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Vegetation recovery in an oil-impacted and burned *Phragmites australis* tidal freshwater marsh

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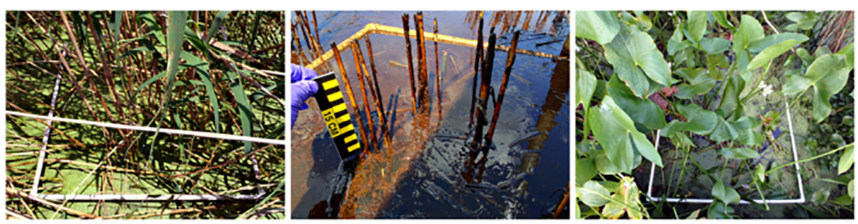
HIGHLIGHTS

- *Phragmites* marsh recovery was examined after an oil spill and in-situ burn.
- Following the oil spill and burn, only short bare plant stems remained.
- However, increases in plant cover were relatively rapid and steady thereafter.
- Marsh habitat was enhanced by burning, native plants and wildlife value increased.
- Burning can be a viable spill response method to consider under similar conditions.

GRAPHICAL ABSTRACT



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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 4200 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,

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Ecological recovery
Scale insect damage

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.

1. 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 4200 gal 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).

2. Methods

This study was conducted on the Mississippi River Delta at Goose Island, south of Octave Pass, within Delta National Wildlife Refuge, Louisiana (Fig. 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 midpoints 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