# NOAA Technical Memorandum:

# Plant Oiling Exposure and Injury Quantification for Louisiana Mainland Herbaceous Saltmarsh

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## Introduction

On April 20, 2010, an explosion aboard the Deepwater Horizon (DWH), a mobile, offshore Macondo prospect (Mississippi Canyon 252 or MC252) oil drilling rig, caused the largest and most prolonged offshore oil spill in United States history (NCDHSOD , 2010; NOAA, 2012). In all, more than 2,000 kilometers (km) of vegetated and un-vegetated shoreline in the northern Gulf of Mexico (GOM) were reported as oiled (Nixon *et al.*, 2015; Michel *et al.*, 2013). This technical memorandum describes the methods used to quantify both exposure and injury to Louisiana mainland herbaceous salt marsh shorelines, and presents the results of this quantification.

## Methods

We used plot-level plant community metrics and oiling data collected by the Coastal Wetland Vegetation (CWV) sampling plan (Hester and Willis, 2010) as part of the Natural Resource Damage Assessment (NRDA) and subsequent detailed analysis of these data (Hester *et al.*, 2015) to evaluate injury to mainland herbaceous marshes in Louisiana by plant oiling class. We combined these estimated injuries with a synoptic shoreline oiling exposure database compiled to document the linear extent of observed oiling along all shorelines (Nixon *et al.*, 2015) to estimate the total lengths of mainland herbaceous marsh shoreline in Louisiana exposed to the different levels of plant oiling. Because the CWV sites were selected based upon a stratified random sampling design from a larger set of sites previously investigated as part of the NRDA Pre-assessment (PA) data collection effort (DWH NRDA, 2010a ), it was necessary to account for this sampling design before computing length estimates. Additionally, we also included estimates of the length of shoreline not documented as oiled in the shoreline oiling exposure database, but where plant oiling actually occurred. Sections below describe in more detail the field data collection of CWV data, analyses of those data to evaluate injury by plant oiling class, and estimation of the lengths of shoreline in different plant oiling classes.

### Field Data Collection

Between May and September 2010, the NRDA Pre-assessment (PA) program collected shoreline and plant oiling data at 2,779 locations along the coastline of the northern GOM from Rollover Lake, Louisiana to Apalachee Bay, Florida (DWH NRDA, 2010a). The compiled information included observations of plant species, height of dominant vegetation, sediment oiling, and length of oiled portions of plant stems. At each site, the oiled proportion of plant stems was computed as percent of average vegetation height. To evaluate plant injury in greater detail, the Coastal Wetland Vegetation (CWV) sampling plan (Hester and Willis, 2010) was subsequently developed for Louisiana in the fall of 2010. This effort involved a statistically-balanced, stratified random sample (Cochran, 1977) wherein the large number of PA sites along coastal wetland shorelines described above were divided into 20 strata according to five classes of plant stem oiling and four habitat types and each stratum was then randomly sampled. Plant stem oiling classes used to describe plant oiling during the PA survey included: 1) 0-0%, which served as the reference condition; 2) 0-10% (or trace-10%); 3) 10-50%; 4) 50-90%; and 5) 90-100%. The habitat types included: 1) mainland herbaceous salt marsh; 2) back barrier herbaceous salt marsh; 3) coastal mangrove marsh; and 4) Delta *phragmite*s marsh. In total, 188 CWV sites were surveyed across the across all strata. Data collected at 78 sites established along mainland herbaceous salt marshes in Louisiana are used to estimate injury described here. The locations of all CWV sites along mainland herbaceous salt marshes in Louisiana are depicted in Figure 1, as well as other CWV sites and

PA sites. Injury to other habitats and mainland herbaceous salt marshes in other states are dealt with separately and not addressed here. Louisiana mainland herbaceous salt marsh sites were repeatedly surveyed during fall 2010, spring 2011, fall 2011, fall 2012, and fall 2013.

A transect was established at each CWV site, with three sampling locations along this transect representing edge and interior exposure zones. The center of the edge (or Zone 1) was located 1.5 m inland from the shoreline, the center of Zone 2 was located inland of the shoreline at 50% of the transect length, and the center of Zone 3 was located inland of the shoreline at 80% of the transect length, with a minimum of a 1 m buffer maintained between zones (Hester and Willis, 2010). Each zone contained one observation ("cover") and one sampling ("productivity") plot. The initial transect length for the reference (0-0% plant oiling) Louisiana mainland herbaceous salt marsh sites was set at 20 m with three (3) zones. However, at oiled sites, the maximum observed oil penetration into the vegetation was used to establish initial transect lengths (Hester *et al.*, 2015). During each survey, numerous measures of vegetative cover, habitat composition, physiological health, plant productivity, soil properties, soil chemistry, plant oiling and elevation/erosion were measured or recorded at each un-eroded zone across all sites. Hester and Willis (2010) and Hester *et al.* (2015) provide detailed descriptions of metrics recorded and methods used.

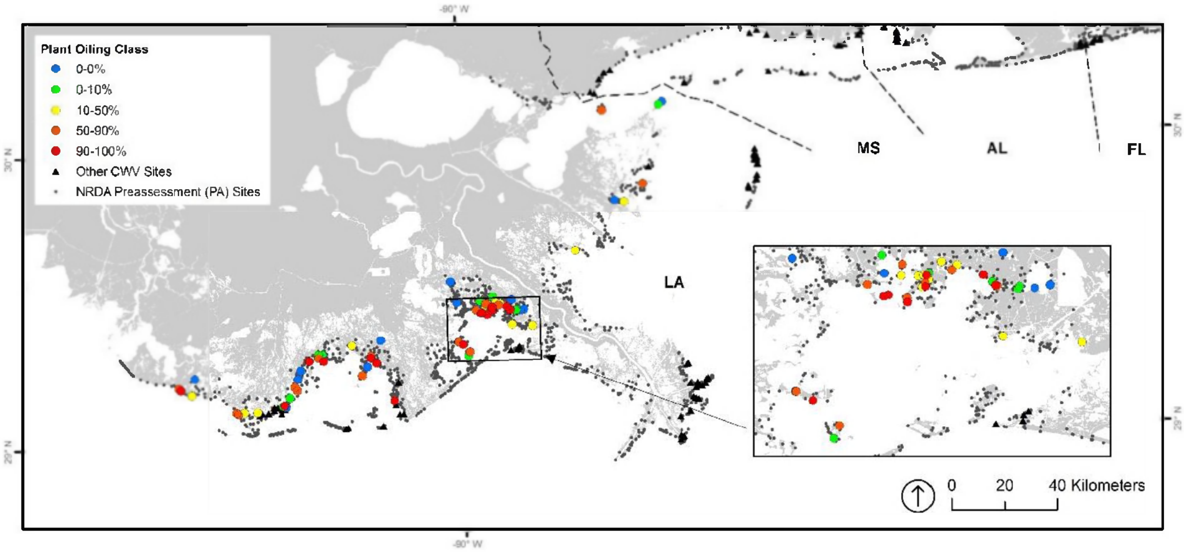


**FIGURE 1.** CWV sites along mainland herbaceous marsh shorelines in Louisiana by PA plant oiling classes. Also shown are PA sites from which CWV sites were selected, and CWV sites outside Louisiana and in non-mainland herbaceous marsh habitats.

## Injury Estimation

Hester *et al.* (2015) describe the methods used to evaluate injury to the plant productivity and health of Louisiana salt marshes exposed to oiling in detail. We use a subset of their results here. Briefly, the authors computed coastal wetland vegetation injury in terms of live cover and above-ground live biomass losses. At all intact or partially eroded zones of each site, live cover was measured as the percent of the 1 m by 1 m cover plot containing live vegetation. The productivity plots of all zones were divided into eight (8) 0.25 m by 0.25 m sections. During each survey, one section of the productivity plot was randomly chosen for destructive sampling. On subsequent surveys, sections were randomly selected from those not previously sampled. Standing vegetation from the chosen section was clipped for laboratory measurement of the live above ground biomass. To account for seasonal and basin-wide variations, each reported live cover and above-ground biomass value was converted into the percent of the corresponding state-, basin-, survey-, and zone-specific average reference values. The computed survey-, site-, and zone-specific injuries were then weight-averaged over all zones at each site in accordance to the un-eroded zone widths at that site in order to generate survey- and site-specific injury values. Resulting negative values were treated as no-injury zero entries.

## Plant Oiling Exposure Quantification

Because the CWV sites were sampled from a frame consisting of all PA sites, it was necessary to reconcile the sampling design of the CWV study with the universe of all possible impacted shorelines as estimated in the shoreline oiling exposure database compiled by Nixon *et al.* (2015). We classified each of the larger set of PA sites by the marsh oiling exposure category of the nearest shoreline segment in the linear shoreline oiling exposure database. We then computed the proportions of all PA sample points by both summer 2010 plant oiling class (henceforth "PA plant oiling class") from the PA data and adjacent shoreline oiling exposure category from the shoreline oiling exposure database. Some sites with no observed plant oiling class in the PA data (0-0% plant oiling) were located along shorelines that were documented as oiled in the shoreline oiling exposure database (Nixon *et al.*, 2015). This is due to the inclusion of both sediment surface and subsurface oiling (as distinct from oiling in the vegetation canopy), as well as the aggregation of potentially patchy alongshore oiling conditions into homogenous linear zones in the shoreline oiling exposure database.

Also, a number of PA sample sites where plant oiling was observed were located adjacent to shorelines were no oiling was documented in the shoreline oiling exposure database. This could have been because a given oiled shoreline location was surveyed by Shoreline Cleanup Assessment Technique (SCAT) or Rapid Assessment (RA) teams prior to or after when oil was actually present on the shoreline, or that oil was present at the time of survey but was not detected by SCAT or RA field teams. To estimate the amount of shoreline that was not documented as oiled in the in the shoreline oiling exposure database, but where plant oiling actually occurred, we compiled all available point-based data sets that could have potentially included manifestations of DWH shoreline oiling, These data included the PA data (DWH NRDA, 2010a), as well as all stranded oil, soil, sediment, and tissue sample locations where the sample in question had been subjected to forensic PAH and biomarker analyses and categorized as either Match A (consistent with MC252 oil) or Match B (probably MC252 oil with some background material present) (Emsbo-Mattingly,. 2015; Rouhani *et al.*, 2015). From this compiled data set of 3,776 point-based oiling manifestations, we extracted all locations within 100 m of the shoreline as represented in the linear oiling exposure database, and selected those that were adjacent to NOO shorelines – termed "unmatched" oiling manifestations. We then aggregated all unmatched oiling manifestations that were coincident. This was necessary to account for oiling manifestations that were so close together (< 1 m) as to functionally represent the same alongshore location. This often occurred where multiple sediment samples were taken from the same plot, and were stored as separate points in the compiled oiling manifestation data set.

We assumed that these oiling manifestation locations are each representative of some unknown length of oiled shoreline, constrained by the total contiguous length of adjacent unoiled shoreline. For example, an oiling manifestation along the shoreline of an island could only represent a maximum length of undetected oiled shoreline equal to the length of the shoreline of the island. Similarly, an oiling manifestation along a length of shoreline between two disjoint lengths of oiled shoreline could only represent a maximum length of undetected oiled shoreline equal to the length of that unoiled portion. From the shoreline oiling database, we extracted and merged all contiguous unoiled shoreline segments coincident with the oiling manifestation locations.

The primary sources of synoptic non-point based surface shoreline oiling information are the SCAT data and observational surface oiling dataset collected by the RA as part of the cooperative NRDA (DWH NRDA, 2010a; Michel *et al.*, 2013; NOAA, 2010a, 2010b, 2013). In both data collection efforts, surface oiling conditions are documented via linear “zones” with consistent surface substrate or vegetation canopy oiling and other characteristics defined along specific alongshore extents of the shoreline. We compiled and summarized the lengths of all 5,941 observed linear shoreline oiling zones in the SCAT and RA datasets that were used to compile the shoreline oiling exposure database in mainland herbaceous marshes (Figure 2) which ranged from less than 1 to 9,874 m. The average length of all individual oiled zones in mainland herbaceous marshes was 408 m.

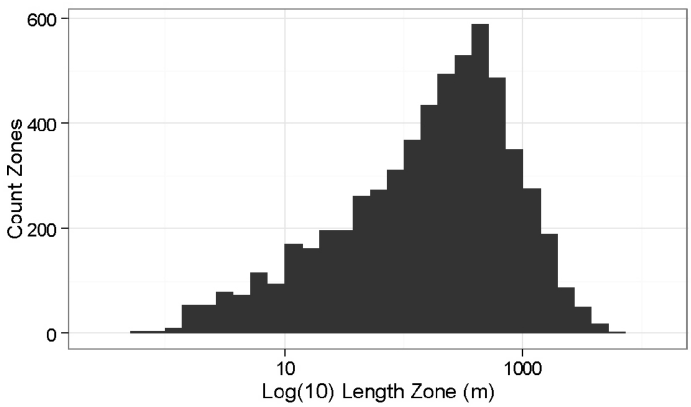


**FIGURE 2.** Histogram of log alongshore length (m) of all individual oiled zones recorded in the SCAT and RA datasets along mainland herbaceous marsh shorelines.

We then buffered each unmatched manifestation location by 204 m (yielding circular polygons with a diameter of 408 m), and extracted all shoreline from the coincident contiguous unoiled shoreline segments within these buffers. These shoreline segments are considered as estimates of the location and amount of unobserved shoreline oiling (termed “NOOx”). As a final step, we computed the length of shorelines in each plant oiling class as the sum product of the total length of oiled mainland herbaceous marsh shoreline in each oiling exposure category (heavier persistent, heavier, and lighter), as well as the amount of unobserved shoreline oiling (NOOx) as estimated above, and the corresponding proportion of summer 2010 PA plant oiling classes.

## Results and Discussion

Across-shore penetration widths of oil into the marsh observed at the CWV sites upon which transect lengths are based varied from 2.9 to 30.0 m (Table 1). While penetration width is not perfectly related to plant oiling class, the highest average penetration widths were observed at heavily oiled sites with 90-100% plant oiling, and lower plant oiling classes generally had smaller average penetration widths.

**TABLE 1.** Oil penetration widths in m for Louisiana mainland herbaceous salt marsh as measured by initial transect lengths by summer 2010 PA plant oiling class.

| PA Plant Oiling Class | Count | Average | Standard Deviation | Min | Max |
|---|---|---|---|---|---|
| 90-100% | 15 | 17.2 | 8.6 | 4.5 | 30.0 |
| 50-90% | 16 | 11.5 | 7.0 | 2.9 | 20.0 |
| 10-50% | 18 | 13.1 | 9.6 | 3.0 | 30.0 |
| 0-10% | 13 | 8.7 | 6.6 | 3.0 | 24.4 |

The average injury of each group, reported as percent change relative to reference conditions, is listed in Table 2. Seasons with maximum injuries for each specific PA plant oiling class are highlighted. Note that these values are weighted averages over all zones for all sites in each plant oiling class. In general, the injuries display declining trends, although sporadic increases in injury were computed in the fall of 2011 and 2012. These fluctuations can be attributed to the smaller sample sizes of CWV sites caused by erosion. These sites have experienced total and partial erosion since the start of the surveys in fall of 2010. As a result, many plots, especially those along the marsh edge, have been lost to erosion. For such plots, live cover and above-ground biomass were not measured and treated as missing values.

**TABLE 2.** Injury to wetland vegetation as a weighted average across all zones of percent reduction in live cover and live aboveground biomass (AGB) relative to seasonal and basin specific reference values for Louisiana mainland herbaceous CWV sites for each survey. Maximum values for each PA plant oiling class are highlighted.

| Survey | PA Plant Oil Class | Live Cover (Avg % change relative to reference) | Live AGB (Avg % change relative to reference condition) |
|---|---|---|---|
| **Fall 2010** | 90-100% | 29.9 | 38.6 |
| | 50-90% | 35.8 | 53.2 |
| | 10-50% | 15.3 | 10.6 |
| | 0-10% | 21.9 | 25.6 |
| **Spring 2011** | 90-100% | 26.5 | Not sampled |
| | 50-90% | 26.0 | |
| | 10-50% | 5.8 | |
| | 0-10% | 21.1 | |
| **Fall 2011** | 90-100% | 20.6 | 49.8 |
| | 50-90% | 37.7 | 40.7 |
| | 10-50% | 14.4 | 7.6 |
| | 0-10% | 10.3 | 0.0 |
| **Fall 2012** | 90-100% | 41.1 | 42.2 |
| | 50-90% | 0.0 | 0.0 |
| | 10-50% | 0.0 | 0.0 |
| | 0-10% | 42.4 | 35.7 |
| **Fall 2013** | 90-100% | 8.6 | 14.9 |
| | 50-90% | 0.0 | 32.9 |
| | 10-50% | 0.0 | 1.9 |
| | 0-10% | 13.9 | 0.0 |

The declining injury trends are generally consistent with the recovery periods observed during previous oil spills in marshes, as documented by Michel and Rutherford (2014), though the CWV data are not sufficient to directly measure recovery in heavily oiled areas (Hester *et al.*, 2015). Recovery periods for plant oiling classes of less than 50% are expected to be 2 years, while higher levels of plant oiling may require recovery periods of 8 or more years (Michel, 2015). The longer expected recovery period for the higher oiling classes is based on case studies of oiled marshes in colder climates where the oil occurred as thick residues on the marsh surface, where recovery times could exceed 30 years (Michel and Rutherford, 2013). However, even heavily oiled marshes in warmer climates recover sooner, in less than 10 years. As such, for the more heavily oiled marshes in Louisiana, a recovery period of eight years is expected, based on the combination of a warmer climate, an oil that was highly weathered prior to stranding, and careful treatment to remove the thick oil on the surface.

Of the 3,776 point-based MC-252 shoreline oil manifestation locations, we identified 433 unique unmatched oiling manifestation alongshore locations adjacent to NOO shorelines (Figure 3).

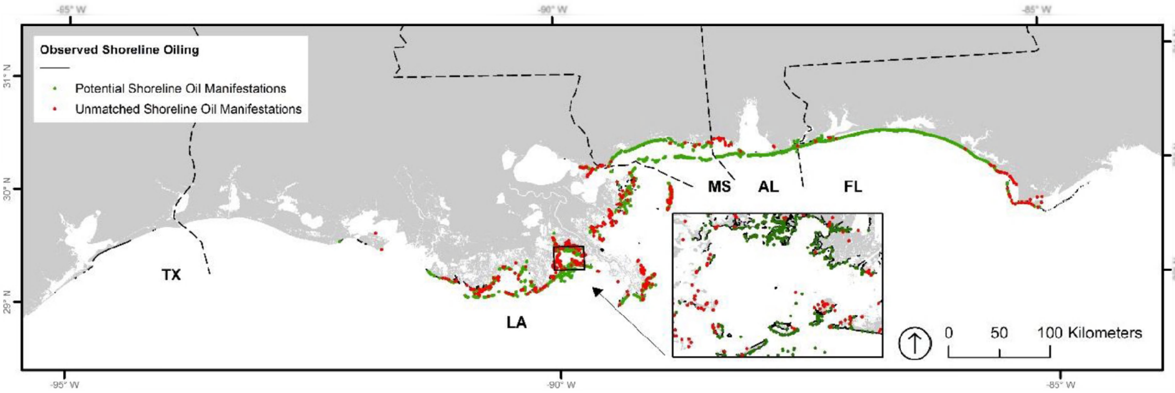


**FIGURE 3.** Maps of all compiled potential shoreline oiling manifestations (3,776) and unmatched manifestations within 100 m of the shoreline but adjacent to NOO shorelines (433).

Using these locations, we identified 99 km of mainland herbaceous marsh shoreline in Louisiana (NOOx) where oiling likely occurred, but where this oiling was not documented in the shoreline oiling exposure database (Figure 4). Proportions of all PA sample points in mainland herbaceous marshes in Louisiana by PA plant oiling class and adjacent shoreline oiling exposure category from the shoreline oiling exposure database are presented in Table 3, as well as the resulting length estimates by plant oiling class. Generally, heavier shoreline exposure categories are associated with larger proportion of PA sites with higher plant oiling categories. Sites located along shoreline categorized as lighter oiling and unobserved oiled shorelines (NOOx) were proportionally similar in terms of PA plant oiling class.

The total estimated length of mainland herbaceous marsh shoreline in Louisiana with plant oiling presented here (563 km) is different from the estimates in Nixon *et al.* (2015) due to several factors. Firstly, these estimates include the 99 km of NOOx shoreline where oiling likely occurred, but where this oiling was not documented in the shoreline oiling exposure database. Secondly, roughly 31% of the length of mainland herbaceous marsh shoreline in Louisiana documented as oiled in the shoreline oiling exposure database is estimated to have had no observed plant oiling (0-0% plant oiling).

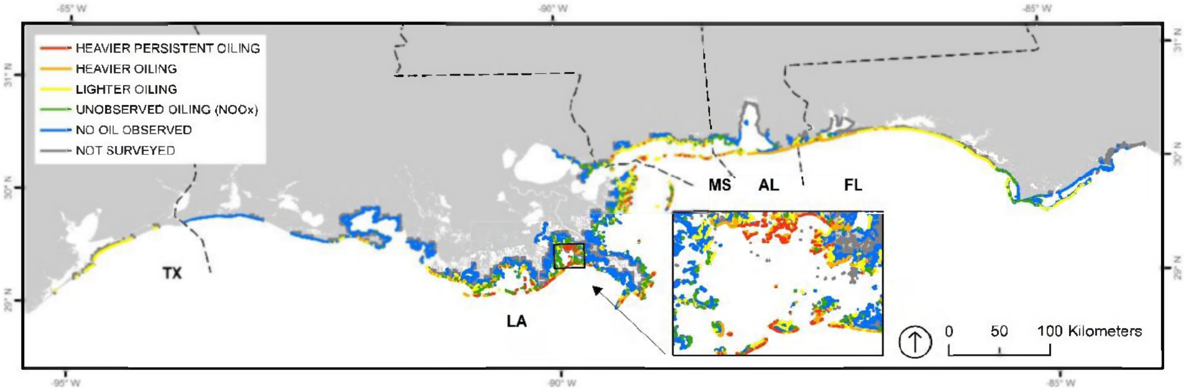


**FIGURE 4.** Maps of shorelines by oil exposure categories for wetland and other shoreline habitats, as well as estimated locations of additional shoreline oiling not documented in the shoreline exposure database (NOOx).

**Table 3.** Proportion of PA sites in each plant oiling class by shoreline oiling exposure category, total length (km and miles) of oiled mainland herbaceous shorelines in Louisiana for each shoreline oiling class, and resultant shoreline lengths in km (and miles) in each plant oiling class. All shoreline lengths rounded to nearest whole km or mile.

| **Shoreline Exposure Category** | **Total length km - (mi)** | **Proportion of PA sites in each plant oiling class by shoreline oiling exposure category** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **0-0%** | **0-10%** | **10-50%** | **50-90%** | **90-100%** | **All plant oiling > 0%** |
| Heavier Persistent | 62 (39) | 7% | 4% | 30% | 30% | 30% | 93% |
| Heavier Oiling | 187 (116) | 29% | 12% | 32% | 16% | 11% | 71% |
| Lighter Oiling | 571 (354) | 47% | 12% | 24% | 12% | 6% | 53% |
| NOOx | 99 (61) | 27% | 27% | 32% | 9% | 5% | 73% |
| Proportion all sites | - | 33% | 14% | 29% | 15% | 10% | 66% |
| **Length - km (miles)** | **919 (570)** | **355 (220)** | 117 (73) | 245 (152) | 125 (78) | 76 (47) | **563 (350)** |

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