September 2016, but differences were not statistically significant; data not shown). This was due to variation in the presence, dominance, and mixture of species among the oiled-and-burned sites. However, combined vegetation cover for species other than *Phragmites* (total non-*Phragmites* cover) revealed strong differences among the oiling/treatment classes (Figure 6, Table S1). For this metric, the reference and oiled-and-not-burned sites had very low cover values across all sampling dates (means 0-3% ± 0-3 SE), whereas the oiled-and-burned sites showed a strong increasing trend in non-*Phragmites* cover starting in September 2014 (mean 19% ± 0 SE) and approaching 60% by September 2016 (mean 58% ± 3 SE).

Oiling and general response disturbance had little effect on the vegetation metrics examined in sites that were not burned. This is not surprising as *Phragmites* is relatively tolerant of oiling and typical response treatments, vegetation oiling was limited to the lower plant stems, and soil oiling was relatively minor (Lin et al., 1999; Judy et al., 2014). Suspected heavier oiling in the burned area precluded clearly differentiating between oiling and burning effects.

It is likely that the combination of heavy oiling and burning, including a hot, sustained burn due to the presence of crude oil, and the season of burning (in summer when aboveground plant growth is more active and belowground reserves reduced), served to reduce and control *Phragmites* dominance in the marsh, opening up space for other plant species and leading to a more diverse mixed marsh assemblage in the burned area. Similar outcomes have been observed for other summer-burned *Phragmites* marshes in the absence of oiling; although such results may not be long-term and burning alone is usually not effective in controlling *Phragmites* (Thompson and Shay, 1985, 1989; Hazelton et al. 2014). The additional species that co-dominated in the burned areas are native, desirable species typical for natural tidal freshwater marshes in the study area, particularly *Sagittaria* spp., which have otherwise been displaced by introduced *Phragmites* across large areas on the Delta (White, 1993; Cahoon et al., 2011; Hauber et al., 2011; Kettenring et al., 2012; White and Visser, 2016). Though outcompeted by *Phragmites*, these other species were likely already present in the marsh and emerged from existing root stocks and soil seed banks following the burn.

Although the oiled and burned area has not entirely recovered to pre-spill conditions relative to *Phragmites*-specific metrics and dominance, the mixed marsh assemblage can be viewed positively from the perspective of native plant diversity and improved waterfowl cover and food value at the local level (USFWS, 1995; Nelms, 2007; Hauber et al., 2011; Kettenring et al., 2012). This is especially relevant as the primary purpose of Delta National Wildlife Refuge is the protection and management of waterfowl and waterfowl habitat (USFWS, 2008). Prescribed burning has been used elsewhere to enhance waterfowl habitat, including *Phragmites* dominated marshes, though often in combination with other methods (Schlichtemeier, 1967; Ward, 1968; USFWS, 2005; Nelms, 2007). We suspect that *Phragmites* may continue to increase and eventually dominate the burned sites in our study area in the absence of other disturbance (e.g., tropical storms, scale insect damage, etc.) or active vegetation management; however, this make take a total of five to six years, based on the recovery trajectory for *Phragmites* in the study sites (see text above and Figure 4).

It is an open question if declines or loss of *Phragmites* across the Delta region from scale insect damage or other factors could lead to a shift to increased dominance by native vegetation, similar to what we observed following the oil spill and burn. As an aside, in several of the reference and oiled-and-not-burned sites, where *Phragmites* stands appeared thinned and stressed in September 2016, *Eichhornia crassipes* (water hyacinth, a floating non-native invasive plant) became dominant in the understory (mean 74% cover, see Figure S3), rather than native emergent species, though this might be a transient condition. Increased dominance by native emergent species could be possible in shallow depositional areas, but less so in deeper or wave-exposed sites. A shift to more native plant species may be desirable as localized patchy areas, but widespread loss of *Phragmites*, even if replaced by native species, could further acerbate coastal erosion and wetland loss, a major concern in the region. This would be a particular concern at the seaward marsh edge fronting the Gulf of Mexico and along major passes and channels. The larger stature of *Phragmites*, its ability to grow in deeper water, and its abundant belowground production and capacity to trap and accumulate sediments and litter may be important for wetland protection and stability in the face of coastal subsidence, sea level rise, and tropical storms (Rooth and Stevenson, 2000; Rooth et al., 2003; Hauber et al., 2011; Kettenring et al., 2012).

Summary and Conclusions

1) The in-situ burn was effective in rapidly removing much of the floating and stranded oil from the marsh and also reduced residual oiling on the marsh vegetation. Oil concentrations in marsh soils were initially elevated in the oiled-and-burned sites, likely due to the degree of oiling and other response activity rather than the burn, but were similar to reference and below background conditions by three months post-burn.

2) Oiling and typical response disturbance had little effect on the vegetation metrics examined in sites that were not burned; however, suspected heavier oiling in the burned area precluded clearly differentiating between oiling and burning effects. The combination of oiling and burning drastically affected the vegetation. Though *Phragmites* had not totally recovered, overall vegetation recovery was relatively rapid based on the metrics examined. In addition, oiling and burning resulted in a mixed species assemblage (including *Sagittaria* spp., *Pontederia*, and *Zizania*) rather than an immediate return to strong dominance by *Phragmites* (Figure S3).

3) The mixed marsh species assemblage in oiled and burned areas can be viewed positively in terms of habitat quality compared to areas strongly dominated by introduced *Phragmites*; although these differences may not persist indefinitely in the absence of other disturbance or active vegetation management. *Phragmites* may continue to increase and eventually dominate the burned areas; however, this make take several years.

4) Overall, in-situ marsh burning was effective for this spill and did not result in long-term adverse effects based on the metrics examined. Habitat recovery was relatively rapid and overall habitat quality in terms of native plant species composition and potential food and cover for waterfowl was locally enhanced by burning, at least for a few years. Based on these findings, in-situ burning appears to be a viable response option to consider during future spills in marshes with similar plant species composition, hydrogeomorphic settings, and oiling conditions.

5) It remains to be seen if non-native scale insect damage, other factors, or a combination of multiple stressors, will further affect *Phragmites* in our study area, including *Phragmites* recovery in the burned sites. It is an open question if loss of *Phragmites* across the Delta region from scale insect damage or other factors could lead to a shift to increased dominance by native vegetation, similar to what we observed following the oil spill and burn. A shift to native plant species may be desirable as localized patches, but widespread loss of *Phragmites*, even if replaced by native species, could further acerbate coastal erosion and wetland loss.

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Figure Captions

Figure 1. Vertical oil cover on the marsh vegetation, 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes. Statistically significant differences in oil cover were observed among oiling/treatment classes, time, and the interaction of oiling/treatment class and time (all $p < 0.01$). Across all time periods, pairwise differences among oiling/treatment classes were not statistically significant for the reference versus the oiled-and-burned sites ($p = 0.41$), but were significant for the oiled-and-not-burned versus the oiled-and-burned sites ($p = 0.02$), and for the reference versus the oiled-and-not-burned sites ($p < 0.01$). For June and September 2014, reference versus the oiled-and-burned sites were also significantly different ($p = 0.10$). No oil was observed in 2015 or 2016.

Figure 2. Total polycyclic aromatic hydrocarbons (tPAH) in marsh soils, 2014-2015. Data are means ± 1 SE. N = 5 for all oiling/treatment classes. Statistically significant differences were observed among oiling/treatment classes, time, and the interaction of oiling/treatment class and time (all $p < 0.01$). Across all time periods, pairwise differences among oiling/treatment classes were statistically significant for reference versus the oiled-and-burned sites ($p = 0.06$). The oiled-and-not-burned versus the oiled-and-burned sites were not significantly different ($p = 0.11$); nor were the reference and oiled-and-not-burned sites ($p = 0.92$). The main differences in tPAH levels among oiling/treatment classes occurred in June 2014 ($p < 0.01$); in September 2014 and 2015 there were no significant differences among oil/treatment classes ($p = 0.68$, $p = 0.33$).

Figure 3. Total vegetation cover, 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes. Statistically significant differences were not observed among oiling/treatment classes ($p = 0.77$); however, significant differences were observed for time and the interaction of oiling/treatment class and time (both $p < 0.01$). In June 2014, treatment effects were statistically significant ($p < 0.01$); and pairwise differences among oiling/treatment classes were significant for oiled-and-burned sites

compared to both reference and oiled-and-not-burned sites (both $p = 0.01$). In September 2016, treatment effects were statistically significant as well ($p < 0.01$); pairwise comparisons among oiling/treatment classes were statistically significant for oiled-and-burned sites compared to reference and oiled-and-not-burned sites (both $p \leq 0.01$).

Figure 4. *Phragmites australis* cover, 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes. Statistically significant differences were observed among oiling/treatment classes ($p < 0.01$); significant differences were not observed for time ($p = 0.28$), but were observed for the interaction of oiling/treatment class and time ($p = 0.01$). Across time periods, pairwise differences among oiling/treatment classes were statistically significant for the oiled-and-burned sites compared to both reference and oiled-and-not-burned sites (both $p < 0.01$); the reference and oiled-and-not-burned sites were not significantly different ($p = 0.59$).

Figure 5. Emergent vegetation species composition by relative percent cover, September 2016. The reference and oiled-and-not-burned sites were both strongly dominated by *Phragmites*. The main secondary species included *Alternanthera philoxeroides* (both) and *Hydrocotyle* sp. (reference). The oiled-and-burned sites were characterized by a relatively even distribution of *Sagittaria latifolia, Sagittaria platyphylla*, *Zizania aquatica*, *Pontederia cordata*, and *Phragmites*.

Figure 6. Total non-*Phragmites* vegetation cover, 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes. Statistically significant differences were observed among oiling/treatment classes ($p = 0.02$), time ($p = 0.01$), and the interaction of oiling/treatment class and time ($p < 0.01$). Pairwise differences among oiling/treatment classes across time were statistically significant for the reference versus the oiled-and-burned sites ($p = 0.03$) and for the oiled-and-not-burned versus the oiled-and-burned sites ($p = 0.04$); the reference and oiled-and-not-burned sites were not significantly different ($p = 1.00$).

Figures

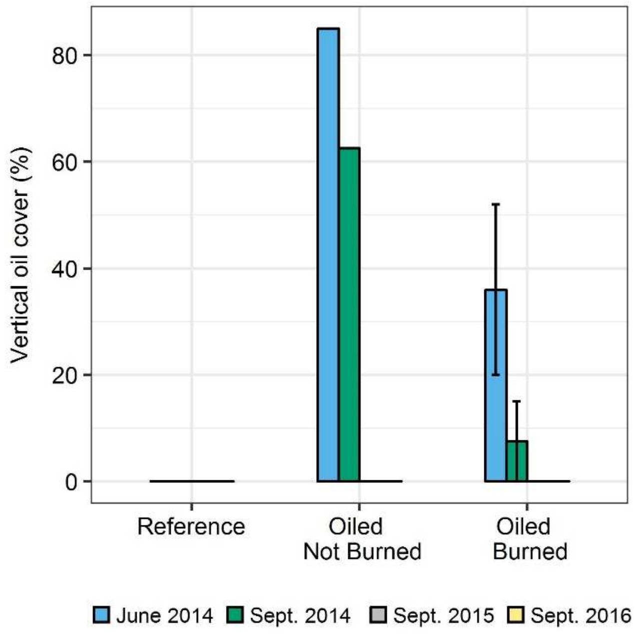


Fig. 1.

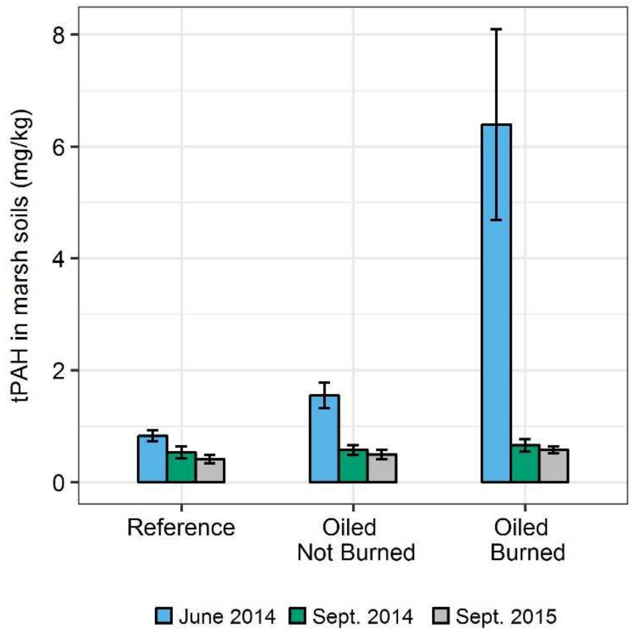


Fig. 2.

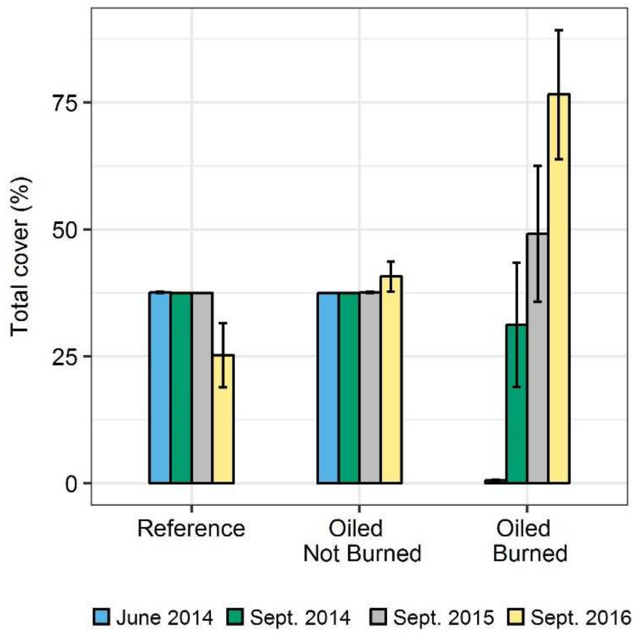

Total cover (%)
75
50
25
0
Reference
Oiled Not Burned
Oiled Burned
June 2014
Sept. 2014
Sept. 2015
Sept. 2016

Fig. 3.

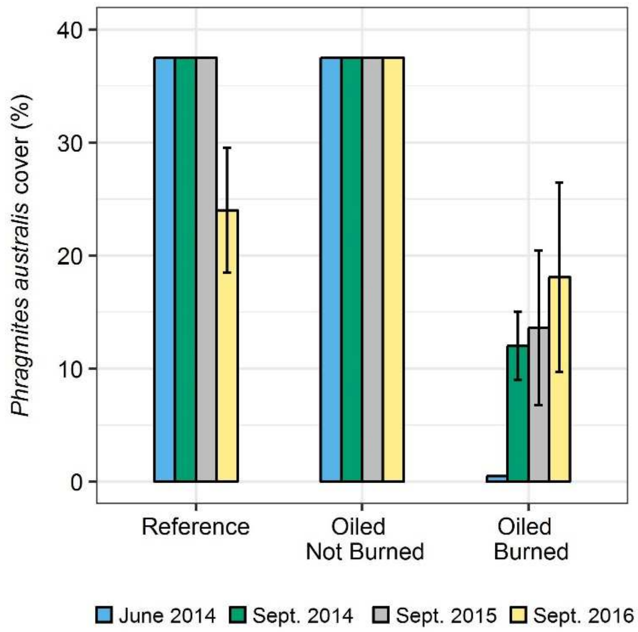

Phragmites australis cover (%)
40
30
20
10
0
Reference
Oiled Not Burned
Oiled Burned
June 2014
Sept. 2014
Sept. 2015
Sept. 2016

Fig. 4.

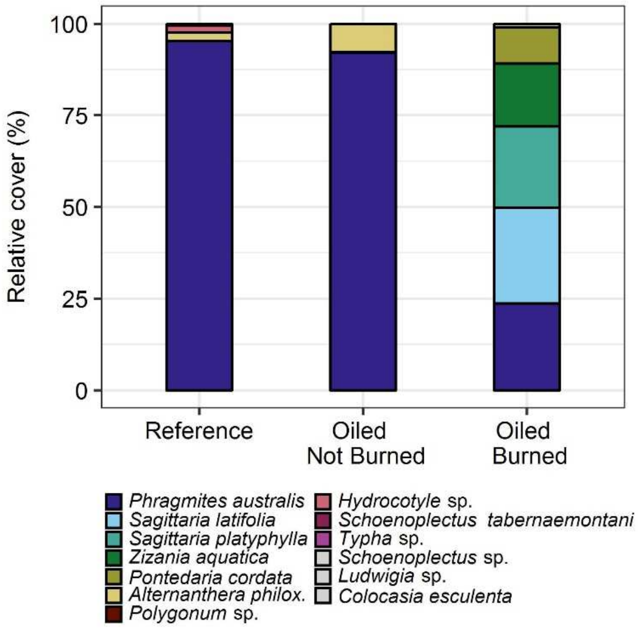

Relative cover (%)
100
75
50
25
0
Reference
Oiled Not Burned
Oiled Burned
Phragmites australis
Sagittaria latifolia
Sagittaria platyphylla
Zizania aquatica
Pontedaria cordata
Alternanthera philox.
Polygonum sp.
Hydrocotyle sp.
Schoenoplectus tabernaemontani
Typha sp.
Schoenoplectus sp.
Ludwigia sp.
Colocasia esculenta

Fig. 5.

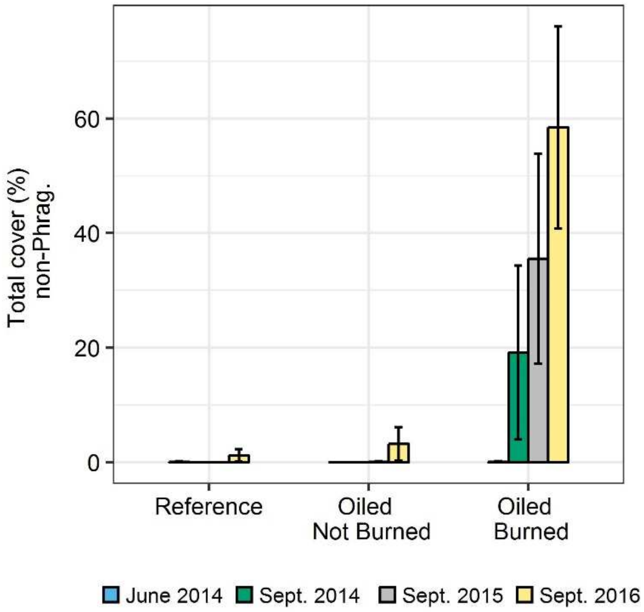
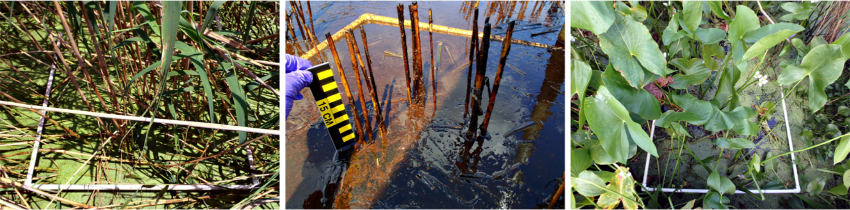

Total cover (%) non-Phrag.
60
40
20
0
Reference
Oiled Not Burned
Oiled Burned
June 2014
Sept. 2014
Sept. 2015
Sept. 2016

Fig. 6.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