TECHNICAL MEMORANDUM

SUBJECT: Development of Oyster Nearshore Injury Quantification

DATE: September 9, 2015

TO: Mary Baker, NOAA

FROM: Henry Roman, IEc

INTRODUCTION

Oil and onshore response activities from the Deepwater Horizon (DWH) spill led to mortality impacts in the nearshore zone that affected oysters of all sizes – spat (<25 millimeters (mm)), seed (between 25 and 75 mm), and market (>75 mm) (Powers et al. 2015). The initial direct injury to oysters in the northern Gulf of Mexico's nearshore environment occurred between the spill in April 2010 and the end of 2011, when the majority of onshore response activities ended. Additional injury to nearshore oysters occurred from 2011-2015 due to the loss of substrate for new recruits' settlement. The loss of oyster habitat fringing vegetated marsh demonstrably increased marsh erosion from 2010-2013. This technical memo describes the process by which we quantified the loss of nearshore oysters in the initial injury years and out-years across the study area, and the calculation of marsh erosion attributable to fringing reef loss. The following calculations support Dr. Powers' et al. "Loss of oysters as a result of the Deepwater Horizon Oil Spill degrades nearshore ecosystems and disrupts facilitation between oysters and marshes" as well as Dr. J. Grabowski's, "*Oyster Reproductive Injury*" (Powers et al., 2015, Grabowski et al., 2015).

METHODOLOGY AND RESULTS

Oyster habitat percent cover

Based on repeated observations by Response surveys (Shoreline Cleanup and Assessment Technique (SCAT)) and Natural Resource Damage Assessment (NRDA) teams, shorelines along the northern Gulf of Mexico were evaluated using linear shoreline evaluation methods and assigned to one of five shoreline oil exposure classes, each describing a particular pattern of oiling over time (Nixon et al. 2015). For vegetated shorelines, these classes included "heavy persistent oiling" (where heavy or moderate oiling was repeatedly observed over a period of 12 or more weeks between April 2010 and February 2015), "heavy/moderate oiling" (where moderate or heavy oiling persisted for less than 12 weeks), "lighter oiling" and "no oil observed". Trustees conducted field studies in 2012 and 2013 to determine whether percent cover of nearshore oyster habitat and oyster abundance differed as a function of shoreline oiling and cleanup activities (NOAA 2012 and 2013). 187 sites from Terrebonne Bay, Louisiana through Mississippi Sound, Alabama were sampled in 2013 after a pilot effort in 2012. Sites (200 meter (m) stretches of shoreline) were mapped to estimate oyster habitat cover (as indicated by presence of shell substrate in adjacent waters). For the purposes of evaluating nearshore oyster injury, the shoreline oiling categories described in Nixon et al. (2015) were reduced to three: heavy persistent oiling as defined above, oiled, and no oil observed. The heavy/moderate and lighter oiling categories were combined into the "oiled" category to distinguish effects of heavy persistent oiling, such as heavy fouling and smothering, from those sites that experienced more subtle effects of oiling.

Field teams mapped oyster shell and other hard substrate in water adjacent to 200 m of shoreline length at each of 187 sites. Each site was divided into 40 transects (20 on each side of a central location that was randomly chosen 0 to 5 m to the right of site center coordinates). Transects, which ran perpendicular to the shoreline, were 15 to 20 m in length (measured from the end of the vegetation line to offshore), and were spaced 5 m apart. At each sampling site, the transect start location (latitude and longitude) and direction (degrees) were recorded. Field teams cast a Y-shaped metal bar (secured to the end of a fiberglass meter tape) between 15 and 20 m from shore in a direction perpendicular to the shoreline and then slowly pulled it back along the sea floor, feeling for vibrations through the tape that would indicate the interaction of the bar with oyster shell. Transect lengths were measured beginning at the nearest meter mark on the tape. All field teams were trained in areas with known configurations of oyster shell and soft substrate prior to field work (NOAA, 2013).

Substrate along each of the 40 transects at a site was recorded as either type 1 (soft mud), 2 (moderately firm mud, firm mud or sand, and buried shell), or 3 (exposed shell or reef) for each meter of the transect. Each meter of substrate was assessed either by the feel of the implement on the substrate as the bar was pulled back toward the shore or through a combination of feel and visual observation when oysters were clearly visible. Some segments of the transects could not be mapped because the implement could not be thrown to the full 20 m extent due to the presence of a dock or other obstruction or if the field crew could not safely map the transect, for example, due to the presence of a deep channel extending from the shoreline at the transect start. The proportion of type 3 substrate cover, i.e., the percent cover of oyster habitat, for each mapped nearshore site was estimated as the total length (m) identified as type 3 substrate divided by the total length (m) mapped at that site (NOAA, 2013).

The width of the measured zone of oyster habitat from the shoreline is 0.015 kilometers (km) (15 m, as explained above) and the width of the extended zone from the shoreline is 0.050 km. The extended zone to 0.05 km offshore is the area that may contain oyster reef, though it was not mapped in the field; this width is consistent with the nearshore oiling model and is a DWH case-wide value for nearshore injury (Zhang et al. 2015). We calculated a percent cover estimate for 0-15 m offshore based on field measurements for each oiling category: 2.3 percent for the heavy persistent (HPO) category, 6.9 percent for the oiling (O) category, and 10.2 percent for the Reference category. The percent cover estimate for 15.01 - 50 m was determined through two-step process: (1) linear regression of all oiling categories' oyster cover data, to determine the distance from shore at which the oyster cover would decrease to zero (Exhibit 1); (2) linear regression of each oiling category's oyster cover data, including the zero-cover datapoint (x-intercept) from step (1), to determine percent cover to 50 m (Exhibit 2). Calculating the area under the regression curves from 15.01 to 50 m, the cover estimates are 0.52 percent for HPO, 1.6 percent for O and 2.4 percent for the Reference category. We then calculated the difference in percent cover between the Reference oiling category and the oiling and heavier persistent oiling categories, respectively. These difference values represent the loss in oyster habitat cover due to oiling and onshore response activities in areas affected by oiling.

Oyster density

Average oyster density estimates (# oysters/m^2) were determined for each oiling category (HPO, O and Reference) based on site-level nearshore site oiling classifications and field measurement data (Exhibit 3).

Exhibit 1: Simple linear regression of site-level oyster cover across all oiling categories. X-intercept = 36 meters from the shoreline.

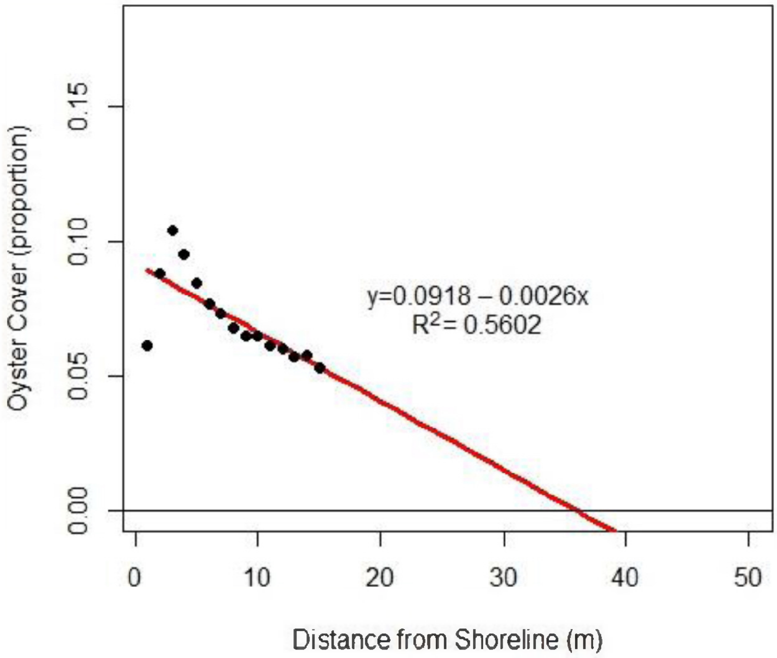

Exhibit 2: Linear regression of site-level oyster cover by oiling category. X-intercepts forced to 36 meters from shore.

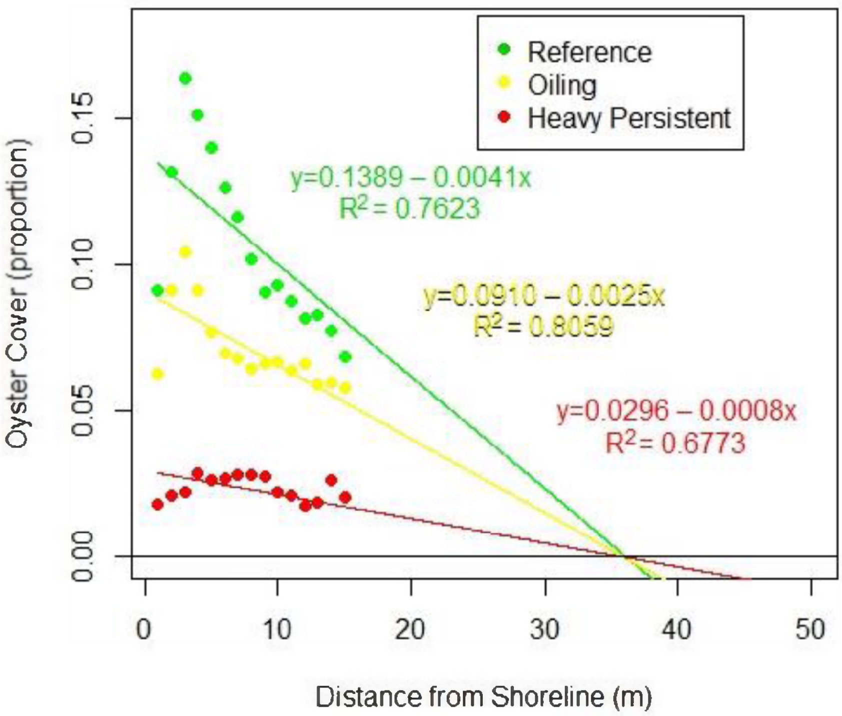

Exhibit 3: Average oyster density by oiling category and oyster size class (# oysters/m^2)

Oiling Category	Average Market Density (#/m^2)	Average Seed Density (#/m^2)	Average Spat Density (#/m^2)
Heavy Persistent	3.65	10.07	2.42
Oiling	3.50	22.08	6.21
Reference	3.29	10.90	3.73

Shoreline distance affected by oiling

Shoreline distance values (km) for each oiling category were obtained from Zach Nixon at RPI, Inc., based on the shoreline length of salt/brackish vegetated marsh within the study area (Nixon et al., 2015). This marsh type comprises probable suitable habitat for oysters in the nearshore environment. Other shoreline categories within the study area, such as intermediate/fresh vegetated marsh, contain relatively less suitable oyster habitat; oysters are known to inhabit intermediate marsh, but fresh marsh conditions are less supportive of oysters (Powers, unpublished data). The distance of shoreline habitat used in this analysis is therefore a conservative estimate of the suitable shoreline habitat available to nearshore oysters in the area of interest.

Injury scaling

Using the oiling category-specific percent cover estimates, oiling category-specific shoreline distances and standard width of the measured zone, we determined the **loss of oyster habitat (acres)** (Exhibit 4). We estimated the loss of oysters (quantity of individuals) in area affected by each oiling category as a function of the lost acres of oyster habitat in each oiling category and the oiling category-specific oyster density measured in NRDA sampling (for each size class). The quantity of lost oysters in each size class was then converted to an estimate of adult equivalent oysters lost; This number is the sum of oysters lost across all size classes, with spat and seed numbers adjusted for the proportion of those oysters that would have been expected to survive to adulthood. The adjustment factors for spat and seed are based on growth and survival factors specific to spat and seed size oysters (Roman and Hollweig, , 2015.). This total market equivalent oyster value represents **the quantity of oysters lost at the end of 2011 due to initial direct injury** (Exhibit 4).

Over their 5 year lifetime, we estimate these oysters would have produced a total of 0.7 million pounds of oyster meat (wet weight). Approximately 40 percent of that total represents an estimate of the weight of the oysters directly killed, and the remaining 60 percent represents additional growth of adult oysters over the rest of their lifespan that did not occur because they were killed.

We also calculated the **annual loss of oyster recruits that occurs due to the loss of substrate**. Oyster larvae require hard substrate for successful settlement the reduction in oyster reef, which represents suitable substrate, associated with the direct nearshore oyster injury is expected to result in reduced recruitment in years following 2011. The annual loss of recruits in affected areas (HPO and O) is a function of the average observed spat and seed density values at Reference sample sites (# oysters/m^2) and the loss of oyster habitat (acres), specific to each oiling category. The annual loss of oyster recruits is calculated for the years 2012 through 2015. These annual values are summed with the loss of oysters at the end of 2011 and presented as Total Oysters Lost and Total Markey Equivalent Oysters Lost in Exhibit 4 (conversion to market equivalents used growth and survival factors specific to spat and seed size oysters from Roman and Hollweig, 2015).

Finally, we determined the **linear shoreline of habitat lost (km)**. This is the estimated distance of Gulf shoreline that would have oyster cover, but for the DWH Oil Spill. If we laid out all lost habitat along the Gulf shoreline within 50m of shore, using Reference percent cover values for the 0-15.0 and 15.01-50 m areas, this is the distance along the shoreline that is now without oyster cover. We estimate this value is 37.2 km for the heavier persistent category and 212.5 km for the oiling category (Exhibit 4).

Exhibit 4: Total oyster habitat, linear shoreline habitat, and oysters lost due to direct injury (2011)

Oiling Category	Oyster Habitat Loss (acres)	Linear Shoreline Habitat Lost (km)	Total Oysters Lost (all sizes)	Total Market Equivalent Oysters Lost	Biomass, lbs wet weight (10^6)
Heavy Persistent	29.0	37.19	2,100,937	1,232,491	0.10
Oiling	165.6	212.49	12,004,996	7,042,596	0.60
Total	194.5	249.7	14,105,933.5	8,275,087	0.70

Marsh erosion associated with lost oyster habitat

A companion NRDA study, the coastal wetland vegetation assessment (CWV), was intended to evaluate the effects of plant stem oiling on plant productivity, cover, and health and shoreline change (Hester et al., *in prep*). 78 of the CWV sites are co-located with nearshore oyster sample sites. CWV sites were classified by degree of oiling on plant stems and by vegetation type. At each site, a transect was established with one to three fixed-location, permanent plot pairs (for observations and destructive sampling). The length of the initial transect was determined by the length of oil penetration into the vegetation, as observed during the pre-assessment survey conducted in the summer of 2010, with a maximum length of 30 m from the intersection of water and vegetation. For reference sites, at which no oil was observed, the default transect length was 20 m. The number of vegetation sampling plots (up to three) and the location of the plots along the transect were determined by transect length. The permanent location of the most shoreward plot pair was established with the shore edge of the plots located one meter from the marsh edge at the time of the first sampling event.

In addition to the plant metrics collected at each plot, observations and measurements of shoreline change were made during each CWV sampling event. The length of the transect was first recorded when sites were established in the fall of 2010 (Louisiana sites) or the spring of 2011 (Mississippi and Alabama sites). At each subsequent survey (Spring 2011, Fall 2011, Fall 2012, Fall 2013), the distance from the inland stake to the marsh edge was measured, and observations of erosion or shoreline change were recorded. GPS coordinates were obtained from the shoreline and inland ends of the transect as well as the lower left corner of each plot (facing inland, the left-hand shoreward corner). Coordinates were generally obtained once per site with a GPS device with sub-meter accuracy (e.g., Trimble GeoXH), typically the first time a site was sampled. Each subsequent time a site was visited, a GPS device such as the Garmin GPSMAP 76 or the Garmin GPSMAP 60 was used (with an estimated accuracy of 3 m). The 78 oyster sites that are co-located with the coastal vegetation sites are used here to extrapolate shoreline change associated with oyster cover loss from the fall of 2010 to the fall of 2013.

Using the 78 co-located sample sites, we calculated the percent of sites within each oiling category that do not have oyster habitat cover (<0.5 percent), based on the 2013 nearshore oyster mapping results. We then compared the percent of sites with no oyster cover between the Reference category and each oiling category (HPO and O), respectively. We multiplied the difference in percent of sites with oyster cover (for HPO or O, individually, compared to Reference) by the oiling category-specific linear shoreline of habitat lost (km); the product is kilometers of shoreline affected by the increased erosion at impacted sites.

Again using the 78 sampled sites, we calculated mean erosion (m) observed over 2010-2013 for two categories: sites with oyster habitat cover (≥0.5 percent) and sites without oyster habitat cover (<0.5 percent) in 2013. We calculated the difference in mean erosion between these two categories; this value represents marsh loss (m marsh per m shoreline) due to lost oyster cover over 2010-2013. We multiplied the marsh loss (m marsh per m shoreline) due to lost oyster cover by each oiling category-specific km of shoreline affected by increased erosion (described in previous paragraph, converted to m for this calculation). This represents the marsh loss in square meters, which was then converted to acres, for areas affected by each HPO and O. Summing the marsh loss of HPO and O areas gives the total marsh loss due to lost oyster reef (acres). The interim and final calculations of lost marsh due to loss of fringing oyster habitat (acres) are presented in Exhibit 5.

Exhibit 5: Marsh erosion due to loss of oyster habitat (2010-2013 total)

Oiling Category	% Sites <0.5% oyster cover	Increase in proportion of <0.5% oyster cover sites vs. Reference	Shoreline affected by increase in proportion of <0.5% oyster cover sites (km)	Marsh loss (m marsh per m shoreline) due to lost oyster cover (2010-2013)	Marsh loss (m^2)	Marsh edge loss (acres)
Heavy Persistent	56%	32%	20.33	4.63	94,075.50	23.25
Oiled	43%	18%	153.44	4.63	709,933.59	175.43
Reference	24%	-	-	-	-	-
					Total marsh edge loss (acres)	198.67

REFERENCES

Grabowski, J.H., S.P. Powers, H. Roman, J. Murray, H.M. Marrison, et al. 2015. Oyster Reproductive Injury. DWH NRDA Oyster Technical Working Group Manuscript.

Hester, M. W., Willis, J. M., Rouhani, S., Steinhoff, M., & Baker, M. (2015). Impacts of the Deepwater Horizon Oil Spill on the Salt Marsh Vegetation of Louisiana. Draft.: DWH Shoreline NRDA Technical Working Group Report.

National Oceanic and Atmospheric Administration (NOAA). 2012. Intertidal Oyster Quadrat Sampling Plan. Workplan.

National Oceanic and Atmospheric Administration (NOAA). 2013. Nearshore Oyster Sampling Plan. Workplan.

Nixon, Z., S. A. Zengel & J. Michel. 2015. Categorization of Shoreline Oiling from the Deepwater Horizon Oil Spill. DWH Shoreline NRDA Technical Working Group Report.

Powers, S.P., S. Rouhani, M.C. Baker, H. Roman, J. Grabowski, S.C. Scyphers, J. Murray, J.M. Willis and M.W. Hester. *In review*. Loss of Oysters as a Result of the Deepwater Horizon Oil Spill Degrades Nearshore Ecosystems and Disrupts Facilitation Between Oysters and Marshes. Ecological Applications.

Roman, H. and T. Hollweg. 2015. Development of Oyster Life Table and Application to Estimate DWH Oyster Injury Metrics. Technical Memo.

Zhang, M., Oehrig, J., and Rouhani, S. 2015. Review of Exposure of Coastal Wetlands to Deepwater Horizon Oil. DWH Shoreline NRDA Technical Working Group Report.