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# Salt Marsh Remediation and the *Deepwater Horizon* Oil Spill, the Role of Planting in Vegetation and Macroinvertebrate Recovery

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## ABSTRACT 300288:

The *Deepwater Horizon* oil spill resulted in persistent heavy oiling in salt marshes, particularly in northern Barataria Bay, Louisiana. Oiling conditions and several ecological variables were compared among reference plots and three types of heavily oiled plots located along a continuous shoreline area in northern Barataria Bay: oiled control plots, mechanical treatment plots, and mechanical treatment plots coupled with vegetation planting (*Spartina alterniflora*). Data were collected more than three years following initial oiling and two years following cleanup treatments and planting. Salt marsh oiling and associated impacts were apparent across all oiling/treatment classes relative to reference conditions. Mechanical treatment with planting showed the most improvement in oiling conditions and was also effective in re-establishing vegetation cover and plant species composition similar to reference conditions, in contrast to the oiled controls and mechanical treatment plots without planting. Marsh periwinkle (*Littoraria irrorata*) recovery was limited across all oiling/treatment classes relative to reference. Impacts to fiddler crabs (*Uca* spp.) were also documented in the heavily oiled plots. Positive influences of mechanical treatment and planting on macroinvertebrate recovery were observed; however, invertebrate recovery may lag the return of *Spartina alterniflora* by several years. Vegetation planting should be considered as a spill response and emergency restoration option for heavily oiled salt marshes where vegetation impacts are substantial, natural recovery may be lacking or delayed, intensive cleanup treatments are used, or where marsh shorelines are at risk of erosion.

## INTRODUCTION:

The *Deepwater Horizon* oil spill resulted in the oiling of 796 kilometers (km) of coastal marsh shorelines as documented by Shoreline Cleanup Assessment Technique (SCAT) teams (Michel *et al*. 2013). Of this total, 135 km of shoreline were described as heavy marsh oiling, based on a combination of oiling width across the shore, oiling percent cover, and oil thickness (Michel *et al*. 2013). Persistent heavy marsh oiling that required cleanup was most widespread in

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salt marshes in northern Barataria Bay, Louisiana, in marshes dominated primarily by *Spartina alterniflora*, and to a much lesser extent by *Juncus roemerianus* (Zengel and Michel 2013, Michel *et al*. 2013).

Previous work by Zengel and Michel (2013) and Zengel *et al*. (2014) tested various marsh shoreline cleanup techniques following the spill, describing changes in oiling conditions and ecological response variables in the heavily oiled northern Barataria Bay "marsh treatment test area" established under the *Deepwater Horizon* spill response. Early monitoring in the marsh treatment test area revealed slow vegetation recovery following oil impacts. As only a limited number of field studies and case histories have evaluated vegetation planting as a response and emergency restoration method in oiled marshes, the marsh treatment test area provided a rare opportunity to evaluate whether transplanting vegetation would be an effective strategy to facilitate ecological recovery (Krebs and Tanner 1981, Baca *et al*. 1987, Bergen *et al*. 2000, Packer 2001, Gundlach *et al*. 2003).

As effects from both oiling and cleanup activities unfold over time, continued study allows broader understanding of ecological effects and recovery. In order to further examine the impacts of oiling, this study continues monitoring of the established marsh treatment test area through the third year following the spill, examining changes in oiling condition and ecological variables. We also compare recovery with and without vegetation planting following cleanup activities by monitoring vegetation transplantation experiments conducted in the marsh treatment test area. This work supplements earlier studies and assessments of *Deepwater Horizon* oil spill impacts and recovery in coastal marshes, most of which did not consider cleanup and restoration influences (Lin and Mendelssohn 2012, McCall and Pennings 2012, Mendelssohn *et al*. 2012, Silliman *et al*. 2012, Kokaly *et al*. 2013, Brunner *et al*. 2013, Khanna *et al*. 2013, McClenachan *et al*. 2013).

We compare surface oiling conditions and several ecological parameters among the following oiling/treatment classes: (a) reference conditions, (b) oiled controls (little to no cleanup), (c) operational-scale mechanical cleanup treatment, and (d) operational-scale mechanical treatment followed by experimental vegetation planting (Figure 1). Parameters examined include oiling conditions; marsh vegetation cover and plant species composition; marsh periwinkle (*Littoraria irrorata*) density and size/age class distribution; and fiddler crab (*Uca* spp.) burrow density, abundance, and species composition. The goal of this paper was to examine medium-term recovery more than three years following initial oil impact and two growing seasons following remediation and restoration actions, providing useful results and interpretation for other on-going studies of this oil spill, as well as for response and restoration efforts following future spills.

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## METHODS:

This study was conducted in the northern Barataria Bay “marsh treatment test area” established under the *Deepwater Horizon* response, located near Bay Jimmy, Louisiana (Figure 1). Initial heavy oiling in the study area occurred in late May and early June 2010. By September 2010, the predominant heavy oiling conditions requiring cleanup included heavily oiled wrack and vegetation mats (oiled and laid over vegetation) overlying a thick layer of emulsified oil trapped on the marsh surface (2-3 cm average oil thickness), with 90-100% oil distribution on the marsh sediments (Zengel and Michel 2013). See Kokaly *et al*. (2013) (their Figures 12b and 13) and Khanna *et al*. (2013) (their Figure 2), depicting heavy oiling distribution in the study area. The oiled control plots, mechanical treatment plots, and mechanical treatment plots with planting were all located within a continuous band of persistent heavy oiling.

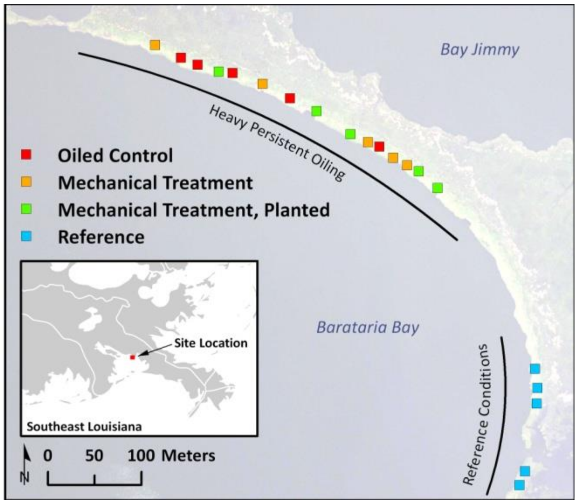

**Figure 1**. Study area map showing the location of the sampling plots by oiling/treatment class.

Sampling plots (Figure 1) were positioned on the seaward marsh edge, each spanning 5 meters (m) along shore and extending 3 m toward the marsh interior (15 $m^2$ total area). The oiled control plots were selected by random as a subset of pre-existing “no treatment” plots (or “set-asides”) established during the prior marsh treatment tests (which were also randomly assigned within the test area, and represented the only comparably oiled sites where major cleanup activities were not applied) (Zengel and Michel 2013). The mechanical treatment plots with planting were located at random (and planted) by Tulane University within operationally treated locations spanning the marsh treatment test area (Bernik 2014). See below for further descriptions of both mechanical treatment and planting methods. The mechanical treatment plots without planting were located at random during the current study from operationally treated locations across the test area but outside the planted plots. Finally, the reference plots were located at random within the nearest contiguous and comparable shoreline area that did not have persistent heavy oiling during the marsh treatment tests, and where the marsh vegetation structure remained intact during the spill (there was some minor oiling in the reference plots in 2010-2011, but to a much lesser degree than in the heavily oiled plots). Although it would have been desirable to have reference plots randomly interspersed among the heavily oiled and variously treated plots, this was impossible due to the distribution of heavy oiling. Five replicate plots were sampled for each oiling/treatment class including the reference plots.

Some of the oiled control plots had limited manual spot treatments prior to the current study (winter 2012-2013 or summer 2013). These plots were still considered oiled controls as the treatments were patchy and relatively ineffective at changing the predominant oiling conditions. During prior sampling in September 2012, oiling conditions in the oiled control plots were very

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similar to conditions recorded two years earlier, including the presence of oiled vegetation mats with an underlying thick layer of emulsified oil, though surface oil cover was somewhat reduced in places, particularly at the seaward edge of the marsh (Zengel *et al*. 2014). Total polycyclic aromatic hydrocarbons (tPAHs) in the surface oil layer averaged ≥833 parts-per-million (ppm) in the oiled controls in September 2011, and tPAHs in marsh sediments below the surface oil layer averaged 260 ppm and 112 ppm in the oiled controls in September 2011 and September 2012, respectively (Zengel and Michel 2013, Zengel *et al*. 2014).

Mechanical treatments were applied in the test area in May-June 2011 at full operational scale as a part of the wider spill response and cleanup (mechanical treatment occurred outside the original treatment test plots, avoiding the oiled control plots). Mechanical treatment involved mechanized grappling, raking, cutting, and scraping (Zengel and Michel 2013, Zengel *et al*. 2014). The mechanical treatments entirely removed the oiled vegetation mats and wrack, reduced the emulsified oil layer, and converted the dominant sediment surface oiling condition from emulsified oil to a more weathered surface oil residue. The overall thickness of surface oil residue was reduced compared to the pre-treatment oiling conditions and the oiled controls. Mean surface oil cover on the sediments was 46% in the mechanical treatment areas in 2012 (Zengel *et al*. 2014). Though oiling conditions were improved overall, there were indications of subsurface oiling, excessive sediment removal, and accelerated marsh shoreline retreat (erosion) resulting from mechanical treatment in the study area, though planting subsequently slowed this erosion (Zengel *et al*. 2014).

Vegetation planting in the mechanically treated and planted plots (Figure 1) involved hand-planting individual bare root *S. alterniflora* stems as a form of emergency restoration following shoreline cleanup (Bernik 2014). A transplanted *S. alterniflora* variety native to Bay Jimmy was used. Stems were planted approximately 45 centimeters (cm) apart along five rows: four rows running shore normal spaced on 90 cm centers, and the fifth row running parallel to shore along the interior or “landward” edge of the plots (resulting in a planting density of 2-3 stems $m^{-2}$). Planting was completed in late summer and early fall 2011. No fertilizer was used during planting. Hand trimming of naturally recruiting aboveground vegetation other than *S. alterniflora* was conducted during planting and subsequently in planted areas.

Sampling for this study was conducted in September 2013, more than three years following initial oiling and two years (and two growing seasons) following the mechanical treatments and planting. Surface and subsurface oiling descriptions were based on SCAT methods applied across each plot (NOAA 2013). Subsurface oiling was examined by digging small trenches (test pits). Vegetation cover was estimated visually across each plot in total and for each plant species observed. Marsh periwinkles and fiddler crab burrows were counted in three 0.25 $m^2$ quadrats per plot, each located roughly 1.5 m from the seaward marsh edge (mid-plot) and spaced roughly equally along the shoreline of each plot. Marsh periwinkle counts included careful searches for small juvenile snails hidden between the vegetation leaf sheaths and stems and in rolled leaves. All marsh periwinkles recorded in the quadrats were measured using digital calipers to determine total shell length. Periwinkle shell length data were used to generate size frequency histograms incorporating the following life-history stages: juveniles (<6 millimeters [mm]), sub-adults (6-13 mm), and adults (>13 mm) (after Hamilton 1978, Stagg and Mendelssohn 2012). Fiddler crab species composition was determined by catching fiddler crabs

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on the marsh surface and from burrow entrances within each plot to make species identifications. A maximum of 10-15 fiddler crabs were identified to species for each plot.

Sediment surface oil cover and multiple ecological parameters were plotted by oiling/treatment class as means ± 1 standard error (SE). Non-parametric statistical analyses were used, including Kruskal-Wallis tests performed on individual sampling parameters across all oiling/treatment classes. Where differences were defined as statistically significant ($p \leq 0.05$) or moderately significant ($p \leq 0.10$) in the Kruskal-Wallis tests, multiple pairwise comparisons between oiling/treatment classes were performed using Mann-Whitney U tests with Bonferroni corrections.

## RESULTS & DISCUSSION:

### Oiling Conditions

No oiling was observed in the reference plots, either on the marsh surface or subsurface at the time of sampling in 2013 (Figure 2). The oiled controls had 45% mean cover of surface oil (Figure 2) ranging from surface oil residue to a matrix of surface oil residue, residual oiled vegetation mats, and emulsified oil. Surface oil thickness was $\geq 1$ cm. Subsurface oiling was observed for the oiled controls, including oil penetration and burial of thick layers of surface oil residue, oiled vegetation mats, and emulsified oil beneath 5-9 cm of relatively clean sediment. The mechanical treatment plots without planting had 29% mean cover of surface oil consisting mainly of surface oil residue with oil thickness $\geq 1$ cm. Subsurface oiling was also observed, including oil penetration and mixing of oil into the sediments to 12 cm depth. The mechanical treatment plots with planting had 11% mean cover of surface oil limited to surface oil residue with oil thickness $\leq 1$ cm. Subsurface oiling was observed, including oil penetration and some mixing of oil into the sediments, though this seemed less prevalent than in the areas without planting.

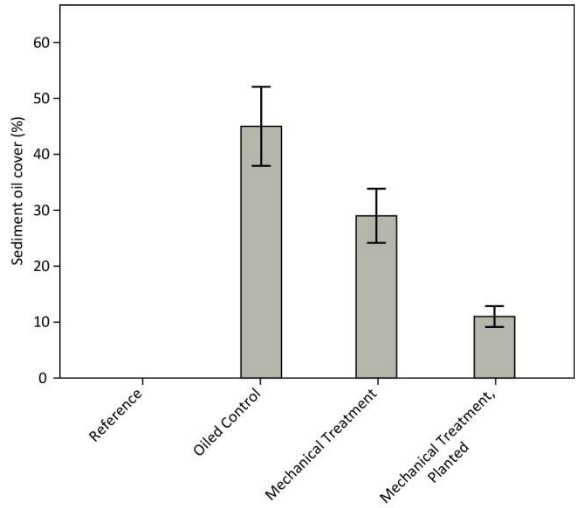

**Figure 2**. Sediment surface oil cover. Differences among oiling/treatment classes were observed ($p < 0.01$). Specific pairwise comparisons were significant for reference versus all other classes; and mechanical treatment with planting versus oiled control (all $p \leq 0.05$). The comparison of mechanical treatment with planting versus mechanical treatment without planting was moderately significant ($p = 0.09$). Data are means ± 1 SE.

Overall, oiling conditions in the heavily oiled plots were still distinct as compared to the reference plots, more than three years following initial oiling. The mechanically treated areas showed improved oiling conditions relative to the oiled controls. Planting further improved oiling conditions, even over a relatively short time frame. This can likely be attributed to rhizome growth and new shoot emergence physically breaking up the residual surface oiling as the vegetation spread, filled in, and increased in density over two growing seasons. More nuanced phytoremediation effects, including enhanced soil oxidation and microbial degradation, may also have played a role (Lin and Mendelssohn 1998, 2008, 2009). Phytoremediation effects

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could also include enhanced infaunal activity (e.g., fiddler crab burrowing), if facilitated by planting.

## Vegetation

Total vegetation cover values were similar in the reference and mechanical treatment plots with planting (Figure 3). The oiled control and mechanical treatment plots without planting were similar to each other, and were roughly 50% of reference values. *S. alterniflora* is the dominant species of salt marsh vegetation in the study area (Chabreck 1970, Visser *et al*. 1998), consistent with cover values from the reference plots (Figure 4). The pattern in *S. alterniflora* cover across study plots was similar to total vegetation cover, with no difference between the reference and planted plots, but with *S. alterniflora* cover a good deal lower for the oiled control and mechanical treatment plots without planting (18-26% of reference values). *J. roemerianus*, another typical salt marsh species in the region (Chabreck 1970, Visser *et al*. 1998), also contributed to vegetation cover in the reference plots; however, this species was not recorded in any of the heavily oiled plots, whether treated or not (Figure 5). In contrast, *Paspalum vaginatum*, a species typical of lower salinity coastal marshes rather than salt marsh (Chabreck 1970, Visser *et al*. 1998), contributed to vegetation cover in the oiled control and mechanical treatment plots without planting, but not in the reference or planted plots (Figure 6).

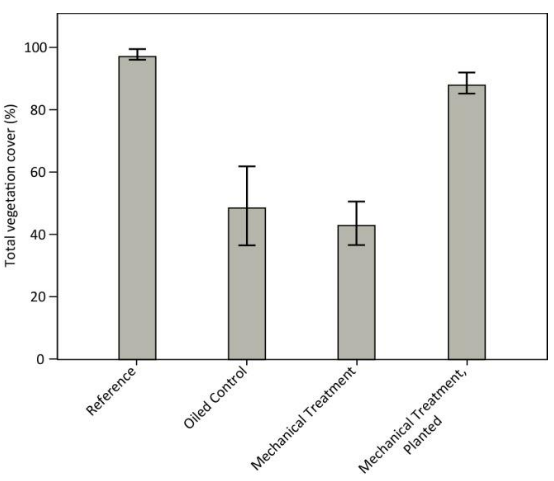

**Figure 3**. Total vegetation cover. Differences among oiling/treatment classes were observed ($p < 0.01$). Specific pairwise comparisons were significant for reference versus oiled control and mechanical treatment without planting; and mechanical treatment with planting versus mechanical treatment without planting (all $p \leq 0.05$). The comparison of mechanical treatment with planting versus oiled control was moderately significant ($p = 0.08$). Data are means ± 1 SE.

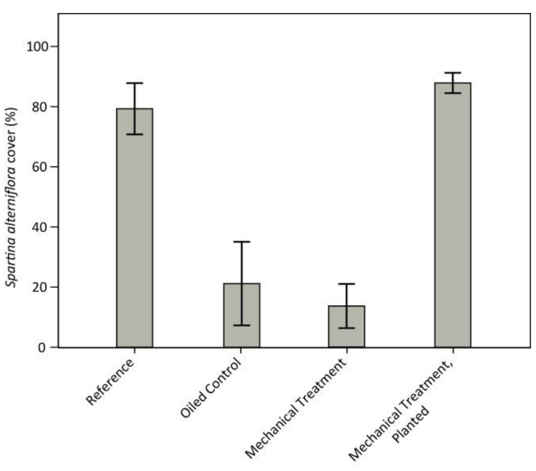

**Figure 4**. *Spartina alterniflora* cover. Differences among oiling/treatment classes were observed ($p < 0.01$). Specific pairwise comparisons were significant for reference versus mechanical treatment without planting; and mechanical treatment with planting versus mechanical treatment without planting (all $p \leq 0.05$). The comparison of mechanical treatment with planting versus oiled control was moderately significant ($p = 0.07$). Data are means ± 1 SE.

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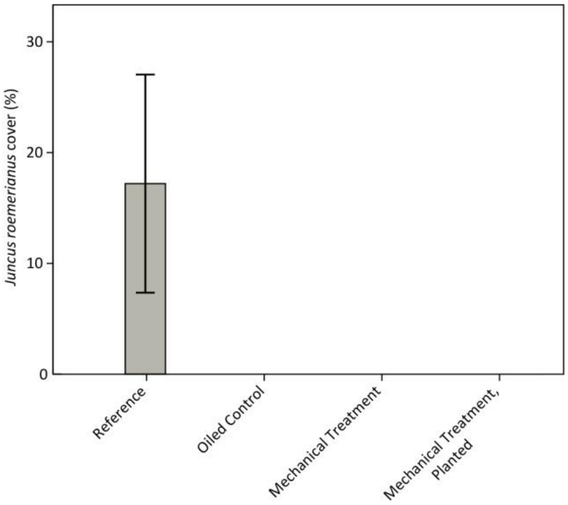

**Figure 5**. *Juncus roemerianus* cover. Differences among oiling/treatment classes were observed (p < 0.01). Specific pairwise comparisons were moderately significant for reference versus all other classes (p = 0.06). Data are means ± 1 SE.

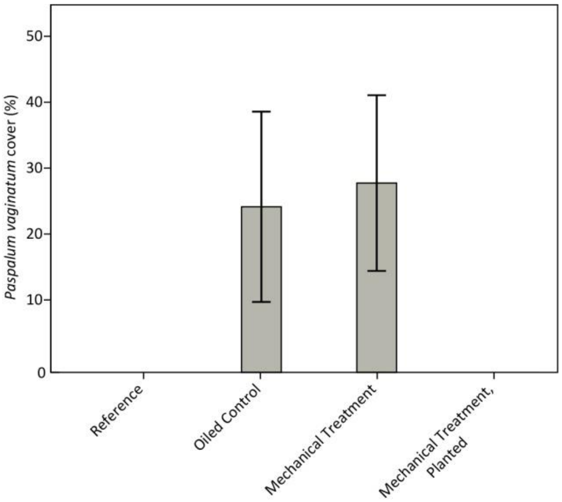

**Figure 6**. *Paspalum vaginatum* cover. Differences among oiling/treatment classes were moderately significant (p = 0.10). Specific pairwise comparisons were not significant. Data are means ± 1 SE.

Both *S. alterniflora* and *J. roemerianus* were originally present and appeared to be dominant prior to the spill in the heavily oiled plots, based on the composition of the oiled vegetation mats and the intact vegetation landward of the plots (based on review of earlier plot photos). Therefore, the pre-spill vegetation composition in the heavily oiled plots was likely similar to the reference area. The observed difference in marsh species composition in the oiled controls and mechanical treatment plots without planting may have been a result of several factors: the nearly complete vegetation dieback resulting from heavy oiling, differing sensitivities to oiling and disturbance among plant species, and initial plant re-colonization during a time of lower salinities associated with freshwater diversion enacted in reaction to the spill (Bianchi *et al*. 2011). In addition, planting appears to have had an obvious positive effect on vegetation cover and dominance by *S. alterniflora*.

Lack of *J. roemerianus* recovery in heavily oiled areas is consistent with prior *Deepwater Horizon* studies (Lin and Mendelssohn 2012). *J. roemerianus* is highly sensitive to oiling, perhaps more so than *S. alterniflora,* and may be one of the slowest species to recover from oiling or disturbance in general (Lin and Mendelssohn 2009, 2012; Anderson and Hess 2012; Michel and Rutherford 2013). The lack of *J. roemerianus* in the heavily oiled plots three years

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following initial oiling and two years following cleanup indicates that recovery for this species may lag substantially behind that of *S. alterniflora*.

Though not a typical salt marsh species, *P. vaginatum* can be a disturbance-associated coastal marsh species, displaying increased cover values and dominance following various sources of marsh disturbance (Shiflet 1963, Miller *et al*. 2005, Bhattacharjee *et al*. 2007). This species may have been able to colonize impacted areas due to unvegetated substrates resulting from the oil spill and lower salinities resulting from freshwater diversion during the spill. Although *P. vaginatum* is providing some vegetation cover in impacted areas, its presence and even dominance in some areas is not indicative of desirable marsh conditions or vegetation recovery. Over time, it is expected that the abundance of *P. vaginatum* in the study area will decline with replacement by vegetation more characteristic of salt marsh habitats.

Overall, two years following cleanup, mechanical treatment alone did not appear to improve vegetation recovery in terms of cover or species composition relative to the oiled controls (neither of which were approaching reference conditions). However, mechanical treatment coupled with planting was effective, resulting in vegetation cover and plant species composition similar to the reference plots.

## Marsh periwinkles

Total marsh periwinkle (*L. irrorata*) densities in the heavily oiled plots were well below reference values across all oiling/treatment classes (2-12% of reference, Figure 7).

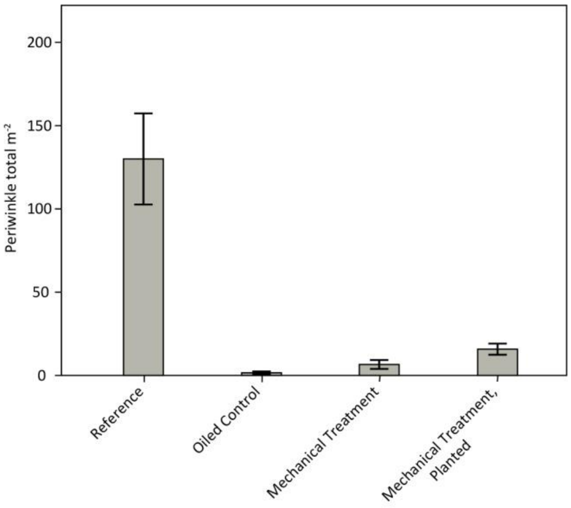

**Figure 7**. Total marsh periwinkle (*Littoraria irrorata*) densities. Differences among oiling/treatment classes were observed ($p < 0.01$). Specific pairwise comparisons were significant for reference versus all other classes; and for mechanical treatment with planting versus oiled control (all $p \leq 0.05$). Data are means ± 1 SE.

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These results are similar to other *Deepwater Horizon* studies, including those from this study site in previous years (Silliman *et al.* 2012, Zengel and Michel 2013, Zengel *et al*. 2014), indicating continuing marsh periwinkle impacts more than three years following initial oiling. In addition, though still low, snail densities in the mechanical treatment plots with planting exceeded those for the oiled controls (densities were intermediate for mechanical treatment without planting), perhaps indicating signs of initial recovery with treatment and planting. Periwinkle size frequency histograms (Figure 8) showed a relatively typical distribution of juveniles, sub-adults, and adults for the reference plots, compared to very low numbers of snails across all life-history stages in the heavily oiled plots without planting. Distinct peaks of sub-adult and adult snails were observed in the mechanical treatment plots with planting, similar in shape though muted in comparison to the histogram for the reference plots. There were also larger numbers of sub-adults relative to adults in the planted plots. These observations point to an impacted population which may be in the process of recovering, though only in the planted areas. Similar patterns of periwinkle population recovery have been documented during other oil spills (Lee *et al*. 1981, Krebs and Tanner 1981).

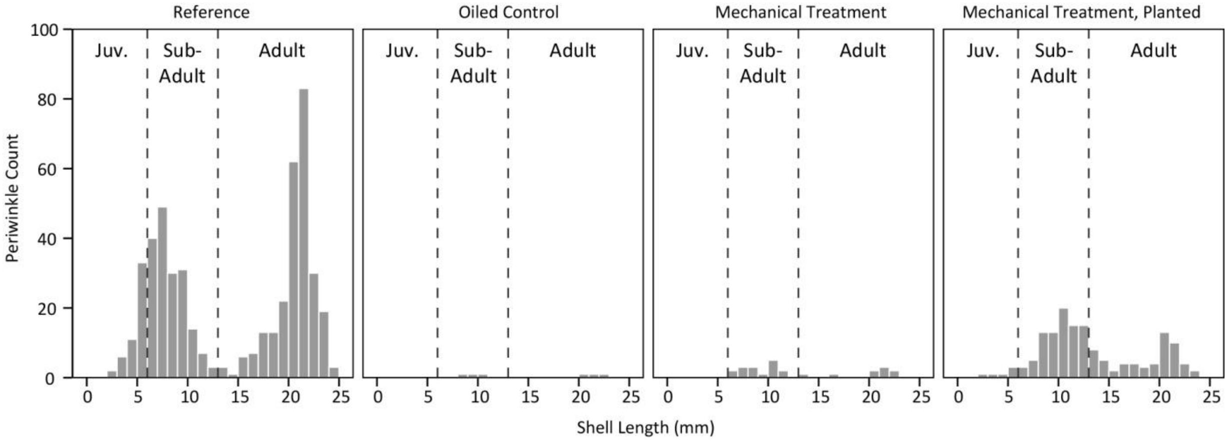

**Figure 8**. Marsh periwinkle shell length frequencies among oiling/treatment classes. Periwinkle life-history size classes defined as juveniles (<6 mm), sub-adults (6-13 mm), and adults (>13 mm).

Marsh periwinkles are closely associated with the dominant salt marsh vegetation, particularly *S. alterniflora*. For example, Kiehn and Morris (2009) reported that marsh periwinkle presence and density were positively correlated with *S. alterniflora* stem density. Similarly, Stagg and Mendelssohn (2012) found that marsh periwinkle growth, survival, and productivity were positively correlated with *S. alterniflora* cover in a sediment-restored salt marsh in Louisiana. Therefore, recovery of marsh periwinkles in the heavily oiled plots may be tied to the recovery of *S. alterniflora*, though residual oiling levels on the sediment surface could also be a factor. Marsh periwinkle recovery, including density and population structure, may still lag *S. alterniflora* recovery for several years once conditions are suitable to support recruitment and survival of juvenile snails, growth to maturity, reproduction, and possible supplemental immigration of sub-adults and adults from adjacent areas.

## Fiddler crabs

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Crab burrow densities (mainly fiddler crabs, *Uca* spp.) were relatively low across all oiling/treatment classes, including the reference plots (Figure 9), compared to other studies at this location and elsewhere in Louisiana (Mouton and Felder 1996, McCall and Pennings 2012, Zengel and Michel 2013, Zengel *et al*. 2014). However, values were still higher for the reference plots compared to the heavily oiled plots (18-55% of reference). The main statistical difference was between the reference plots and mechanical treatment plots without planting. The treated plots with planting had intermediate burrow density, perhaps indicating a positive influence of planting. However, during the capture of fiddler crabs for species identifications, more crabs were documented in the reference plots compared to the heavily oiled plots, regardless of treatment or planting (Figure 10), indicating possible continuing impacts for fiddler crabs in the study area.

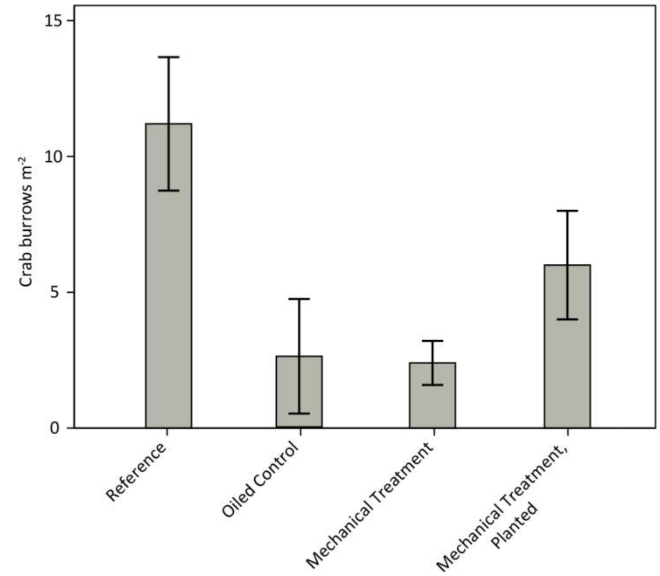

**Figure 9**. Crab burrow densities (mainly *Uca* spp.). Differences among oiling/treatment classes were observed (p = 0.05). Specific pairwise comparisons were significant for reference versus mechanical treatment without planting (p = 0.05). Data are means ± 1 SE.

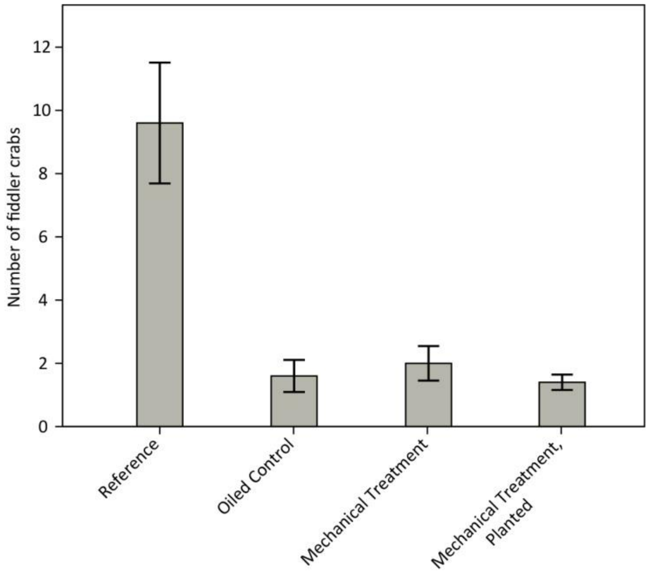

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**Figure 10**. Number of fiddler crabs (*Uca* spp.) captured per plot. Differences among oiling/treatment classes were observed ($p = 0.01$). Specific pairwise comparisons were significant to moderately significant for reference versus all other classes (all $p \leq 0.08$). Data are means ± 1 SE.

Fiddler crab species composition also points to other differences in the heavily oiled plots that were not planted (Figure 11). Gulf marsh fiddler crabs (*Uca longisignalis*) were 100% dominant in the reference and mechanically treated plots with planting, whereas the oiled control and mechanically treated plots without planting had relative compositions of 50-79% spined fiddler crabs (*Uca spinicarpa*) and 21-50% *U. longisignalis*. Oiling and associated habitat alterations may have led to these differences. *U. longisignalis* typically dominates vegetated salt marsh sites in Louisiana, whereas *U. spinicarpa* dominates clay banks with sparse vegetation (Mouton and Felder 1996). Where the two species co-occur in salt marsh sites, *U. longisignalis* is dominant and *U. spinicarpa* is typically restricted to the seaward marsh edge, comprising ≤10% of the population (Mouton and Felder 1996). Reduced vegetation cover coupled with greater areas of surface oil residue, often overlaid with a thin algal mat and a veneer of fine clay sediments, may have led to greater relative abundance of *U. spinicarpa* in the oiled control and mechanical treatment plots without planting. During sampling, *U. spinicarpa* were usually captured from burrows in sparsely vegetated areas with surface oil residue on the substrate.

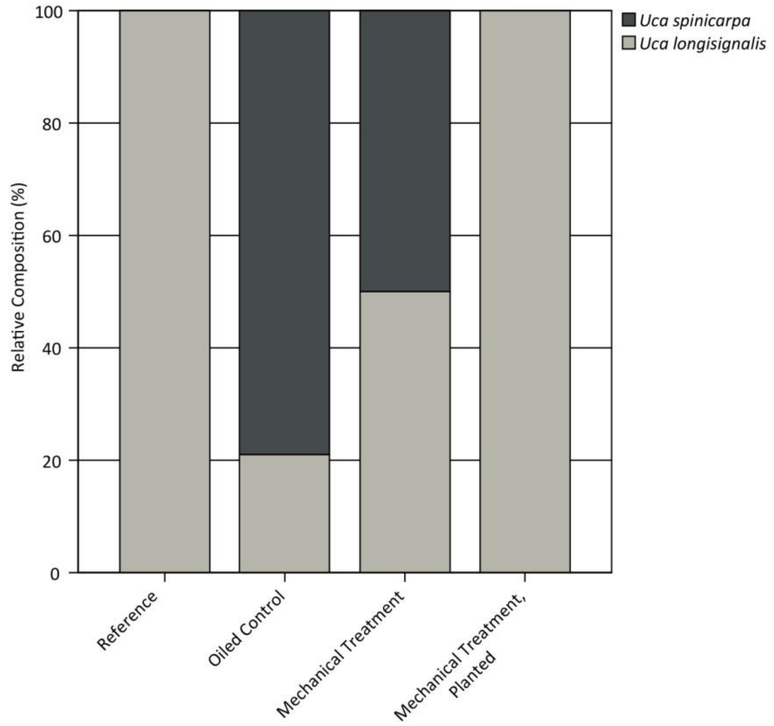

**Figure 11**. Fiddler crab species composition among oiling/treatment classes.

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Impacts to fiddler crabs, as well as signs of recovery, have been reported in previous *Deepwater Horizon* studies, including those in this same study site in prior years (McCall and Pennings 2012, Zengel and Michel 2013, Zengel *et al*. 2014). Unique in this case is the possible positive role of vegetation planting on both burrow density and species composition (but not fiddler crab abundance). As with marsh periwinkles, the return of fiddler crab burrow density, abundance, and species composition to reference conditions may be linked in part to vegetation recovery, though some aspects of fiddler crab recovery may lag the re-establishment of *S. alterniflora* as well.

## CONCLUSIONS:

1) Heavy residual oiling remained in the initial heavily oiled plots more than three years post-spill, including plots with remediation treatments, contrasting with no visual oiling in the adjacent reference plots. However, mechanical treatment, and especially mechanical treatment combined with *S. alterniflora* planting, improved oiling conditions relative to the oiled controls.

2) Vegetation recovery was limited in the oiled controls and mechanical treatment plots without planting. However, mechanical treatment with planting improved vegetation recovery in terms of plant cover and species composition, including *S. alterniflora* dominance. Vegetation characteristics in the mechanical treatment plots with planting were very similar to the reference plots, with the exception of the absence of *J. roemerianus*.

3) Macroinvertebrate recovery was variable but limited in the heavily oiled plots and may lag the return of *S. alterniflora* by several years. Marsh periwinkles in particular showed little recovery more than three years following oiling, though initial signs of recovery may have been observed for the mechanical treatment plots with planting. Periwinkle recovery may especially lag the re-establishment of *S. alterniflora*.

4) Though more subtle, fiddler crab impacts were observed for the heavily oiled plots as well. Improved recovery was indicated for the mechanical treatment plots with planting, for both fiddler crab burrow density and species composition, but not fiddler crab abundance. Fiddler crab species composition differed from reference in both the oiled controls and mechanically treated plots without planting, likely due to sparser vegetation and remaining surface oil residue.

5) Based on the findings of this study, vegetation planting with the appropriate plant species should be considered as a spill response and emergency restoration option for heavily oiled salt marshes where: vegetation impacts are substantial, natural recovery may be lacking or delayed, intensive cleanup treatments are used, or where marsh shorelines are at high risk of erosion. Although planting may enhance ecological recovery, full recovery may still lag the return of vegetation cover.

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