In Situ Burning and Ecological Recovery in an Oil-Impacted *Phragmites australis* Tidal Freshwater Marsh at Delta National Wildlife Refuge, Louisiana

Scott Zengel, Jennifer Weaver, Zachary Nixon
Research Planning, Inc. (RPI), 247 E. 7th Avenue, Suite 200, Tallahassee, FL 32303

Susan L. Wilder
U.S. Fish and Wildlife Service, 61389 Highway 434, Lacombe, LA 70445

Jeff Dauzat
Louisiana Dept. Environmental Quality, 201 Evans Road, Suite 420, New Orleans, LA, 70123

Chris Sanfilippo
Texas Petroleum Investment Co., 207 Town Center Parkway, Suite 150, Lafayette, LA 70506

Scott Miles
Louisiana State University, Dept. Environmental Sciences, Baton Rouge, Louisiana 70803

Kyle Jellison[1], Paige Doelling, Adam Davis, Steven Wall
NOAA Emergency Response Division, 500 Poydras Street, Suite 1213, New Orleans, LA 70130

ABSTRACT

In situ burning of oiled marshes is a response method that can be more effective and less damaging to the marsh environment than more intrusive manual and mechanical methods, given appropriate conditions for burning. In situ burning has been examined for a variety of oiled marsh types and vegetation species; however, little to no published data are available for in situ burning of oiled *Phragmites australis* marshes (common reed, Roseau cane). In late May 2014, a pipeline spill occurred in Delta National Wildlife Refuge, Louisiana, releasing an estimated 4,200 gallons of South Louisiana crude oil into a semi-permanently flooded *Phragmites* tidal freshwater marsh located on the Mississippi River Delta. Due to the remote location, degree of oiling, and difficulty of oil removal within the dense vegetation, an in situ burn was conducted in early June 2014 while the marsh was flooded. In order to examine the effectiveness and environmental effects of in situ burning for this marsh type, and ecological recovery over time,

[1]Current: Maine Department Environmental Protection

we monitored oiling conditions and ecological metrics for more than two years, comparing sites from three oiling/treatment classes: (a) reference (not oiled or burned), (b) oiled-and-not-burned, and (c) oiled-and-burned. The burn was effective in rapidly removing much of the gross oiling 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, but were similar to reference conditions and below background levels after three months. Initial oiling and burning drastically affected the marsh vegetation and a common marsh invertebrate; however, overall ecological recovery was relatively rapid and habitat quality in terms of native plant species composition and wildlife value was enhanced by burning at a local scale, at least for several 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, environmental setting, and oiling conditions.

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., 2016). Emergency response and cleanup operations in oiled marshes involve a fine balance among 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, including (but not necessarily limited to) 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, 2013, 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: 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* occurs 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 oiled and unburned sites examined.

In order to examine the effectiveness and environmental effects of in situ burning in this marsh type, and ecological recovery over time, our study monitored oiling conditions, several vegetation metrics, and a common marsh invertebrate over four sampling periods beginning in June 2014 (roughly one week after burning) and annually from September 2014-2016 (total monitoring period ~2.3 years). 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 ecological 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 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 1). 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 on the following dates: 11-12 June 2014, 9 September 2014, 16 September 2015, and 21 September 2016.

Oiling Conditions. 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 (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 the 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. Vegetation data collected for each site included *Phragmites* cover, stem density, and stem height; 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. *Phragmites* stem density was determined by counting the number of rooted stems within a 1-m^2 quadrat. *Phragmites* plant height was determined using an expandable profile rod, measuring from the soil surface to the visually estimated average height of the vegetation. 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*, all species except *Phragmites*). Calculated vegetation metrics were determined using the mid-points of the cover classes described above. All vegetation metrics were based on rooted emergent species only. Data on floating aquatic plant species were collected but are not presented. No data were collected on submerged aquatic plants.

Marsh Snail. Each 1-m^2 quadrat was also searched for live *Neritina usnea* (olive nerite) snails occurring on the vegetation or on vegetation debris/litter down to a depth of ~15 cm below the water surface (the general limit of visibility). The presence/absence and number of snails was recorded. Snails were not collected or removed from the sampling sites.

Data Analysis. 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. Data figures were visually compared in terms of means and variation around the means by oiling/treatment class and over time. Cover values were calculated using the mid-points of each cover class (after Mueller-Dombois and Ellenberg, 1974; Pahl et al., 2003).

RESULTS/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 2).

Oiling conditions. 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 1). 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 compared to the oiled-and-burned sites, indicating a positive influence of burning on oil removal, even for the vegetation that remained after burning (Figure 3). 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, particularly in the oiled-and-burned sites relative to the reference sites in June 2014 (Figure 4). In September 2014 and 2015, tPAH values were below reported minimum background levels for *Phragmites* marshes in the delta region (Rouhani et al., 2016) 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 have also 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.

Vegetation. Total vegetation cover in the reference and oiled-and-not burned sites was similar throughout the study (Figure 5). The oiled-and-burned sites had very little vegetation cover immediately after the burn (<1%), but total cover increased steadily thereafter, exceeding the reference and oiled-and-not-burned sites by September 2016. The exceedance of the reference and unburned cover values suggests other underlying changes in the burned marsh, discussed further below.

Phragmites was the dominant marsh plant throughout the study area prior to the spill and at the onset of this study, based on field observations and the review of pre-burn ground and aerial photography. Not surprisingly, similar to total vegetation cover, *Phragmites* cover in the reference and oiled-and-not burned sites was also similar (Figure 6). Also like total cover, the oiled-and-burned sites had greatly reduced *Phragmites* cover immediately after the burn, 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 had not reached the typical levels observed in the reference and unburned sites by September 2016 (the decreased *Phragmites* cover in the reference sites in September 2016 was due to leaf senescence across much of the study area, possibly caused by extended high water levels prior to sampling). 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 was also similar in the reference and oiled-and-not-burned sites throughout the study, but was reduced in the oiled-and-burned sites (Figure 7). In this case there appeared to be an overall lack of a recovery trend for the burned sites, although in September 2016 there may have been some initial indication of recovery.

Phragmites plant height in the reference and oiled-and-not burned sites was also similar (Figure 8). In contrast, the oiled-and-burned sites had greatly reduced *Phragmites* height immediately after the burn, with increasing values thereafter, indicating initial impact followed by recovery. In September 2015, *Phragmites* height values in the burned sites were similar to reference, and by September 2016 there were no longer differences among any of the oiling/treatment classes, indicating recovery of *Phragmites* plant height in the 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 9). *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 platyphylla* (delta arrowhead), *Sagittaria latifolia* (broadleaf arrowhead), *Zizania aquatic* (southern wild rice), *Pontederia cordata* (pickerelweed), and *Phragmites*. *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 some *Sagittaria platyphylla* as well. This progressed to typical total cover values and near equal dominance by *Phragmites*, *Sagittaria platyphylla*, and *Sagittaria latifolia* 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 averaged across sites (e.g., means for *Sagittaria* spp. were ~20% cover in the oiled-and-burned sites versus 0 to <1% cover in the reference and unburned sites, but with wide error bars; 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 10). For this metric, the reference and oiled-and-not-burned sites had very low cover values across all sampling dates, whereas the oiled-and-burned sites showed a strong increasing trend in non-*Phragmites* cover starting in September 2014, approaching 60% by September 2016.

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 perhaps 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. 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 are otherwise being displaced by introduced *Phragmites* in the region (White, 1993; Cahoon 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 the soil seed bank following the burn. Although the oiled and burned area has not 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 scale (USFWS, 1995; Nelms, 2007; 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). We suspect that *Phragmites* may continue to increase and eventually dominate the burned areas in the absence of other disturbance or active vegetation management; however, this make take several years.

Marsh snail. *Neritina usnea* was found in all the reference sites during all sampling periods (Figure 11). There was some indication that oiling alone may have affected this species to some degree in the oiled-and-not-burned sites, and there was a clear negative effect of oiling and burning, including the complete absence of snails for up to a year or more in the oiled-and-burned sites. We suspect that the combination of oiling and burning killed all or most snails in the interior of the burned areas, then, as the vegetation returned, snails immigrated into the burned sites from surrounding nearby areas. In the unburned sites, impacts may have been more patchy or localized depending on oiling levels. By September 2016, snails were observed at all sites across all oiling/treatment categories. Densities were highly variable, but were similar in

September 2016 across oiling/treatment classes, with mean values ranging from 10-18 individuals m^{-2}.

CONCLUSIONS

1) The in situ burn was effective in rapidly removing much of the gross oiling 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, although 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 12).

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) Oiling and burning effects on the marsh snail (*Neritina usnea*) were also observed; however, the occurrence and density of this species recovered within roughly two years.

5) Overall, in situ 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 enhanced by burning at a local scale, 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, environmental setting, and oiling conditions.

ACKNOWLEDGEMENTS

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FIGURES

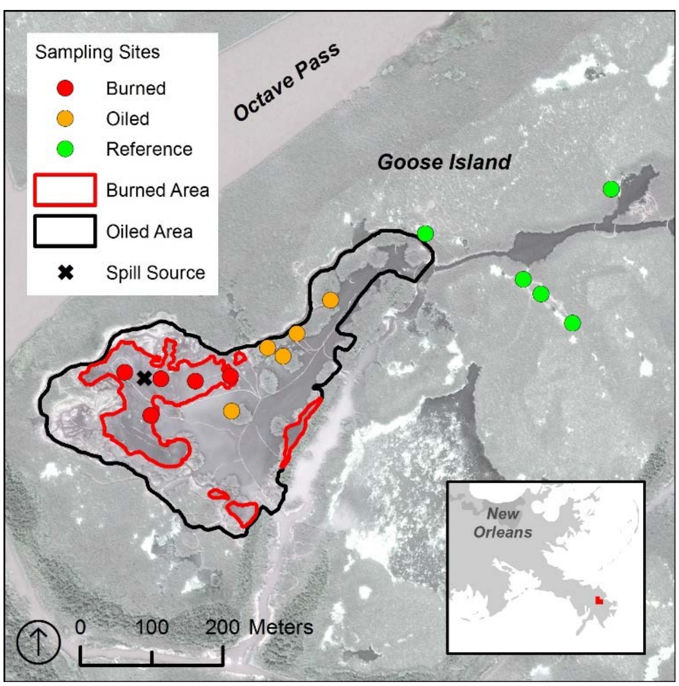

Figure 1. Study area map with locations of sampling sites by oiling/treatment class, including reference (green), oiled-and-not-burned (orange), and oiled-and-burned sites (red). The oiled area is outlined in black, the oiled-and-burned area in red. Aerial photography date is 17 June 2014, shortly following the first sampling period.

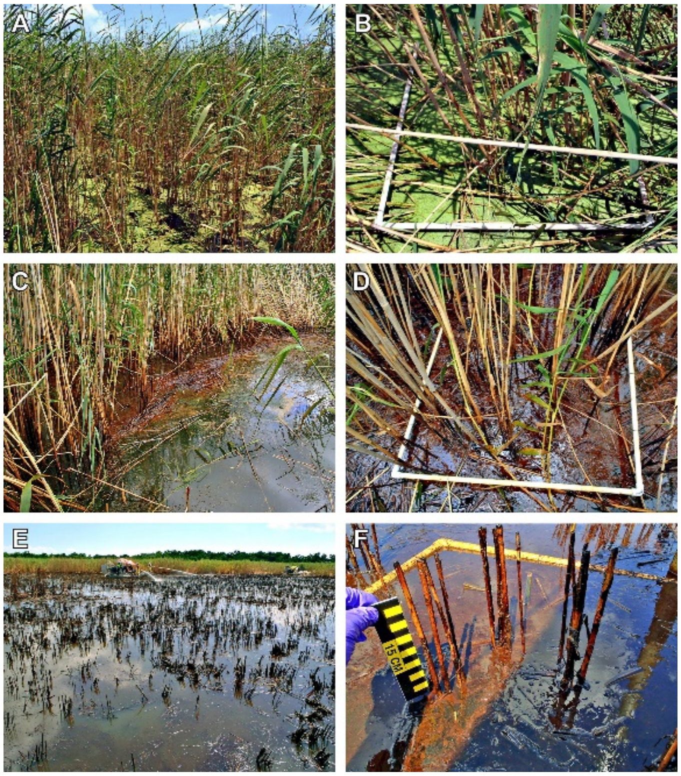

Figure 2. Example conditions across oiling/treatment classes in June 2014 at the onset of the study. (A) reference site, landscape side view of unoiled *Phragmites* marsh; (B) reference site, plan view of vegetation sampling quadrat; (C) oiled-and-not-burned site with oil band visible on the lower *Phragmites* stems; (D) oiled-and-not-burned quadrat with oil visible on the vegetation and water surface; (E) oiled-and-burned site with remaining stubble of *Phragmites* stems; (F) oiled-and-burned quadrat with oil visible on the remaining *Phragmites* stems and water surface.

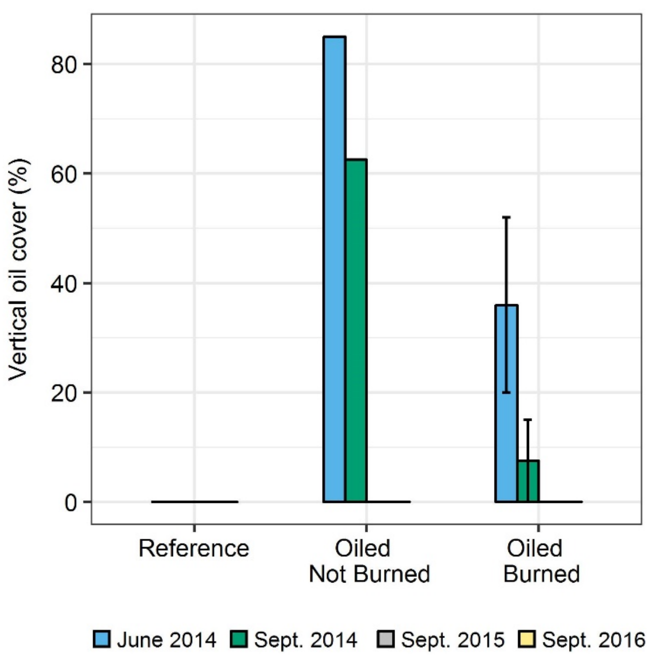

Figure 3. Vertical oil cover on the marsh vegetation, 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes. No oil was observed in 2015 or 2016.

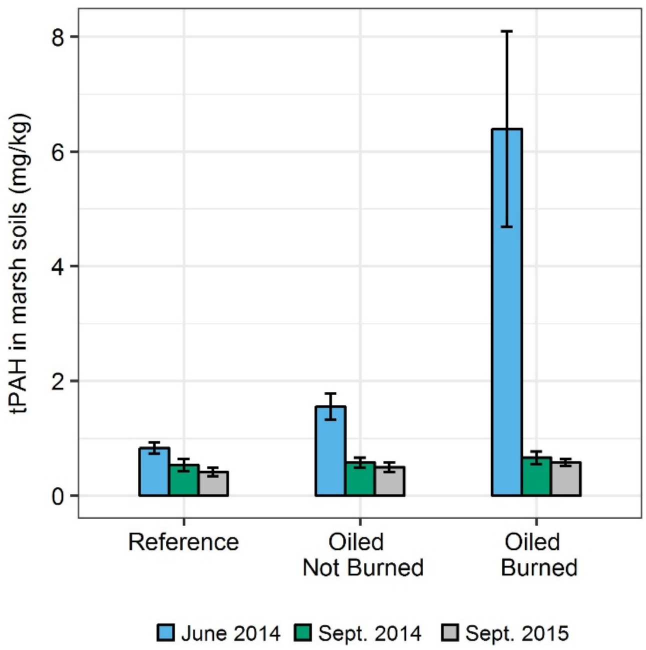

Figure 4. Total polycyclic aromatic hydrocarbons (tPAH) in marsh soils, 2014-2015. Data are means ± 1 SE. N = 5 for all oiling/treatment classes.

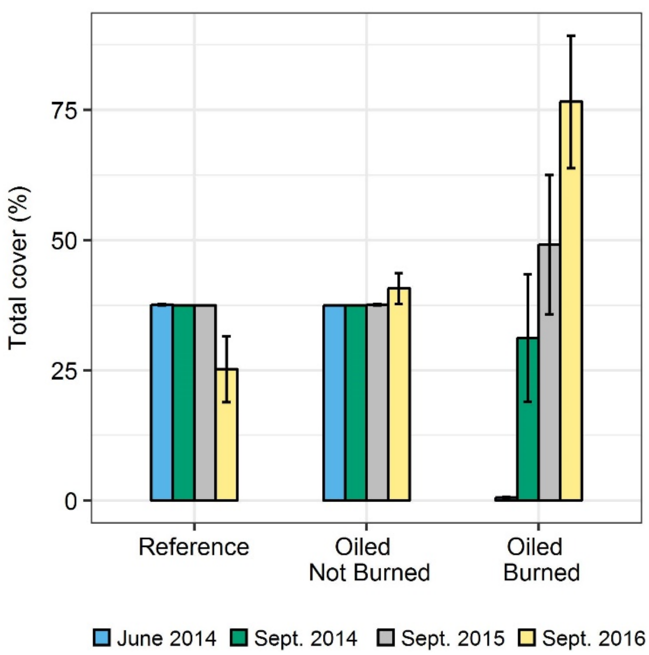

Figure 5. Total vegetation cover, 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes.

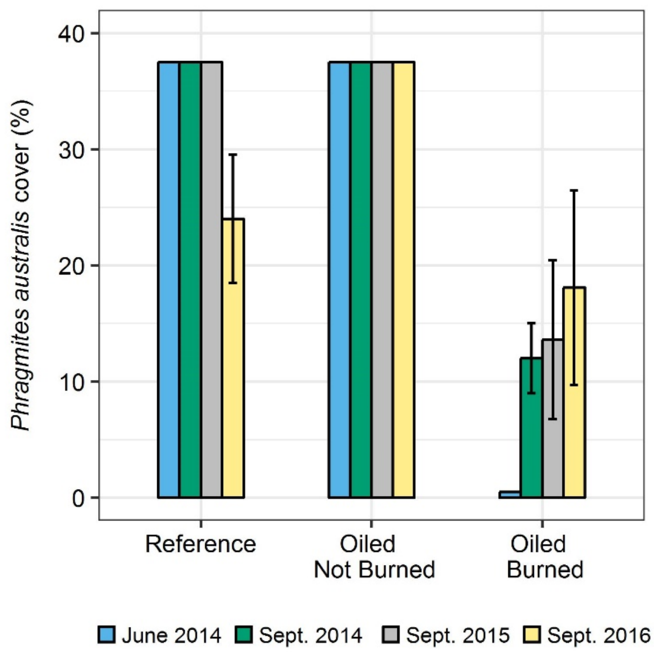

Figure 6. *Phragmites australis* cover, 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes.

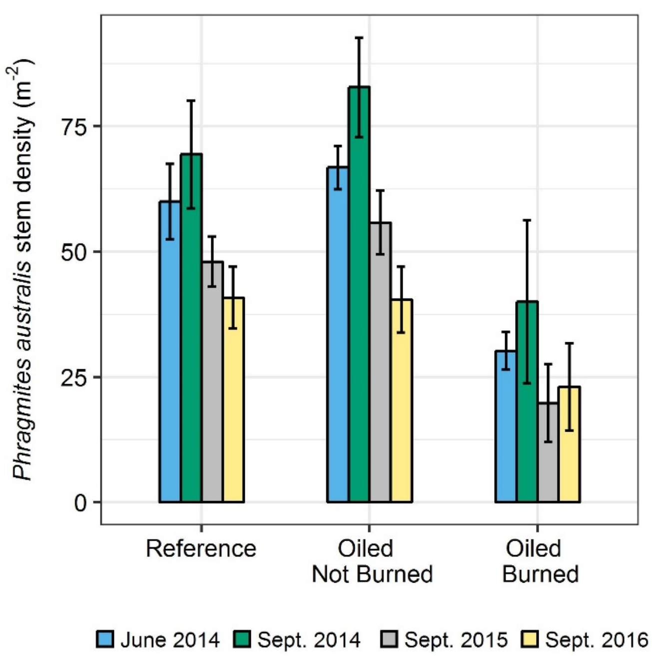

Figure 7. *Phragmites australis* stem density, 2014-2016. Data are means ± 1 SE. N=5 for all oiling/treatment classes.

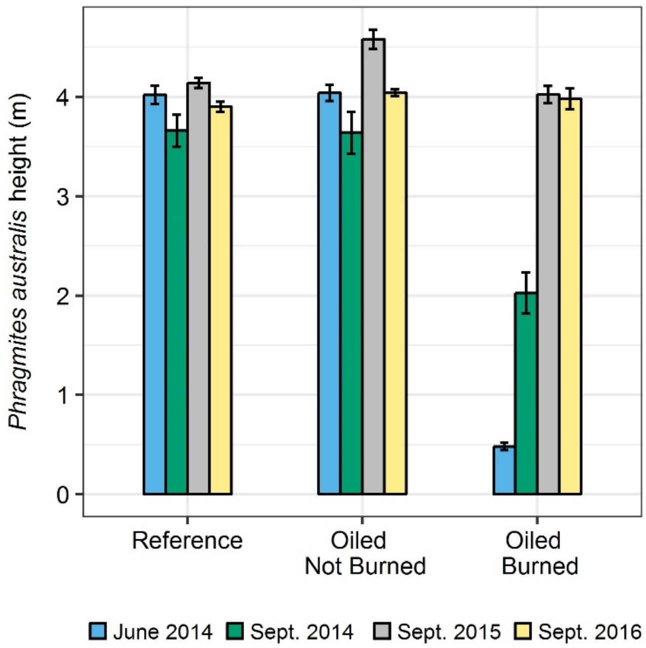

Figure 8. *Phragmites australis* plant height, 2014-2016. Data are means ± 1 SE. N = 4-5 for all oiling/treatment classes.

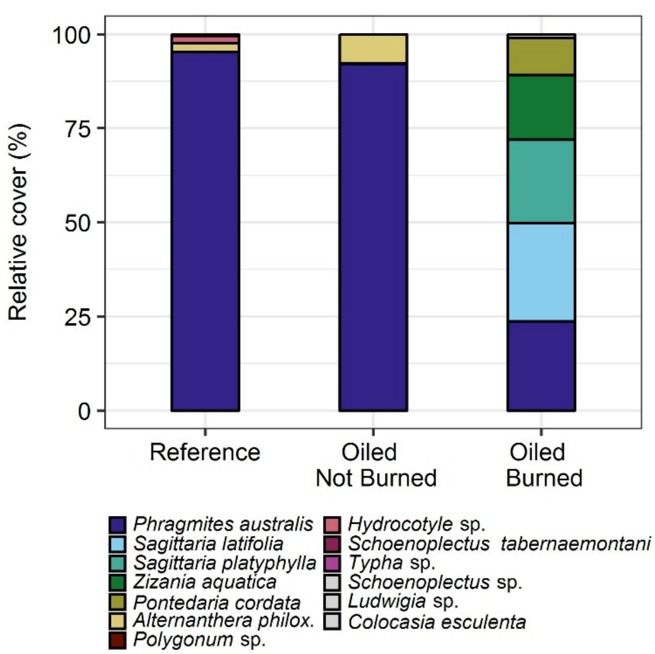

Figure 9. Vegetation species composition by relative percent cover (rooted emergent species only), September 2016.

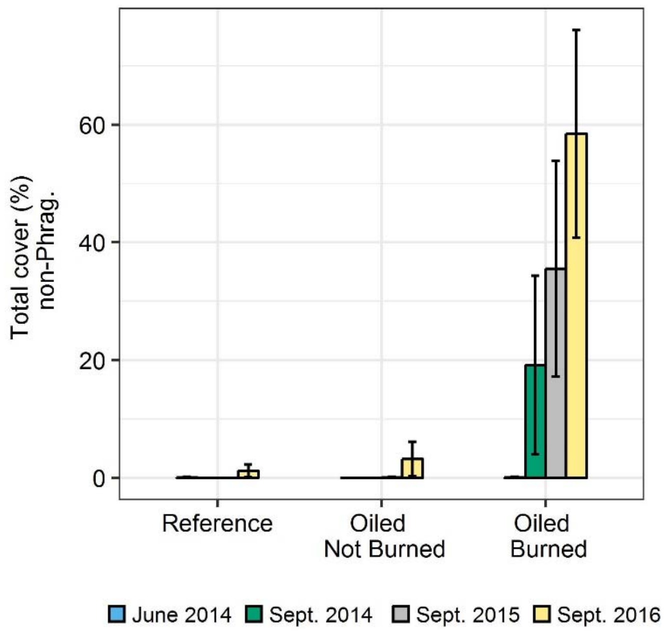

Figure 10. Total vegetation cover (non-*Phragmites australis*), 2014-2016. Data are means ± 1 SE. N = 5 for all oiling/treatment classes.

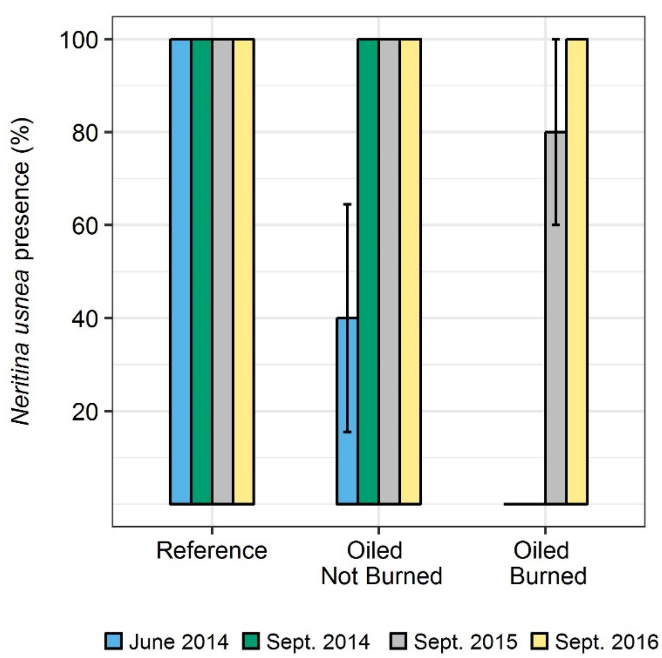

Figure 11. *Neritina usnea* snail presence/absence. No snails were observed at oiled-and-burned sites in June or September 2014. In September 2016 snails were observed at all sites.

Figure 12. Example conditions across oiling/treatment classes in September 2016 during the last sampling period. (A) reference site, landscape side view of unoiled *Phragmites* marsh; (B) reference site, plan view of vegetation sampling quadrat, *Phragmites* stems with *Eichhornia crassipes* (water hyacinth, a floating invasive plant) visible in the understory; (C) oiled-and-not-burned site dominated by *Phragmites*; (D) oiled-and-not-burned quadrat, *Phragmites* stems with *Eichhornia crassipes* in the understory; (E) oiled-and-burned site dominated by mixed *Sagittaria platyphylla*, *Sagittaria latifolia*, and *Pontederia cordata*; (F) oiled-and-burned quadrat dominated by *Sagittaria latifolia*.

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