



Abstracts for Oral Presentations

Organized by Track and Session

Gulf Ecology

ECO-001: Role of Microbes in the Response and Resiliency of Gulf Ecosystems

Isotopic Tracers of Petrocarbon Contribution to Pelagic Food Webs in the Gulf of Mexico

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Petrocarbon enters offshore waters of the Gulf of Mexico via many natural seeps as well as occasional accidental releases through human activities (spills). Seeps and spills inject petrocarbon into pelagic ecosystems on very different spatial and temporal scales. Seep inputs are relatively constant but spatially variable, while spills typically inject petrocarbon into offshore ecosystems from point-sources over shorter time scales. We used the stable isotopic contrast between average marine organic matter ($\delta^{13}\text{C} = \text{ca. } -20\text{‰}$) and petrocarbon (oil $\delta^{13}\text{C} = \text{ca. } -27\text{‰}$, methane $\delta^{13}\text{C} = \text{ca. } -57\text{‰}$) as a robust tool for exploring the pathways and mechanisms of assimilation of petrocarbon into both phyto- and zooplankton in offshore waters of the Northern Gulf of Mexico, drawing on annual cruises spanning the time since the Deepwater Horizon spill in 2010. Our measurements provide a multiyear record of the contribution of oil and gas to the planktonic food web in the years following the Deepwater Horizon disaster and provide a measure of petrocarbon penetration into the food web as well as the time-course of recovery of Gulf ecosystems since the spill.

Effect of Crude Oil and Dispersant on the Growth and Grazing Responses of Heterotrophic Dinoflagellate *Oxyrrhis marina* and Ciliate *Euplotes* sp.

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During the Deepwater Horizon oil spill in 2010, an estimated 7.94×10^8 - 1.11×10^9 L of crude oil and approximately 2.9×10^6 L of dispersant (Corexit) were released into the Gulf of Mexico. Exposure to dissolved components of crude oil and dispersant, and consumption of chemically and physically dispersed oil droplets can affect marine planktonic organisms. However, effect of oil pollution on the biology of microzooplankton, one of the important consumers of primary production in the sea, has not been thoroughly studied. We conducted experiments to investigate the influence of crude oil and dispersant on the growth and grazing responses of heterotrophic dinoflagellate *Oxyrrhis marina* and ciliate *Euplotes* sp. In growth response experiments, monocultures of photo-autotrophs *Isochrysis galbana* and *Rhodomonas* sp. and cultures of *O. marina* and *Euplotes* sp. fed with algal prey were exposed to different concentrations of dispersant-treated-crude-oil (DO). The nominal concentrations of DO ranged from $0 \mu\text{L L}^{-1}$ to $30 \mu\text{L L}^{-1}$, with the volume of crude oil to dispersant ratio equaled 20:1. Results show that *O. marina* is relatively resistant to oil pollution than *Euplotes* sp., as reflected by the specific growth rates in control treatment (i.e. $0 \mu\text{L L}^{-1}$ nominal concentration of DO) and DO treatment for both species. In grazing response experiments, four treatments, namely 1) crude-oil-alone; 2)

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dispersant-alone; 3) dispersant-treated-crude-oil (DO); and 4) control, were used in combination with dilution method. Nominal concentration of $10 \mu\text{L L}^{-1}$ crude oil and $0.5 \mu\text{L L}^{-1}$ dispersant was used for predator-prey pair *O. marina* and *I. galbana*, while that of predator-prey pair *Euplotes* sp. and *Rhodomonas* sp. was $3 \mu\text{L L}^{-1}$ crude oil and $0.15 \mu\text{L L}^{-1}$ dispersant. Compared to control treatment, lower grazing coefficients were found in DO and crude-oil-alone treatments for grazer-prey pair *O. marina* and *I. galbana*. It indicates that oil pollution has negative effect on the grazing impact of *O. marina* on algal prey. These results suggest that top down control on primary production by micro-grazers is impaired by oil pollution.

Extracellular Enzyme Activities in a Mesocosm Experiment: Insight into the Microbial World during Deepwater Horizon Oil Spill

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Extracellular enzymes are actively released by microbes in response to the available carbon and nitrogen sources in the environment. The activities of these enzymes vary depending on the type and concentration of carbon and nitrogen source. The 2010 Deepwater Horizon (Deepwater Horizon) oil spill introduced 4.9 million barrels of oil into the Gulf of Mexico, thus providing copious amount of carbon in the form of hydrocarbons. However, how this might have impacted the microbial process is still not clearly understood, particularly in surface waters. Enzyme activity measurements were carried in mesocosm experiments in water accommodated fraction of oil (WAF) and dilute chemically enhanced water accommodated fraction of oil (DCEWAF). A linear relationship between the oil degrading enzyme lipase and estimated oil equivalents was found. A diauxic (dual phase) growth pattern in the microbial community was observed in the WAF treatment, with oil acting as the carbon source in the first phase and exopolymeric substance (EPS) providing the carbon during the second phase. However, the DCEWAF treatment showed a more complex growth pattern, perhaps due to the presence of several components in Corexit, providing a mixture of carbon sources in addition to oil and EPS. Isolation of Corexit degrading bacteria from DCEWAF treatment further supports this finding. Moreover, microbial community and CDOM by PARAFAC analysis are underway to complement our results and provide a greater insight into the microbial process during the Deepwater Horizon oil spill; initial results will be presented.

Deepwater Coral-Associated Microbial Communities in the Gulf of Mexico are Species-specific and Include Sulfur-oxidizing Taxa

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Deep-sea coral communities occur throughout the Northern Gulf of Mexico including near cold seeps that release oil, gas, and hydrogen sulfide. This chemical environment may shape the microbial community associated with corals. Similar to their role in shallow water corals, microbes may provide specific functions to deep-sea corals ranging from disease resistance to nitrogen cycling. Thus, understanding this role is particularly important for coral communities that were acutely impacted by the Deepwater Horizon oil spill. To characterize the deep-sea coral-associated microbial community in relation to active seepage, we collected over 12 species of corals and sediment from across the

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Northern Gulf of Mexico for 16S tag sequencing. Among the corals sampled were *Callogorgia delta* growing near and far from active seepage. Microbial communities were coral specific and differed from the sediment. Many related microbes were shared among coral species including taxa in the genera *Endozoicomonas* and *Alteromonas*. Close relatives of two sulfide-oxidizing symbionts of *Bathymodiolus* spp. were associated with corals from lease blocks with active seepage: members of a large symbiotic clade of SUP05 were abundant in three species and epsilon-proteobacteria within a newly described family of mussel epibionts were found in two species. In addition, *C. delta* was dominated by an unknown bacterium that may represent a new family related to *Mycoplasma*. Fluorescence in situ microscopy of *C. delta* revealed aggregates of multiple bacteria within the tissue. Specific microscopy probes were developed to determine which bacterial taxa are present in these aggregates. Finally, sequencing of metagenomes and metatranscriptomes of paired *C. delta*, water and sediment is underway to determine the effect of seepage on microbial community composition and gene expression. These data suggest that microbes may play an important role in deep-sea coral physiology and may interact with seep chemistry.

Intestinal Microbiota of Red Drum *Sciaenops ocellatus* following Exposure to South Louisiana Crude Oil-contaminated Feeds

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The microbiota associated with organisms have significant impacts on host health by aiding in food digestion and nutrient uptake, modulation of immune function, and competitive exclusion of pathogens. When microbiota structure is altered from a normal, healthy state, it is considered to be in dysbiosis. Environmental factors including diet, seasonal parameters, and exposure to pollutants can result in dysbiosis, which has been linked to numerous disorders. Microbiota composition is tightly linked to immune function of the host, which suggests dysbiosis may indicate immunosuppression brought on by stressor events. Due to the intimate interactions between microbiota, environment, and host health, shifts in bacterial taxa abundances may be used as a non-lethal monitoring strategy of fish health during oil spills. In the presented study, adherent and fecal intestinal microbiota of Red Drum *Sciaenops ocellatus* was collected and subjected to high-throughput sequencing for characterization in fish fed South Louisiana crude oil-contaminated and control feeds. Subsequently, numerous parameters relating to immune function were quantified. Sequences were generated using an Illumina miSeq, processed for quality, and classified to the lowest possible taxonomic level. Bacterial species diversity was compared between exposed and non-exposed fish. Differences in microbiota composition between treatments was statistically determined and predicted metabolic profiles were generated for each treatment. Microbiota structure was related to measured immune parameters and polycyclic aromatic hydrocarbon (PAH) levels using partial linear regression in order to determine bacterial taxa that may represent biomarkers of immunosuppression or PAH exposure. This marks one of multiple studies involving numerous fish species and exposure routes to determine the impacts of oil exposure on fish-associated microbiota and the feasibility of identification of bacterial biomarkers to assess fish health.

The Impacts of Weathered Oil on Ecosystem Function in Coastal Sands

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Weathered crude oil from the Deepwater Horizon (DWH) blowout impacted approximately 1773 km of Gulf coast shoreline in 2010. Although DWH oil contamination was often shown to impact microbial community composition in coastal ecosystems, little information is available on the impacts of oiling on ecosystem function in coastal sediments. In this study, we employ advective-flow chambers that simulate *in-situ* pressure gradients found in saturated coastal sediments to test hypotheses generated from field studies of Gulf beaches. Our objectives are to (1) determine the acute impacts of weathered crude oil on carbon and nitrogen cycling processes, and (2) directly link the metabolic pathways and controls of biodegradation to specific microbial groups. Incubations were conducted over a 3-month period and oxygen consumption rates as well as nutrient concentrations were monitored. Results support field data to show evidence of nitrogen limitation and organic matter turnover as well as a succession of microbial populations that parallels the chemical evolution of petroleum hydrocarbons in response to oiling. Whereas soluble inorganic nitrogen forms remained depleted in oiled chambers, a progression of ammonium to nitrate accumulation indicated active nitrification in controls. Rate measurements confirmed that nitrification was shut down in oiled sands whereas rapid rates were measured in control treatments. In contrast, nitrogen fixation and denitrification processes were enhanced by oiling. Microbial groups known to carry out nitrification were diminished with time in oiled chambers whereas hydrocarbon degrading bacteria were stimulated. A keystone group we identified in the field, *Macondimonas diazotrophicus*, which shows the potential to simultaneously degrade hydrocarbons while fixing nitrogen, was abundant in oiled mesocosms. Overall, our results show pronounced impacts of oil contamination on the microbial nitrogen cycle in coastal sands.

Biogeography of Ammonia Oxidizers: Comparisons between the Gulf of Mexico and New England Salt Marshes

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Prior to the Deepwater Horizon oil spill, few data existed on nitrifying microorganisms in the Gulf of Mexico (GoM), and we knew even less about them in Gulf Coast salt marshes, despite their critical roles in the nitrogen cycle. Using data collected from 2012 to 2016 in Louisiana marshes, we compared community composition and abundance of ammonia-oxidizing archaea (AOA) and bacteria (AOB) from Gulf Coast salt marshes to marshes in New England. Community composition and abundance were based on TRFLP and QPCR analyses of the ammonia monooxygenase genes (*amoA*). For AOA communities, regional differences between GoM and NE marshes were much stronger than differences related to vegetation type between marshes in the same region. *Nitrosopumilus*-related *amoA* genes were abundant in all marshes, but relative abundance of most AOA populations differed significantly between regions. AOB communities were highly variable between regions and among marshes within the same region. No single AOB population dominated across all marshes, with some dominated by *Nitrosospora* sequences and others dominated by *Nitrosomonas*. The only marshes with similar AOB communities were two marshes in Connecticut that are 6 km apart. In all marshes, AOA were always

more abundant than AOB. Both AOA and AOB abundances were significantly greater in NE marshes compared to GoM marshes, yet potential nitrification rates were significantly higher in GoM marshes. Finding opposite patterns of abundance and rates, as well as different communities, suggests that ammonia-oxidizing communities process nitrogen differently in marshes in these two regions, providing new insight into Gulf Coast microbial communities.

High Spatial Variability in Biogeochemical Rates and Microbial Communities across Louisiana Salt Marsh Landscapes

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Salt marshes are important sites for retention and transformation of carbon and nutrients. Much of our current marsh biogeochemistry knowledge is based on sampling at times and in locations that are convenient, most often vegetated marsh platforms during low tide. Wetland loss rates are high in many coastal regions including Louisiana which has the highest loss rates in the US. This loss not only reduces total marsh area but also changes the relative allocation of subhabitats in the remaining marsh. Climate and other anthropogenic changes lead to further changes including inundation patterns, redox conditions, salinity regimes, and shifts in vegetation patterns across marsh landscapes. We present results from a series of studies examining biogeochemical rates, microbial communities, and soil properties along multiple edge to interior transects within *Spartina alterniflora* across the Louisiana coast; between expanding patches of *Avicennia germinans* and adjacent *S. alterniflora* marshes; in soils associated with the four most common Louisiana salt marsh plants species; and across six different marsh subhabitats. *Spartina alterniflora* marsh biogeochemistry and microbial populations display high spatial variability related to variability in soil properties which appear to be, at least in part, regulated by differences in elevation, hydrology, and redox conditions. Differences in rates between soils associated with different vegetation types were also related to soil properties with *S. alterniflora* soils often yielding the lowest rates. Biogeochemical process rates vary significantly across marsh subhabitats with individual process rates differing in their hotspot habitat(s) across the marsh. Distinct spatial patterns may influence the roles that marshes play in retaining and transforming nutrients in coastal regions and highlight the importance of incorporating spatial sampling when scaling up plot level measurements to landscape or regional scales.

Salt Marsh Resilience in the Anthropocene: Evaluating N Removal in Response to Human-driven Disturbances

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Salt marshes provide valuable ecosystem services including removing excess nitrogen (N) from coastal waters. However, salt marshes in the northern Gulf of Mexico (nGoM) are threatened by human-driven disturbances, potentially reducing ecosystem capacity for N removal. We conducted a study in the Chandeleur Islands (LA) to evaluate the impact of two types of disturbance on salt marsh N removal. Our first objective was to assess the long-term impact of the 2010 Deepwater Horizon oil spill on salt marsh denitrification. Denitrification (DN) is a microbial process that reduces nitrate (NO_3^-) to nitrous oxide and dinitrogen gases. We measured denitrification capacity rates, functional marker abundance,

and sediment characteristics at 3 sites subjected to a range of oiling during the spill, including one site where oil residue is present. DN capacity ranged from 28–64 $\mu\text{mol N m}^{-2} \text{ h}^{-1}$, which was comparable to rates reported in the nGoM prior to the spill. The presence of oil residue had no measurable impact on DN, rather, sediment porosity and nitrite reductase (*nirS*) gene abundance were the best predictors of DN capacity. Our second objective was to determine the effect of mangrove expansion on NO_3^- reduction in salt marshes. Warming winter temperatures associated with climate change have promoted *Avicennia germinans* (black mangrove) expansion into salt marshes in the nGoM but there is limited knowledge regarding the effects of mangrove expansion on N removal. We compared potential DN and dissimilatory NO_3^- reduction to ammonium (DNRA) rates from *S. alterniflora* and *A. germinans* dominated sediments. Initial findings show similar DN rates between *S. alterniflora* and *A. germanins* sediments (24 and 31 $\mu\text{mol N kg}^{-1} \text{ h}^{-1}$) but DNRA rates were over 2X higher in *S. alterniflora* than *A. germanins* sediments (12 vs. 5 $\mu\text{mol N kg}^{-1} \text{ h}^{-1}$). Our findings show that salt marshes may be more resilient to pulse disturbances (e.g. oil spills) than chronic disturbances (e.g. mangrove expansion).

Indigenous Microbial Communities in Louisiana Saltmarsh Soils following the Deepwater Horizon Oil Spill

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Oil spills may directly affect microbial communities inhabiting wetland soils or indirectly via impacts on their habitat. This study employed conventional and molecular assays to determine the possible impacts of the Deepwater Horizon oil spill on soil microbial communities of the saltmarshes in northern Barataria Bay over a course of six years after the spill. Cultivation-based microbial analyses of surface sediment showed that the ratio of oil degrading bacteria to total heterotrophic bacteria increased by approximately a factor of 50 at heavily oiled and 25 at moderately oiled sites relative to reference sites 16 months after the oil spill. A significant positive correlation was found between oil degrading bacterial abundance and TPH concentration in the sediment ($P < 0.002$). The 16S rDNA sequencing of oil-degrading bacterial isolates and the qPCR quantification of oil degrading genes identified that the majority of the oil degrading bacteria in the sediment were gram-positive. 16S rDNA-based community analyses revealed that bacterial communities were significantly altered by the spill 7 months following the landfall of oil. The communities experienced a recovery with time, with a faster speed of recovery in moderately oiled sites than in heavily oiled sites. However, the relative abundances of certain species were still significantly different after six years.

Oil History Drives Unique Responses in the Above- and Below-ground Fungi Microbiome of *Spartina alterniflora*

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The plant microbiome, composed of diverse interacting microorganisms, plays key functional roles to hosts that can scale up to ecological and ecosystem processes. Pervasive environmental perturbations such as oil pollution have been shown to alter the diversity and composition of these plant microbiomes, yet these impacts may vary between above-ground (leaf) and below-ground (root and

soil) microbial communities as they may interact with environmental factors differently. Six years after the Deepwater Horizon oil spill, we examined the effects of oil history on above-ground and below-ground endophytic fungal communities of the saltmarsh grass, *Spartina alterniflora*, at two sites in southeastern Louisiana. Using a metagenomics approach, we characterized responses of fungal communities to oil history by comparing these to corresponding communities in non-oiled areas within the two sites. Both above-ground and below-ground fungal microbiomes showed significant reduction in species richness and diversity in response to oil history, with endophyte leaf communities decreasing in species diversity with increase in polycyclic aromatic hydrocarbon (PAH) content ($r^2 = 0.11$, $p = 0.05$). However, oil history drives significant composition turnover (beta-diversity) only among below-ground, i.e. soil, and not in above-ground communities. This turnover among soil communities is accompanied by changes in the dominant fungal class: while *Sordariomycetes* remain the most abundant class in soil communities regardless of oil history, *Agaricomycetes* increased in abundance at one site, while *Leotiomycetes* in another. Taken together, these results show that even within the same individual host, the impacts of oil pollution can vary. This variation may have consequences for *Spartina* physiology, and ultimately, to ecosystem functions such as land building.

GoM-SCHEMA: The Deepwater Horizon Spill's Impact on Historic Shipwreck Microbiomes in the Northern Gulf of Mexico

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There are more than 2,000 historic shipwrecks in the Gulf of Mexico spanning 500 years of human history. Shipwrecks serve as artificial reefs and hotspots of biodiversity by providing hard substrate for organismal settlement. The Deepwater Horizon (DWH) spill released crude oil into the deep Gulf. Because of physical, biological, and chemical interactions, DWH oil was deposited on the seafloor in areas where historic shipwrecks are present. The spill created potential for contact of oil with shipwreck remains and the microbiological biological communities around them. The interaction of oil and dispersants used in the spill mitigation effort with shipwreck microbiomes may have synergistic effects that accelerate degradation of the structures they inhabit. Accordingly, the Gulf of Mexico-Shipwreck Corrosion, Hydrocarbon Exposure, Microbiology and Archaeology (GoM-SCHEMA) study examined the DWH spill's lasting effects on sedimentary microbiomes surrounding 7 historic shipwrecks. The study included steel-hulled World War II-era shipwrecks and wooden-hulled 19th century shipwrecks discovered prior to the DWH spill. Through comparative analysis of 16S rRNA sequence libraries for sediment microbiomes from wrecks located within and external to the DWH seafloor footprint, this study documented that the German U-boat *U-166* and the wooden-hulled sailing vessel known as the Mardi Gras Wreck were exposed to deposited oil. Impacts to shipwreck microbiomes included a significant increase in sequences related to Piscirickettsiaceae in surface sediments, and reduced biodiversity relative to sites outside of the spill. The work provides the first evidence of DWH spill residues interacting with historic shipwrecks on the seafloor.

ECO-002: Characterizing Crude Oil Exposure and Effects: From Molecular to Whole Animal Approaches

Polycyclic Aromatic Hydrocarbon Exposure in Seaside Sparrows following the 2010 Deepwater Horizon Oil Spill

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The seaside sparrow (*Ammodramus maritimus*) is an abundant and permanent resident of coastal salt marshes impacted by the 2010 BP Deepwater Horizon oil spill. Such terrestrial species are often overlooked in the aftermath of marine spills, despite potential for long-term oil exposure. From 2011-2014, we sampled the livers of seaside sparrows residing in oiled and unoled sites and quantified expression of CYP1A, a gene involved in the metabolism of polycyclic aromatic hydrocarbons (PAHs). We also collected sediment samples from the same marshes for a total concentration analysis of aromatics. CYP1A expression was markedly higher in birds sampled from an oiled area compared to an unoled area in August 2011, but differences disappeared by June 2012. In June 2013, following Hurricane Isaac, CYP1A expression was elevated on all sites, even those that had not been directly oiled following Deepwater Horizon, but was significantly attenuated again in June 2014. PAHs in sediment samples exhibited a similar pattern to the CYP1A data, supporting the link between marsh PAHs and bird CYP1A expression. These results indicate that contamination from marine oil spills can extend to terrestrial ecosystems, and that storms, weather, or other factors may influence the dynamics of oil exposure for several years.

Oxidative Stress Induced by PAH Metabolism: Comparing Three Exposure Routes in Red Drum, Florida Pompano, and Southern Flounder to Deepwater Horizon Surrogate Oil

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The magnitude of the oil and dispersant released during the Deepwater Horizon blowout caused significant immediate, and often lethal, damage to exposed organisms. However, the sub-lethal impacts of the chronic spill on offshore and nearshore biota are still not fully characterized. To help understand one of the most significant responses in important Gulf fish species, four different exposure-route experiments, DWH surrogate oil contaminated feed, sediments, and seawater, were designed and carried out to examine biological responses of aquaculture reared red drum, Florida pompano, and southern flounder. Environmental pollutants, like polycyclic aromatic hydrocarbons (PAHs) found in crude oil, have the potential to unbalance the antioxidant system of marine organisms. Oxidative stress occurs when there is an imbalance between the production of reactive oxygen species (ROS) and the organism's ability to detoxify reactive intermediates, such as those generated by metabolism of PAHs by cytochrome P450 (CYP1). Depending on the severity of oxidative stress, this imbalance can lead to DNA damage in a variety of ways, such as oxidized bases, apurinic/apyrimidinic sites (AP sites), single or double strand breaks and DNA adducts. Exposure to PAHs can lead to increase DNA damage, such as those created by AP sites (purine loss) and the formation of DNA adducts, in which PAH metabolites intercalate into the DNA. Total PAH concentrations were analyzed in exposure matrices, as well as fish livers and whole bodies to determine specific dosages. Multiple assessments have been carried out to examine oxidative stress; including, total antioxidant power analysis, 2-

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Thiobarbituric Acid Reactive Substances analysis, GSH/GSSG ratio determination, AP site quantitation, and 8-OHdG quantitation. Evidence of oxidative stress will be discussed comparing multiple pathways of exposure, and resulting impacts in terms of biological and ecological implications.

Integration of microRNA and mRNA in Early Life Stages of Mahi after Exposure to Deepwater Horizon Oil

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Deepwater Horizon (DWH) oil causes developmental cardiotoxicity in a number of fish species, but the molecular mechanisms are still not well understood. MicroRNAs (miRNA) play key roles in a number of diverse biological processes including heart development. In our study, we evaluated the effects of DWH oil on miRNA expression in mahi-mahi (*Coryphaena hippurus*) embryos exposed to weathered slick oil and non-weathered source oil. miRNAs were sequenced and annotated either using the *Fugu rubripes* genome (term as Fugu-guided approach) or aligned and annotated to known mature animal miRNAs (miRBase) using the Basic Local Alignment Search Tool (BLAST) method (termed as the phylogenetic-guided approach). Using the phylogenetic-guided approach, more differentially expressed (DE) miRNAs were identified in all treatment groups at all stages. Exposure of embryos to slick oil resulted in more DE miRNAs at all developmental stages (24hpf, 48hpf, and 96hpf). The most common DE miRNAs were miR-21b, miR-7641 and miR-92b, which were observed at all stages. The expression of miRNAs and their target mRNA was further compared using advanced bioinformatics with subsequent target organ predictions based on their interactions. Gene ontology (GO) analysis on the target mRNAs was consistent with pathway analysis of miRNAs, predicting disruption of cardiovascular system development after oil exposure and showed that specific miRNA-mRNA interactions may contribute to these effects. Slick oil caused an overexpression of miR-133a and miR-15b, which correlated to the decrease in the expression of genes related to the cardiovascular system such as KCNH2 and KLF15. This work is the first study linking miRNAs and mRNAs in fish responsive to DWH oil exposure, providing a new opportunity for better understanding of the molecular mechanism(s) of oil toxicity.

Epigenomics of Oil-exposed Red Drum (*Sciaenops ocellatus*)

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The Deepwater Horizon oil spill released nearly 5 million barrels of oil that has been found throughout the Gulf of Mexico. While laboratory studies have found dramatic effects of oil exposure on fish fecundity, embryo survival and larval development, the links to population-level effects are not clear and transgenerational effects are unknown. Oil exposure has been found to alter the gene expression of fishes and these changes may persist after the exposure event. DNA methylation is a known epigenetic mechanism for altering gene expression and can persist after a stimulus is removed from the system. These epigenetic changes can have long-term population effects because methylation patterns can be passed from parent to offspring. We used reduced representation bisulfite sequencing (RRBS) to survey the epigenome of heart, muscle and fin tissue in CEWAF exposed red drum, a non-model organism. This data is then related back to previously described transcriptional data to evaluate

which gene expression alterations could be passed on to new generations. These genetic alterations could have an important impact upon the survival of offspring based upon the conditions they encounter.

Early Life Stage Fishes Exposed to Crude Oil Have Reduced Visual Development and Function

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Polycyclic aromatic hydrocarbons (PAHs) have been shown to cause developmental malformation in fishes, with effects greater during early life stages. Downregulation of genes important in eye development and function, as well as morphological abnormalities have resulted from exposure to PAHs present in Deepwater Horizon oil. Mahi-mahi, red drum, and sheepshead minnow embryos were exposed to weathered crude oil and assessed for visual function using the flicker-fusion principle to monitor an optomotor response, with subsequent histological analysis carried out of each larvae's retina. Oil-exposed larvae exhibited a reduced optomotor response with a reduction in retinal layers that play an important role in visual function and image processing. The present study relates oil-induced histological effects to behavioral endpoints and shows that weathered crude oil affects the visual system in early life stage fish. This research was made possible by a grant from The Gulf of Mexico Research Initiative.

Impacts of Crude Oil on Heart Cell Function in the Mahi-mahi (*Coryphaena hippurus*)

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Crude oil from the Deepwater Horizon oil spill has been shown to impair cardiac function across levels of biological organization in larval and adult mahi. At the organ level, *in-situ* preparations from adult fish have recently revealed that oil reduces cardiac output by ~40%. This decline in organ function likely explains detrimental impacts to intact animal performance following oil exposure, including reduced maximal metabolic rate and reduced swim performance. In the present study, we studied the underlying causes of oil-impaired cardiac function at the organ and intact animal level by examining how crude oil impacts isolated mahi ventricular heart cells. Cellular contractility was measured via sarcomere shortening using an IonOptix contractility recording system (1) over a range of PAH concentrations and (2) over a range of stimulation frequencies (1.5-3.0 Hz) representative of *in situ* measured heart rates in mahi (100-180 beats per minute). Isolated mahi heart cells exposed to extracellular saline containing water accommodated oil exhibited significantly reduced contractility at all tested PAH levels (3.2, 7.2, 15.4 $\mu\text{g l}^{-1}$ Σ 50PAH). These reductions in contractility were more pronounced at higher stimulation frequencies, supporting observations of impaired function during intense exercise in intact animals. This research was made possible by a grant from The Gulf of Mexico Research Initiative. Grant No: SA-1520; Name: Relationship of Effects of Cardiac Outcomes in fish for Validation of Ecological Risk (RECOVER).

* Student presenter

Combined Effects of Oil Exposure, Temperature and Ultraviolet Radiation on the Early Life Stages of Mahi-mahi (*Coryphaena hippurus*)

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The timing and location of the 2010 Deepwater Horizon incident within the Gulf of Mexico resulted in crude oil exposure of many commercially and ecologically important fish species, such as mahi mahi, during their sensitive early life stages (ELS). Mahi embryos are positively buoyant for the duration of their development except for a brief period leading up to hatch, and hatched larvae float and remain in the upper layers of the water column. Therefore, ELS mahi may be directly exposed to the cardiotoxic tricyclic PAHs dominating the oil slicks in surface waters for a significant portion of their developmental period. Further, these embryos are transparent and are likely also exposed to simultaneous stressors occurring in surface waters such as increased temperature and ultraviolet (UV) radiation. Our research focuses on how developmental parameters such as cardiac function, oxygen consumption, waste excretion, buoyancy control, hatch time and energy utilization are differentially affected when mahi are raised under ambient conditions compared to those exposed to oil alone and/or combined with other environmentally relevant stressors. Our data suggests that exposure to the aforementioned stressors have significant deleterious effects on developing mahi, including but not limited to, bradycardia and cardiac edema, increased waste excretion and reductions in energy reserves. Further, exposed embryos displayed premature onset of negative buoyancy, coupled with faster sinking rates, likely altering dispersal potential and causing embryos to sink out of suitable hatching habitat. Although many of the observed effects in our study were sublethal in nature, they have the potential of resulting in profound impacts on the population and sustainability of this important fish species. This research was made possible by a grant from The Gulf of Mexico Research Initiative. Grant No: SA-1520; Name: Relationship of Effects of Cardiac Outcomes in fish for Validation of Ecological Risk (RECOVER).

The Effect of Temperature on the Toxicity of Oil to the Ghost Shrimp (*Lepidophthalmus louisianensis*)

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The northern coast of the Gulf of Mexico is home to *Lepidophthalmus louisianensis*, a species of burrowing crustacean. This species lives at densities as high as 400 individuals/m², and produces intricate burrows that can reach depths greater than two meters below the sediment surface. These characteristics make this species crucial to the overall health of the local ecosystem. Multiple toxicity bioassays using adult *L. louisianensis* and sparged oil have been performed. Initial experiments revealed that adult shrimp do not experience significant mortality during 21 days of exposure to light - moderate levels of oiling at 24°C, but that sublethal changes such as cuticle lesions may occur. A bioassay using three different oil treatments (0, 10, & 50µL/cm²) and three different temperatures representing different times of year (15.5, 24.5, & 30.0°C) was performed over 21 days. Again, no significant mortality was observed for any of the treatment/temperature combinations. There was a significant difference ($p = 0.014$) in lesion prevalence between control and oil exposed shrimp, but only at the high temperature. Cuticular lesions can result in loss of limbs or degradation of the cuticle. The presence of other sublethal effects is still under investigation.

* Student presenter

Why Tag a Captive Fish? Improving our Understanding of Habitat Utilization, Swimming Speeds, and Spawning Behaviors in Wild Mahi-mahi Exposed to Oil

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Mahi-mahi (*Coryphaena hippurus*, “mahi” in the following) is a highly migratory pelagic fish species that inhabit tropical and sub-tropical waters around the world. The 2010 Deepwater Horizon blowout released approximately five million barrels of crude oil into the northern Gulf of Mexico (GOM) and coincided spatially and temporally with the spawning window for mahi. In the laboratory, environmentally realistic oil exposures reduce cardiac performance and aerobic swimming speed of adult mahi. As a high-performance fish, the ecology of mahi is tied to their vertical dives, migrations, and spawning; all of which is poorly studied and may be affected as a result of crude oil exposure. To better understand behavior in wild mahi, we collaborated with Wildlife Computers to build pop-up satellite archival tags (PSATs) to measure acceleration, depth, temperature, and light levels (for geo-location modeling). To model acceleration patterns around spawning we tagged wild-caught captive mahi with PSATs and observed them for three weeks. Currently, we are deploying 22 96-day custom-built PSATs on mahi caught in the Florida straits and the GOM and are using our captive based models to predict spawning behavior as well as gain information about temperature and depth distributions and migrations of wild unexposed mahi. In the summer of 2018 we hope to conduct an experiment in the GOM where wild mahi will be exposed to oil for 24-hours onboard our research vessel, tagged with PSATs, and released into the wild along with tagged control mahi. The spawning and habitat utilization information from these PSATs will be a vital component of understanding the ecology of mahi and will also provide important information about the fate and performance of mahi exposed to oil in the wild. This research was made possible by a grant from The Gulf of Mexico Research Initiative. Grant No: SA-1520; Name: Relationship of Effects of Cardiac Outcomes in Fish for Validation of Ecological Risk (RECOVER).

Behavioral Consequences of Dietary Exposure to PAHs in the Siamese Fighting Fish (*Betta splendens*)

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Uptake by fishes of polycyclic aromatic hydrocarbons (PAHs) occurs via gills, dietary intake, or via diffusion through the skin. Dietary exposure to crude oil is environmentally relevant, and induces physiological disruptions in all developmental stages. However, the impacts of these compounds on fish social behavior and their possible influences on reproductive success are poorly understood. As a part of their social interactions, male Siamese fighting fish (*Betta splendens*) exhibit highly stereotypic behavioral displays that make this species a suitable model to test PAH behavioral effects. After 2 weeks of acclimation, male adult betta fish were split into three groups and exposed with food spiked with water (control), low or high PAH concentrations (Σ Total PAH concentrations ~340, 3960 or 8732 $\mu\text{g/g dw}$, respectively) to measure alterations in behavioral displays. Compared with control fish, “Opercular flaring” - an aggressive display - was increased in PAH-exposed fish ($P = 0.03$). Concurrently, bubble nest building was reduced in treated fish. Reductions also occurred in the mass of the testes and the brain ($P < 0.05$). Hematocrit of treated groups was increased about 6% in comparison with the control group ($P = 0.018$). The present study demonstrates that dietary exposure to low levels of PAHs could lead to an increase in aggressive behavioral displays and additional morphological changes in

^{*} Student presenter

treated fish. Although increases in aggressiveness and boldness have been related to higher reproductive success, directly involved reproductive traits such as nest building and gonadal mass are negatively affected by PAH exposure.

The Effects of Acute Oil Exposure on Anti-predator Behavior in Marine Fish

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Oil is a pervasive environmental contaminant in marine systems, epitomized by the 2010 Deepwater Horizon oil spill that released over 700 million litres of crude oil into the northern Gulf of Mexico. Decades of research on oil toxicity has helped shape a scientific consensus that lethal and sub-lethal effects of oil exposure are the result of impaired cardiac development and function, which can lead to reduced cardiac output, aerobic scope, swim performance and ultimately reduced growth, survival and fitness. Recent RECOVER work related to the Deepwater Horizon oil spill, while also demonstrating cardiotoxicity, has begun to reveal novel behavioral toxicity endpoints of ecological significance that are as, or more, sensitive than cardiotoxicity. Across a variety of experiments spanning four different species, we have consistently observed elevated risk-taking - as defined by reduced thigmotaxis - as well as reduced sociability and shoaling behavior. This collection of results points to the presence of an oil induced behavioral syndrome that may increase predation risk. This premise was supported by the findings from mesocosm habitat selection and predation study involving two coral reef species. When exposed to HEWAF containing $5.7 \mu\text{g l}^{-1}$ ΣPAH for 24 h, larvae reef fish showed decreased thigmotaxis and smaller group sizes, while also showing a reduced tendency to identify and recruit to healthy coral reef habitat. As expected, when a predator was introduced to the mesocosm, fish that had been exposed to oil showed significantly higher predation rates. While the exact mechanisms for oil induced behavioral impairments are unknown, transcriptomic studies for embryonic red drum revealed oil induced gene expression profiles that were indicative of abnormal brain development, which suggests that polycyclic aromatic hydrocarbons may act directly on the brain.

Impacts of Multiple Predator Effects on Prey Assemblages in the Northern Gulf of Mexico: A Mesocosm Test Using Additive and Substitutive Designs

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Consumer biodiversity is perceived to have a significant impact on marine ecosystem functioning. The generality of this perception may be questioned, however, based on recent reviews. The reason for variability in the results of biodiversity experiments may be a consequence of the simplicity of the study designs. Specifically, few of these studies have considered how variance in consumer density affects biodiversity's effects on ecosystem processes. Here we report the findings of a mesocosm experiment that manipulated the density and species diversity of invertebrate and vertebrate predators and measured their effects on three species of prey common in the northern Gulf of Mexico. Predator density strongly modified multiple predator effects on prey density. We found no evidence of either interspecific competition for prey or intraguild predation among consumers in any of our trials. We also found no evidence that the polyculture performed better than the best vertebrate monoculture. The invertebrate predator we used had limited effects on prey density. Overall, our

results indicate that vertebrate predator identity, not species richness, was a key determinant of the transfer of energy across adjacent trophic levels.

ECO-003: Gulf-wide Impacts, Recovery and Connectivity of Marine Invertebrates in the Context of Oil Spills and Environmental Variability

Using Benthic Foraminifera to Assess Oil Spill Impact, Resilience, Long-term Preservation, and to Provide a Measure of Gulf-wide Benthic Baselines

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Benthic foraminifera (BF) provide useful tools to assess three primary aspects of oil spills in the Gulf of Mexico (GoM): 1) monitoring the impact, response, and resilience of the benthic habitat from the 2010 Deepwater Horizon (DWH) oil spill, 2) recording the effects and resilience from the Ixtoc oil spill (1979-80) in the sedimentary record and 3) providing contemporary, Gulf-wide, environmental baseline measurements of benthic habitat health and variability. Initially, in the aftermath of the DWH oil spill, there was an 80-93% decrease in BF density and a 30-40% decrease in BF species richness and heterogeneity in the northern GoM. From 2010-2012, BF also incorporated petroleum carbon (PC) into their calcite tests (shells). Following this period of impact, BF density and diversity reached a resilient state of equilibrium from 2013-2015, suggesting that the rate of resilience for the benthic habitat is on the order of three years following an event like the DWH. However, preliminary evidence suggests that post- DWH BF species composition remains significantly different from composition prior to DWH. Secondly, the sedimentary records of BF were used to assess the impact, preservation and resilience following the Ixtoc oil spill. A noticeable decrease in BF diversity as well as a depletion in the stable carbon isotopes (indicative of PC incorporation) of BF calcite occurred in the sedimentary interval corresponding to 1979-80. These results have implications for determining the long-term preservation of oil spills, assessing PC mineralization and burial, and contributing to overall oil spill budgets. Finally, Gulf-wide (US, Mexico, Cuba) maps of BF density, diversity and stable carbon isotopes have been developed in an effort to provide a contemporary overview of benthic environmental baselines. These environmental baseline measurements provide a means to quantitatively determine impact, resilience and recovery following any future oil spills.

How Quickly Will the Deep Sea Ecosystem Recover from the 2010 Deepwater Horizon Oil Spill? Lessons Learned from the 1979 Ixtoc-1 Oil Well Blowout Event

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The Deepwater Horizon (DWH) accident occurred on April 20, 2010 in the Northern Gulf of Mexico at a water depth of 1525 meters. The accident resulted in a deep-sea plume of petroleum hydrocarbons

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and a marine oiled snow sedimentation and flocculent accumulation (MOSSFA) event. Research indicates that benthic meiofauna and macrofauna were impacted directly following the DWH event and remain disturbed at the DWH site. These results prompt a critical question: how long will it take to recover? Answers to this important question can be inferred from a similar sub-surface oil release that occurred 38 years ago in the Bay of Campeche, Mexico: the 1979-1980 Ixtoc-1 blowout. Tracking meio- and macro-faunal changes during and after the Ixtoc-I blowout event will allow us to predict when the Northern Gulf of Mexico deep-sea habitat is likely to recover from DWH. Sediment cores collected from sites surrounding the Ixtoc-I spill have been analyzed for chemistry (i.e. petroleum hydrocarbons inputs and sediment redox changes) and benthic macrofauna, and meiofauna (i.e., abundance and diversity). Based on accurate chronologies, chemical and benthic biological signals associated with the Ixtoc-1 oil spill are recorded about 4 cm beneath surface sediments. The reduction in the abundance and species diversity of benthic meio- and macrofauna continue for at least 35 years after the Ixtoc-1 event. Because the infauna zone in deep sea sediments is about 10 cm, we estimate that it will take another 40-50 years for the Ixtoc area to recover. This implies that the DWH area will recover when about 10 cm of fresh sediment caps the contaminated sediment in the deep sea.

How Suitable are Species Level and Family Level Identifications of Gulf of Mexico Polychaetes for Multivariate Biodiversity Assessments?

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Changes in marine infauna community structure along environmental gradients, such as oil contamination after a spill, can be detected with powerful multivariate analyses based on lists of species. Taxonomic sufficiency is the concept that hierarchically higher taxonomic units ("taxonomic surrogates") may be viable alternatives for species level analyses. Using taxonomic surrogates makes the identification process much easier and faster, which is important when rapid assessments of environmental pollution are needed. The performance of family level surrogates of polychaetes from the northern Gulf of Mexico continental shelf, and the loss of information caused by exclusion of specimens that could not be identified to species level was tested. Lacking species level information is a common problem because many benthic organisms may be too damaged or poorly preserved to identify them, and thus are excluded from analyses. In contrast, polychaete families are usually sufficiently distinct to identify damaged specimens. Several datasets were used to create similarity matrices between sampling stations, based on polychaete species and families. Taxonomic surrogates of northern Gulf of Mexico polychaetes performed well and indicated small levels of information loss. Surrogate performance was not influenced by the ratio of identified specimens. The exclusion of unidentified specimens resulted in an information loss that was logarithmically correlated to the percentage of identified specimens. Taxonomic surrogacy and exclusion of unidentified specimens performed approximately equally well when 50-60% of specimens could be identified. These results indicate identifications at the family level are sufficient for environmental assessments and testing restoration success.

Persistent and Significant Impacts of the Deepwater Horizon Oil Spill on Deep-sea Megafauna Seven Years Later

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In scope and severity, the Deepwater Horizon (DWH) oil spill in 2010 represented a major environmental disaster with commensurate impacts on the economic and ecological health of the Gulf of Mexico. Although the surface expression of oil and its impacts on coastal ecosystems received considerable public and scientific attention, the far greater part of the spill occurring in the deep ocean and subsequent impacts received considerably less attention. Although studies examined the deep-sea impacts from 2010-2014 and continues for deep-sea corals, a considerable knowledge gap for continued post 2014 impacts on the deep-sea exists. In the summer of 2017 an ROV survey of the Deepwater Horizon wellhead and wreckage documented a significant lack of megafaunal diversity, including the absence of major taxonomic groups common in the deep Gulf of Mexico and the lack of structure associated invertebrates on wreckage. In addition, we observed and quantified substantial organismal damage in several key species including the large mobile crab *Chaceon quinquedens*. Individuals of this species showed dramatic discoloration, increased ectoparasite loading, carapace and appendage deformities, and missing limbs. Behavioral response of *C. quinquedens* were also abnormal with most failing to display common defensive postures and retreat at the sight of the ROV. Using historical data prior to the DWH spill and recent evidence from healthy unimpacted areas of the deep Gulf of Mexico, we quantify a dramatic and persistent impact of the DWH event on deep-sea megafauna vicinity of the DWH wellhead and rig wreckage.

Stratification Drives Taxon-specific Distribution of Gelatinous Plankton at Fine Scales in the Northern Gulf of Mexico

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Distribution of zooplankton during different seasons is crucial to assessment of exposure and vulnerability to oil, dispersants and other potential pollutants. Gelatinous zooplankton, important members of the northern Gulf of Mexico (nGOM) ecosystem, are among the most sensitive to oil, yet the environmental drivers that determine their distribution patterns are poorly understood. This lack of basic ecological information is mainly due to sampling biases of net-based systems, which integrate abundances across large spatial scales and thus do not accurately quantify gelatinous zooplankton distributions. In this study, we used a plankton imaging system (the *in-situ* Ichthyoplankton Imaging System - ISIIS) equipped with a CTD, oxygen sensor, PAR sensor, and chlorophyll-a fluorometer, to obtain fine-scale taxon-specific spatial distributions of gelatinous zooplankton in relation to the physical environment of the nGOM during different seasons (2015-2016). Daytime “tow-yo” transects (~54 km-long) from surface to ~4m from the bottom off Perdido Bay, Florida were performed during the fall, spring and summer seasons. The ISIIS revealed that distribution patterns varied among taxa, particularly during summer when the water column was highly stratified. In summer, chaetognaths and ctenophores displayed non-overlapping distributions, occupying relatively high and low salinity waters, respectively. Hydromedusae and siphonophores displayed spatial overlap, but their communities were split into two main “clusters”, each one associated with differing salinities. Salps and doliolids were

most abundant at the pycnocline, while gelatinous mollusk larvae were restricted to coastal waters, independent of salinity or any other physical parameter. The spatial distributions of most taxa were less structured during the weakly stratified spring and fall seasons. The relative abundance of taxa also varied among seasons, indicating a seasonal change in zooplankton community composition. Our findings highlight the high degree of structured distribution of plankton in stratified coastal waters and the need for refined sampling during spills to better understand exposure and ecosystem consequences.

Resilience of Zooplankton Communities During and after the Deepwater Horizon Oil Spill

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The Deepwater Horizon oil spill was a major environmental perturbation in the NE Gulf of Mexico. The highest oil concentrations occurred in the upper 20 m of the water column, while intermediate concentrations occurred down to 100 m. Zooplankton are known to be sensitive to toxic oil exposures, with maximum abundances in the upper water column. SIPPER camera imaging data showed that 39% (geomean; range: 9-99%) of the zooplankton community in the upper 100 m occurred between 0-20 m depth during May and June 2010 during the oil spill and, therefore, was likely exposed to relatively high oil concentrations. Despite this, total zooplankton showed little difference in abundances between May-June and shortly after the oil spill (August - September 2010). However, some differences were observed for specific taxa. *Trichodesmium* colonies increased throughout the sampling period, with maximum abundances increasing from 100s m⁻³ during May-June to >1000 m⁻³ during August, and >4000 m⁻³ during September. *Noctiluca* and other dinoflagellates were very abundant (>5000 m⁻³) in the upper 38 m during May and numerous *Noctiluca* were observed on marine snow particles. Chaetognaths, the most common carnivorous zooplankter, were 4-48% more abundant at stations unimpacted by oil in May and June. Doliolids also significantly increased in abundance between May and September. Some August-September 2010 stations had elevated marine snow, phytoplankton, and zooplankton abundances in low-salinity surface waters due to enhanced Mississippi River discharge. Bongo net results from August 2010 to August 2014 showed that total zooplankton abundance was highest and more variable near shore and lower at offshore sites. May and September 2011 had the highest abundances and August 2010 the 2nd highest at a near-shore station near Panama City, likely due to high river discharge during those periods, while stations over the shelf slope and deep water had similar abundances between seasons and years.

Zooplankton Community Structure in the NE Gulf of Mexico: Impacts of Environmental Variability and the Deepwater Horizon Oil Spill

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Impacts of the Deepwater Horizon oil spill on the beta diversity of zooplankton communities in the NE Gulf of Mexico were investigated using samples collected during and after the oil spill along two transects. The PCB eastern transect was located across the west Florida shelf over the DeSoto Canyon, while the western DSH transect was located over the shelf slope and deep water south of Mobile Bay

and east of the Mississippi River. August 2010 non-copepod zooplankton communities were significantly different compared to the years 2011-2014. Differences were driven by the presence of ostracods and absence of siphonophores and stomatopods. Copepod communities in August 2010 were significantly different only compared to August 2012, driven by the abundance of *Centropages* spp. However, interannual variability was high across all years. In general, there were significant differences in non-copepod assemblages between spring and summer seasons, across years, as well as between western and eastern transect lines in summer. Stomatopods, doliolidae, and euphasiids accounted for 20% of the variability along the western section in summer, while nearly 20% of the variability along the eastern section was attributed to ostracods, salpidae, and echinoderm larvae and juveniles. Deepwater Horizon station assemblages were similar to outer shelf, slope, and deepwater stations, but significantly different from inner shelf stations. Copepod communities also showed significant seasonal difference between both transects and across years. Forty-three % of the seasonal variation was driven by *Centropages* spp., *Temora* spp., and *Lucicutia* spp. Integrated chlorophyll and salinity were the primary drivers separating environmental conditions at stations. Zooplankton communities and environmental conditions from 2005-2009, collected as part of the NOAA SEAMAP surveys, are being analyzed to determine whether variability in biological data was due to natural seasonal and interannual changes or as a response to the oil spill.

Species Abundance, Spatial and Vertical Distributions of Heteropods (Pterotracheoidea) in the Northern Gulf of Mexico

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We describe species abundance, richness and distribution of heteropod molluscs (Pterotracheoidea) in the oligotrophic ecosystem of the northern Gulf of Mexico (GoM) after the 2010 Deepwater Horizon oil spill based on two midwater programs, the Offshore Nekton Sampling and Analysis Program (ONSAP) and Deep Pelagic Nekton Dynamics of the Gulf of Mexico (DEEPEND). Over 3,835 preserved identified heteropods were taken at 44 sampling stations during 8 cruises during 2011-2017. Samples were collected using a Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS) deploying six nets collecting at predetermined depths ranging from 1500 meters to the surface. Seven species of heteropod molluscs were identified with the genus Pterotrachiidae being most abundant. This study examines the possible diel migration patterns which we think will have peak abundances at mesopelagic depths (200-1000 m) during the daytime and shallower at night (0-200 m). We compared eye diameter with depth and body size to examine possible correlation of vision parameters with water depth and environmental conditions. The information presented here revises previously published patterns of spatial and vertical distributions for heteropod species for the northern GoM.

DEEPEND: What Have We Learned Since 2011 about Cephalopods of the Northern Gulf of Mexico?

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Two recent studies that focused on the deep water column in the Gulf of Mexico (GOM) were the 2011-2016 Offshore Nekton Sampling and Analysis Program (ONSAP) and 2015-2017 Deep Pelagic Nekton Dynamics of the Gulf of Mexico (DEEPEND) program. These programs produced a combined dataset of over 12,500 midwater-cephalopod records for the northern GOM region and this talk summarizes multiple cephalopod-related projects that have been completed. These projects include: (1) a connectivity study of three species using Sanger and Nextgen sequencing between the GOM and the northern Atlantic Ocean; (2) a stable isotope analysis of selected species to evaluate the role of cephalopods in the midwater food web; (3) a temporal examination of polycyclic aromatic hydrocarbon concentrations relative to the Deepwater Horizon spill and their possible effect on cephalopods from 2011-2017; and (4) an update on cephalopod species richness of the GOM highlighting newly discovered cephalopods. The results of these collaborative studies demonstrate the importance of cephalopods in the midwater ecosystem of the GOM.

DEEPEND: DNA Barcoding Enhances Large-Scale Biodiversity Initiatives of Crustaceans in the Gulf of Mexico

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The Deepwater Horizon Oil Spill highlighted the paucity of baseline data for the Gulf of Mexico (GoM), and reminded the world of the need for large-scale initiatives that document biodiversity. As part of the DEEPEND consortium, we are currently utilizing molecular methods in addition to taxonomic approaches in order to fully document and characterize crustacean biodiversity in the GoM. This includes obtaining DNA barcodes through both traditional Sanger sequencing and genomic techniques. A genetic barcode is a unique section of DNA that can be used as a representative sequence for its corresponding species. This method provides a standardized approach for species identification that can be used to aid alpha taxonomy, adult-larval linkages, and new species discoveries. Approximately, 3634 crustacean specimens have been collected from the GoM and Florida Straits during 6 research cruises from 2015 to 2017. Once collected, standard protocol involves identifying the specimen through dichotomous keys, extracting abdominal muscle tissue to extract DNA, and amplifying the “barcoding” regions, 16S and COI mitochondrial genes. Due to the limited success of universal primers, new primers were designed for several lineages. These newly designed primers proved instrumental in obtaining high-quality DNA barcodes for the species in these families. However, the abovementioned approach was unsuccessful in several groups, especially those that have very limited genetic resources, including but not limited to Lophogastridae, Euphausiidae, and Amphipoda. For ~45 specimens, we are generating full mitochondrial genomes through a *de novo* high-throughput sequencing protocol. To date, we have identified over 100 species and have barcodes for ~65 species across 4 orders of Crustacea. All barcodes are being deposited in open-source databases to aid species inventory efforts of deep-sea crustaceans, as well as studies on adult-larval linkages, population connectivity,

phylogenetics, and cryptic species complexes. This will ultimately contribute to a more accurate monitoring of the GoM's biota and provide a baseline for future studies in this highly important body of water.

DEEPEND: Does the Atlantic Serve as a Genetic Reservoir for the Gulf of Mexico? A Comparative Population Genomics Investigation of Six Midwater Invertebrate Species

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Genetic connectivity between ocean basins can have crucial implications for resident species, providing a genetic reservoir to replenish diversity following a local ecological perturbation. Population genomics analyses can measure and characterize connectivity and its impact on genetic diversity. When focused on key species across the trophic web, these insights may be extrapolated to diagnose the health and resilience of the ecosystem. This comparative study surveys six of the most abundant invertebrate species from the Gulf of Mexico (GOM) midwater: three shrimp (*Acantheephyra purpurea*, *Systellaspis debilis*, and *Sergia robusta*) and three cephalopods (*Cranchia scabra*, *Pyroteuthis margaritifera*, and *Vampyroteuthis infernalis*). Our goal was to determine the extent to which the Atlantic Ocean (ATL) serves as a genetic reservoir for the GOM. To accomplish this, we 1) analyzed changes in genetic diversity over time to determine the relative genetic assets of each basin following a massive anthropogenic disturbance and 2) assessed the ability of these species to recover from such events by measuring levels of genetic connectivity across major ocean basins. Samples were collected from the GOM in 2011, 2015-2017, and from the northern ATL. Additional crustacean samples were obtained from the Florida Straits. Given the small geographic range and relatively short timescale, we utilized a next-generation sequencing method, double-digest Restriction-site Associated DNA sequencing, to sequence thousands of loci. This study quantifies relative health and recovery over a seven-year period in the GOM midwater and challenges the assumption of a "closed" GOM, characterizing species-specific patterns of gene flow between the GOM and the ATL. Focusing on relatively unstudied taxa in this frequently over-looked habitat, our research fills a large data gap in understanding the state and flux of genetic diversity and connectivity in invertebrate species occupying the GOM midwater.

Asymmetric Larval Connectivity between Oceanographic Provinces of the Gulf of Mexico and Resilience of Fish Communities to Disturbances

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The Gulf of Mexico (GoM) marine ecosystem is experiencing natural (hurricanes, river runoffs) and anthropogenic (oil spills, chemical dispersants) stressors impacting fish populations. Sedentary demersal fish species inhabiting the continental shelf may be particularly vulnerable to these disturbances. Yet, the ability of their pelagic larvae to move beyond the spatial range of local populations can be critical to the resilience of these populations and the entire ecosystem. A recent study of historical drifter data has shown that the GoM surface ocean is comprised of weak interacting provinces. However, larval dispersal patterns between these provinces is unknown. Here we take a biophysical modeling approach to estimate the probability of larval exchange between these

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oceanographic provinces. We use the locations and Catch per Unit Effort (CPUE) adjusted abundances of major functional groups of fish species collected on the GoM continental shelf between 20-500 m depth over 7 years, to initialize a GoM-HYCOM hydrodynamic model coupled to the open-source Lagrangian application of the Connectivity Modeling System (CMS). We evaluate the model output with 20+ years of data from the South Area Monitoring Assessment Program (SEAMAP) ichthyoplankton survey. We find asymmetric connectivity between oceanographic provinces and identify central nodes linking local populations, which partly explain the degree of fish species richness and similarity between sub-regions. We discuss the role that these expected connectivity patterns play on the resilience of continental shelf fish communities in the GoM.

ECO-004: Offshore Fishes: Deepwater Horizon Oil Spill Research from the Shelf to the Deep Ocean

A Spatiotemporal Analysis of Hepatic Polycyclic Aromatic Hydrocarbon Levels and Pathological Findings in Red Snapper (*Lutjanus campechanus*), Post-Deepwater Horizon
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In 2010, the Deepwater Horizon (DWH) subsurface blowout released ~4.9 million barrels of crude oil into the Gulf of Mexico (GoM). Since the DWH blowout, the Center for Integrated Modeling and Analysis of Gulf Ecosystems (C-IMAGE) has conducted annual demersal longline surveys to assess fisheries health and associated polycyclic aromatic hydrocarbon (PAH) tissue residues. The recreationally and commercially valuable species, red snapper (*Lutjanus campechanus*), was one of the target species collected during these surveys. The objective of this study was to conduct a spatiotemporal analysis of hepatic polycyclic aromatic hydrocarbon levels and pathological findings in red snapper sampled from select sites in the northern GoM collected since 2012. Liver samples ($n=76$) were processed using QuEChERS methodology and analyzed for 46 parental PAHs using gas chromatography - tandem mass spectrometry (GC-MS/MS). Gross and histological evaluation were also conducted on the livers to identify significant pathological changes, including the frequency of occurrence of external skin lesions. Understanding environmentally relevant PAH residues in wild caught fish tissues and their associated pathological changes is essential in order to assess potential health impacts following oil spills.

Ecosystem Impacts of Deepwater Horizon

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We present ecosystem-scale impacts of the Deepwater Horizon oil spill including indicators of changes in ecosystem structure and function as well as forecasted recovery times for a variety of species. Projections are made using an Atlantis ecosystem model. Effects in the model consider impacts on growth rates estimated from otolith measurements, impacts on mortality rate estimated from fish pathology, recruitment effects based on larval sampling, and effects of spatial-temporal fishing closures and restrictions. Growth and mortality effects are based on dose response models. Uptake

and depuration rates are informed by laboratory exposure experiments. Location of the oil relies on oil-fate model coupling and accounts for microbial degradation rates from high-pressure experiments. We validate model predictions by comparing to in situ measurements of reef fish and invertebrate densities. This work improves over previous estimates by including impacts on the invertebrate assemblage. Results from a parallel Atlantis modeling project studying the Ixtoc oil spill indicate similarities between the spills and hold implications for long-term recovery prospects.

Movement Ecology and Reproductive Resilience in Gulf of Mexico Marine Fish

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The Deepwater Horizon oil spill has highlighted the need to better understand interconnectivity and spatial processes and how they affect ecosystem health. Movement ecology is a relatively new field, but one which can help inform ecosystem based management as the structure of a movement path is a reflection of the basic processes that produced it—both intrinsic drivers and extrinsic factors resulting in movement forming the foundation of many ecosystem processes, including predator/prey interactions and phenology. Reproductive resilience is the capacity of a population to maintain the reproductive success needed to result in long-term population stability despite disturbances. A population's reproductive resilience is driven by the underlying traits in its spawner-recruit system, selected for over evolutionary time scales, and the ecological context within which it is operating. Traditionally, marine fish populations have been assumed to be relatively open and well mixed, with homogenous vital rates and stocks defined over large geographic scales. But this assumption is increasingly questioned, as technology provides new tools to assess spatial processes and thus our ability to develop risk assessment methods for spatial disturbances such as oil spills. Most marine fish are pelagic spawners and use disparate habitat depending on life stage, with spawning site selection and diversity affecting later spatial components of the life cycle and the productivity and vulnerability of the stock to spatial disturbances, climate change, and fishing. Spotted seatrout, red drum, red snapper, gag grouper and red grouper are all highly fecund pelagic spawners but the spatial range of their life cycles differs, as does con-specific density at spawning sites, and spawning and nursery habitat thus affecting their resilience. We integrate data from multiple studies on these species to demonstrate how movement ecology affects resilience to disturbance.

Tracking Oil's Toxicological Transgressions through Tilefish Transcriptomics

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As long-lived, sediment-associated, burrow-forming teleosts with high site fidelity, Golden tilefish (*Lopholatilus chamaeleonticeps*) are an excellent candidate organism for environmental toxicology studies, including those examining effects of oil exposure. An initial baseline assessment of 124 Golden tilefish sampled off the United States and Mexico in 2015-2016 exhibited statistically significant differences in health response in areas distinguished both by geographic location and oil inputs. Notably, this included a lack of immune, antioxidant, and oxidative stress response in fish collected from the Deepwater Horizon-impacted De Soto canyon area, particularly when compared to that in fish from the platform-dense Campeche Bay region off Mexico, as measured by plasma lysozyme,

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superoxide dismutase, sorbitol dehydrogenase, and the frequency of abnormal erythrocyte nuclei. This lack of response in De Soto Canyon fish was unexpected, given elevated levels of biliary polycyclic aromatic hydrocarbons at this location, leading to the hypothesis that historically contaminated populations may develop protective resiliency mechanisms. To test this theory, a subset of five, sexually mature, female fish were selected from single stations in the De Soto Canyon, the oil field in Campeche Bay, and the platform-free Yucatan Peninsula. Total RNA was isolated from fish liver samples and then individually sequenced using RNAseq. After initial quality assessment of reads by FastQC and trimming low quality reads and adapter sequences with Trimmomatic, a pooled de novo transcriptome assembly was created with Trinity. Individual fish transcriptomes were aligned back to this assembly using Bowtie and differential expression of genes was quantified using DESeq2 in the Bioconductor package, followed by annotation with mpiBLAST. In particular, the aryl hydrocarbon receptor pathways, oxidative stress genes, and immune system networks were explored for aberrant expression. The results of this study and new putative targets for oil exposure will be discussed in this paper.

Female-specific Highly-dense Linkage Map for Golden Tilefish

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Recent advances in high throughput sequencing methods allow for time and cost-effective generation of datasets consisting of several thousand genetic markers to characterize adaptive and neutral genomic variation in non-model species. Golden tilefish, which have a strong interaction with the sediment, have been shown to have high biliary PAH-levels post-Deepwater Horizon oil spill. While no genome-wide, population-level changes in diversity have been detected, locus-specific responses have been identified. However, without a fully sequenced and annotated genome it can be difficult to determine which genes are located in chromosomal regions associated with these loci. A highly-dense linkage map which groups loci into linkage groups corresponding to chromosomes, provides insight into the positions of identified loci relative to one another. Further, comparative bioinformatics can be used to localize genes which may be involved in short- and long-term responses to oil exposure. Unfortunately, many non-model species, including golden tilefish cannot be crossed in the lab. Here, we discuss a novel method for creating a highly-dense linkage map using whole genome amplification of DNA extracted from eggs of individual females. In addition, we report on methods to integrate gene expression and population-level genomic data from experiments in the lab with studies of wild populations using a comparative genomics framework.

Establishing a Baseline and Analyzing Resilience of Golden Tilefish and Deep-Water Grouper Species in the Gulf of Mexico

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The Deepwater Horizon spill had a catastrophic impact on aquatic organisms throughout the Gulf of Mexico, a number of which are economically important. We have sampled these species in approximately 300 locations distributed throughout the Gulf in the six years following DEEPWATER HORIZON. Sampling was done using a demersal longline system with 450-500 baited hooks in depths

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from 20-600 m. Using data from these surveys, I report on the distribution and abundance of golden tilefish, yellowedge grouper, and snowy grouper throughout the Gulf, establishing a baseline that DWH made apparent is largely absent. The growth rates of these fishes are examined to determine if there was any effect from PAH exposure, and the responses of these demersal species are compared with other ecosystem groups using a model simulation of the oil spill. While the growth rates of other fish species in the northern Gulf of Mexico were not shown to be significantly altered by DWH, the unique life history and habitat preferences of these demersal species make PAH exposure especially toxic. Therefore, comparing the resiliency of these species through growth rates and ecosystem modelling will be vital to understanding how the effects of anthropogenic perturbations vary between ecological groups.

Factors Determining Observed Patterns of Continental Shelf Fish Species Distribution and Apparent Connectivity in the Gulf of Mexico

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Continental shelf fish communities in the Gulf of Mexico are structured by water depth and by sub-regional modularity. Using results from seven years of demersal longline sampling and 20+ years of data from the SEAMAP ichthyoplankton survey, we quantify differences in species richness, density and species associations among Gulf sub-regions. However, just because adjacent regions may have some shared species, such analyses do not provide insights into how species populations may be linked, in terms of larvae that may be transported among regions, or movement patterns of adult fishes. As well, the apparent patterns of species similarity are likely influenced by demersal habitat types on Gulf shelves (e.g., terrigenous sediments, carbonate shelf, mesophotic reefs) upon which juvenile fish settle. We review available fish movement data based on literature summaries and fish larval information from plankton surveys as a basis for modeling of movements of various life stages based on particle tracer studies and Lagrangian geography, based on drifter studies. The importance of such studies to natural resource management and oil spill preparedness outcomes is discussed.

Fish-based Isoscapes for the American, Mexican and Cuban Continental-shelf Habitats of the Gulf of Mexico

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Isotope maps (isoscapes) of adequate spatial resolution are essential to the interpretation of fish isotopes from otoliths, eye lenses, muscle, and other tissues. Fish-based isoscapes can also be applied to non-fish animals such as mollusks, sea turtles, and marine mammals. Despite their broad utility, isoscapes are rarely available except as large-scale (e.g., whole Earth) models that tend to be sparsely supported by local, empirical observations. We compared one set of continental-shelf isoscapes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) that was based on trawl catches from the eastern Gulf of Mexico with another set of isoscapes for the same geographic area that was based on longline catches, and found major geographic trends to be similar, despite differences in the size of fish collected by the two gear types. Examination of spatial isotopic trends at the community level revealed that the isotopic trends result from a combination of (1) geographic variation within species and (2) geographic variation in fish community composition. Variation in $\delta^{13}\text{C}$ was consistent with basal-resource variation, and variation

in $\delta^{15}\text{N}$ was consistent with variation in nutrient sources. Longline-based isoscapes have been extended to the remainder of the Gulf of Mexico's continental-shelf waters, including Mexican and Cuban waters. Double isoscapes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) for the entire Gulf of Mexico indicate 8 distinct geographic regions: inner and outer West Florida Shelf, inner Mississippi-Louisiana shelf, inner Louisiana-Texas shelf, outer Louisiana-Texas shelf, Campeche, east and west Yucatan shelves. The Gulf-wide double isoscapes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) will be discussed in terms of the factors that produce/control these isoscapes and how they could be used to evaluate fish life history, characterization of regional baselines and ecosystem changes resulting from large scale environmental perturbations.

Has Abundance of Continental Shelf Fish Species Declined after Deepwater Horizon?

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Demersal longline sampling was undertaken beginning in spring 2011 to assess the abundance, species composition and fish health in the vicinity of the Deepwater Horizon (DWH) accident. These surveys were continued through 2017. This poster summarizes trends in abundance (CPUE), size distribution and species composition in the northern Gulf of Mexico from 2011-2017. Trends are summarized for four species groups: (a) snappers/groupers, (b) other demersal species, (c) large pelagic species, and (4) elasmobranchs (sharks and rays). Additionally, data are reported for selected species of economic or ecological significance in the region. Changes in the abundance of species and species groups are evaluated with respect to potential impacts of DWH.

Bioenergetics and Trophic Demands of Mahi-mahi (*Coryphaena hippurus*)

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Since 2010, research on the impacts of the Deep-Water Horizon oil spill on mahi-mahi ("mahi" in the following) has provided extensive information about energy allocation and demands for this abundant pelagic. Mahi serve as circumglobal top predators in tropical, subtropical, and temperate oceans and are themselves prey for larger pelagics, many of which are at historically low numbers. Consequently, insight into energy demands of mahi is important for understanding pelagic trophodynamics in undisturbed as well as oil-contaminated oceans. Mahi are ram ventilators, fast moving, exhibit impressive growth rates and high reproductive output, adding up to high energetic demands. To sustain this energy demand, adult mahi ingest 5-12% of their body mass daily. Captive mahi show high growth and low food conversion rates (6.2-7.6:1, wet/wet) compared with other pelagics, like yellowfin and Bluefin tuna, despite substantial investments in spawning. Female mahi can spawn every other day and release eggs at up to 5% of their body mass per event. Pop-up satellite tag data has identified the mahi thermal niche to be 18-31 °C and demonstrated extensive migration activity of up to 100 km/day equivalent to an average swim speed of 1.45 body lengths/sec. Swim tunnel respirometry has quantified the cost of transport at that swim speed to be 0.5 mg O₂/kg/m, allowing for estimated energetic demand of migratory activity. Costs of migration will be combined with metabolic cost of growth, reproductive output, and basal metabolic rates in the light of thermal niches to estimate energy demands and thus prey consumption of wild mahi. Furthermore, metabolic cost of processing an ingested meal has been quantified and will be included in energy budgets constructed for wild mahi. This research was made possible by a grant from The Gulf of Mexico Research Initiative. Grant No: SA-

1520; Name: Relationship of Effects of Cardiac Outcomes in fish for Validation of Ecological Risk (RECOVER).

How Do Warm-core Eddies Structure the Deep-pelagic Fish Fauna of the Gulf of Mexico?

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Mesoscale oceanic features, such as cyclonic and anti-cyclonic eddies are important in structuring pelagic faunal assemblages by generating regions of environmental heterogeneity at scales of tens to hundreds of kilometres. In the Gulf of Mexico (GoM), anticyclonic loop-current eddies (LCEs) are major semi-permanent, upper-ocean oceanographic features that are characterised by warm, oligotrophic waters, and that typically persist in the GoM for several months. However, the extent to which they may influence oceanic fauna, and particularly the deep-living pelagic fish fauna is not well known. In the present study, we use depth-stratified trawl catches and sensor data to characterise LCEs and examine their influence on both the assemblage structure of deep-living fishes (0 - 1500 m), and the distributions of the dominant migratory and non-migratory species captured during five research surveys conducted between May 2015 and May 2017. Overall, our findings suggest that samples occurring within LCEs generally contained a different composition of fishes, and a lower abundance of fishes than those outside the LCEs, but that significant effects of the LCEs were generally restricted to the upper water column (< 1000 m). Below 1000 m, very little assemblage structure was observed. Given the increasing range of human activities that target deep-ocean resources, we anticipate that these findings will provide valuable context when attempting to assess the potential ecological impacts of those activities.

DEEPEND: Evidence of Dramatic and Persistent Declines in Deep-Pelagic Fish Abundances in the Oceanic Gulf after Deepwater Horizon

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The Deepwater Horizon oil spill (DWHOS) represented a worst-case scenario with respect to environmental damage assessment - a massive, whole-water-column disturbance in an environment with no pre-event baseline data. In order to provide information on the meso- and bathypelagic faunal composition and abundance of the northern Gulf of Mexico, a large-scale, quantitative sampling program was conducted over a 10-month period in 2010 and 2011. Ensuing analyses revealed a highly speciose ichthyofaunal assemblage - in fact the highest species richness for any oceanic ecosystem reported to date. A follow-on sampling program in 2015, 2016, and 2017, using the same gear and sampling methods, revealed dramatic reductions in fish numbers and biomass across a wide range of taxa, with 3-to-4-fold decreases among some of the dominant constituents (e.g., lanternfishes). This decrease ostensibly has ramifications up and down the food chain (e.g., prey for deep-diving mammals, zooplankton grazing impact, respectively). The lack of pre-spill data precludes determination of causality, but the largest-scale view of this phenomenon leaves a relatively small number of options: 1) 2011 could have been a particularly "good" year for deep-pelagic fishes, with abundances above

baseline; 2) deep-pelagic fish abundances naturally vary on time-scales larger than that encompassed in this study; and/or 3) the Gulf deep-pelagic fauna has experienced increased mortality since the DWHOS. Evidence of a continuing presence of DWHOS contamination in the deep-pelagic fauna will be presented. This study emphasizes the need for research on community baselines before commercial exploitation, particularly in deep-sea ecosystems whose natural restorative capacity is unknown.

ECO-005: Development of Sampling Techniques and Identification of Indicator Species to Assess Coastal Ecosystem Health and Recovery in the Northern Gulf of Mexico

Controls on Louisiana Wetland Soil Greenhouse Gas Fluxes

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Coastal wetlands experience numerous environmental stressors including changes in salinity regime and inundation patterns, climate induced changes in vegetation, and episodic perturbations such as oil spills. We present results from a series of studies examining spatial and temporal variability in and controls on rates of greenhouse gas (GHG: CO₂, CH₄, and N₂O) fluxes from wetland soils. GHG fluxes decrease with ambient salinity from fresh through intermediate and brackish marshes to *Spartina alterniflora*-dominated salt marshes which tend to have comparable CO₂ fluxes but lower CH₄ and N₂O fluxes than *Avicennia germinans* soils. Both CO₂ and CH₄ fluxes increase with distance from the marsh edge and elevation while N₂O fluxes don't vary consistently. CO₂ fluxes are more strongly correlated with soil properties than either N₂O or CH₄ fluxes. CO₂ production increased and CH₄ production decreased with incubation salinity in Terrebonne Bay and Barataria Bay salt marsh soils and along a salinity gradient with the slope of the CO₂ response positively related to soil organic C availability. Temporal measurements of net soil GHG fluxes at 4 sites (2 unoiled, 2 oiled) in Terrebonne Bay from 2012-2016 showed significant seasonal and inter-annual variability. Oiled sites consistently had lower CO₂ and N₂O and higher CH₄ fluxes with differences persisting for 4 (CO₂ and N₂O) - 5 (CH₄) years post-spill. Increases in CO₂ fluxes with distance into the marsh were much stronger in unoiled than oiled sites whereas CH₄ fluxes showed different patterns in oiled (-) and unoiled (+) sites. Laboratory incubations showed CO₂ production was greater in unoiled marshes and comparable between *Spartina* and *Avicennia* soils; CH₄ production was greater in oiled marshes and *Avicennia* soils; N₂O was higher in unoiled marshes and *Avicennia* soils. These results have important implications for wetland carbon models and how fluxes may respond to both episodic (e.g., oil spills) and climate-related (e.g., altered salinity and vegetation) stressors.

What Drives the Long-Term Recovery of Saltmarsh Benthos after Oil Spills; Recovery of Foundation Species, Soil Quality or Food Resources?

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We monitored the salt-marsh meiobenthic community in northern Barataria Bay, Louisiana with bi-annual collections at reference, moderately and heavily oiled sites following the Deepwater Horizon oil

spill. Here we examine environmental factors that influenced recovery over a 4.5-year period beginning 2 years after the spill. Multivariate statistics were used to determine which factors influenced variation in the benthic community. A Distance-Based Linear Model utilizing PERMANOVA software found that 8 factors explained ~25% of the variation in the community. Contributions from 5 variables (*Spartina* aboveground biomass explained 8.2%, chlorophyll a explained 7.1%, *Juncus* aboveground biomass explained 5.3%, dead aboveground plant biomass explained 3.2% and bulk density explained 1.4% of the total variation) were significant. Live belowground biomass of roots and rhizomes, pH and total petroleum hydrocarbons explained an insignificant amount of variation. Correlation analysis using Kendall's Tau revealed that the abundances of nematodes, copepods, ostracods, tanaids, amphipods and juvenile bivalves and gastropods were positively correlated with *Spartina* aboveground biomass and/or with chlorophyll a (and most of these taxa were negatively correlated with dead aboveground plant biomass). Neither kinorhynchans nor the polychaete *Manayunkia aestuarina* recovered within our time frame and both were negatively correlated with total petroleum hydrocarbons and pH and positively correlated with *Juncus* aboveground biomass, dead aboveground plant biomass, bulk density and belowground biomass. Thus, suites of factors influenced recovery, which was highly variable among taxa, but the most important drivers were the recovery of foundation plant species and benthic microalgae.

Recovery of Horse Fly Populations in the Aftermath of the 2010 Deepwater Horizon Oil Spill in Louisiana Marshes

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The Deepwater Horizon oil spill in April 2010 had unprecedented impact on the marine and coastal environments in the Gulf of Mexico. We established the greenhead horse fly (*Tabanus nigrovittatus* Macquart) as a bioindicator of marsh health using population census and genetics. This species is bound to coastal marshes, since its larvae develop as top invertebrate predators in the marsh soil. Immediately after the oil spill (2010-2011) populations of this horse fly crashed in oiled areas of Louisiana marshes with significant impacts on genetic structure detected via microsatellite genotyping. In this follow-up study five years after the catastrophic event (2015-2016) we report signs of recovery of populations in oiled areas. Fly numbers are on the rise. Formerly detected severe genetic bottlenecks in oiled populations have disappeared. Migration into oiled areas replenished formerly depleted horse fly populations in impacted regions. Parameters of family structure that had been impacted by the oil spill (number of breeding parents, effective population size, number of family clusters) have rebounded to levels similar or exceeding those in non-oiled control areas. Although many species on higher trophic levels still suffer in the aftermath of the oil spill, it is encouraging to report signs of recovery at the level of a top arthropod predator of the invertebrate community in salt marshes.

Saltmarsh Insect Community Response to Oil and Hurricane: A Lesson in Resiliency

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In the aftermath of the Deepwater Horizon oil disaster in south Louisiana saltmarshes Hurricane Isaac inundated oiled and unoled sites with storm surge for ~72h. The result was a "pulse" disturbance on

an already stressed ecosystem. The subsequent impact of sustained saltwater inundation allowed us to test hypotheses about how the insect community is structured and whether that community is driven by stochastic or deterministic processes. Salinity impacted species composition, and random dispersal induced by the hurricane was short-lived. Decreases in β diversity and the emergence of environmental effects on insects suggested a reduction of the importance of stochastic forces. One of the reasons is likely because *Spartina* dominated the marsh and wasn't radically affected by the storm. The close proximity of refuges allowed for insects to repopulate the sites in a deterministic pattern in the later stages of succession. Within a year of the hurricane, species composition progressively returned after the initial divergence caused by Isaac. Our results indicate that marsh insects exhibit high resilience to hurricanes of the strength of Isaac and prolonged storm surge.

Genetic Assessment of the Long-Term Diet of Seaside Sparrows (*Ammodramus maritimus*) in Response to Oil and Altered Prey Communities

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Seaside Sparrows (*Ammodramus maritimus*) reside in the coastal saltmarsh along the Gulf of Mexico where they act as top-level consumers in the terrestrial food web, preying on insects and other small invertebrates. Since they are non-migratory and abundant, Seaside Sparrows are an excellent indicator species for interpreting the integrity of the terrestrial food web after large-scale disturbances such as the 2010 Deepwater Horizon oil spill. Following the spill, carbon derived from DWH oil was found in sparrow crop contents and incorporated into their feathers, indicating birds interacted with oil that persisted in their environment. Interestingly, tissue analysis of sparrows showed birds fed at the same trophic level on oiled and unoiled plots, which contrasts with the recorded crashes of marsh invertebrate populations after oiling. To address this paradox and identify any long-term changes in sparrow diet following the spill, we identified the species of invertebrates consumed by sparrows on oiled and unoiled (control) sites in the seven years following the spill. We used Sanger sequencing and DNA metabarcoding of the COI mitochondrial gene to identify the species of prey in 400 fecal samples, gizzard contents, and ligature samples (food collected from nestlings) in Barataria Bay, Louisiana. DNA metabarcoding takes advantage of a short, conserved region of DNA to easily and reliably identify many prey species at once, allowing for a robust analysis of the prey present in each dietary sample. After identification of prey items, dietary makeup was compared across sites (oiled vs unoiled) to evaluate the impact of oiling on diet composition. By understanding how this high-level predator responded to disruptions in prey communities following the DWH disaster, we can begin to more clearly understand long-term resiliency in the face of future large-scale ecological disturbances in the saltmarsh ecosystem.

Daily Nest Survival and Nest Predators of Seaside Sparrows (*Ammodramus maritimus*) Following the Deepwater Horizon Oil Spill

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The 2010 Deepwater Horizon oil spill affected hundreds of kilometers of saltmarsh, potentially impacting the birds that nest there. We monitored Seaside Sparrow (*Ammodramus maritimus*) nests from mid-March through June of 2012-2017 in Louisiana salt marshes affected by the Deepwater Horizon oil spill. A majority (ca. 70%, n = 286) of nests failed, with 83% of nest failures due to predation. Estimates of daily nest survival (DNS) were marginally lower on oiled plots (0.897 ± 0.009 SE) compared to unoiled plots (0.919 ± 0.010) in all 6 years. Even so, plot-level oiling status was not a top variable in models of DNS. Instead, vegetation structure and timing of nest initiation did a better job of predicting DNS. Plots that received oil tended to be in more exposed, south-facing shorelines. This orientation is associated with shorter vegetation structure, which, may make sparrow nests easier for predators to find. Video cameras provided the first empirical identification of Seaside Sparrow nest predators along the Gulf Coast: Marsh Rice Rat (*Oryzomys palustris*), American Mink (*Neovison vison*), and Squareback Marsh Crab (*Armases cinereum*). In the timeframe of this study, DNS of Seaside Sparrows appeared to be influenced by inherent plot characteristics more strongly than any lingering effects of oil, but additional work is needed to better understand possibly interrelated effects of oiling, predator density, vegetation structure, and weather.

Shrinking Fish, Changing Food Webs, Apex Predators and Oil

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Does fish size change with a warming coast? The size-at-age of one million *Brevoortia tyrannus* and *B. patronus*, harvested from Maine to Texas over 65 years was analyzed to determine if there is evidence of changes consistent with the well-documented temperature change rules; there is. The average weight and length for age 3, 4 and 5 year old fish declined on both the Atlantic and Gulf of Mexico (GOM) coasts. For example, the average size of a 4-year old fish captured in 2010 from the Atlantic and Gulf of Mexico, relative to an average 4-year old fish captured in 1987, is 15% and 11% lighter, respectively. Small changes in the year-to-year size of same-aged fish were closely related to variations in the annual air temperature for fish on both coasts. The size-at-age of GOM fish are also smaller during overfished periods compared to under-fished periods by 10 to 24%, and decrease about the same percent as indicated by temperature changes. The most plausible explanation for these size changes is that they are a consequence of recent coastal and oceanic warming. The future of menhaden fish size-at-age (one-half of the US Atlantic fish harvest by weight) will be, it seems, even smaller as oceanic temperatures rise. There are consequences of these size changes for the community of its offshore and estuarine predators, regardless of how well we understand and model them. Older fish produce two to three times more eggs than females aged 3 years old, the percent body oil increases with age and size for clupeids, and the gape size and swimming speed of prey and predator changes with size. An example will be given using a 37-year-old data base for the Gulf of Mexico to demonstrate how predator stress changes with the diminished prey sizes before and after the BP oil spill.

Evaluating Trophic Relationships in a Saltmarsh Food Web Using Stable Isotopes

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Responses to the 2010 Macondo Oil Spill varied among different taxonomic groups. For instance, fishes inhabiting the marsh surface did not exhibit clear differences in either community composition or population characteristics between oiled and unoled sites, despite clear evidence of physiological impacts on individual fish. In contrast, marsh insects and spiders responded to the effects of hydrocarbons. Both insects and spiders are components of the marsh food web and represent an important trophic link between marsh plants and higher trophic levels. Because differences in oil impacts throughout the marsh food web have the potential to significantly alter food webs and energy flow pathways and reduce food web resilience, our goal was to quantify differences in marsh food webs between marshes that were directly impacted by the oil spill and ones that were not to test the hypothesis that oiling has resulted in simpler and less resilient food webs. Diets and food web connections were quantified through a combination of stomach content, stable isotope, and fatty acid analysis. The combination of these three techniques provides a more robust approach to quantifying trophic relationships than any of these methods alone. First, we present the results of the stable isotope approach ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{34}\text{S}$) which focused on samples collected in the spring and fall of 2015 from a range of terrestrial and aquatic consumer species, including insects, mollusks, crustaceans, seaside sparrows, and piscivorous fishes. Niche metrics suggest that trophic structure in these marshes is similar regardless of season and saltmarsh and the three energy channels identified (phytoplankton, detritus, and marsh grasses) are coupled at higher trophic levels.

Evaluating Trophic Relationships in a Saltmarsh Food Web using Fatty Acids

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Saltmarsh ecosystems will undoubtedly continue to face unprecedented change in the coming decades. The identification of food web structures that confer stability to these systems is, therefore, a priority. Here, we use fatty acid profiles to resolve the food web structure and the terrestrial vs. aquatic energetic contribution to consumers from two different saltmarshes located in Barataria Bay, Louisiana. One saltmarsh was directly impacted by the 2010 DHOS and the other was not. Fatty acids are key nutritional components required for normal growth, development, and reproduction, and their biosynthesis largely occurs in primary producers. The fatty acid composition of producers differs—for example, aquatic producers contain higher total omega-3 ($\Sigma n-3$) fatty acid content, whereas terrestrial producers contain a higher total omega-6 ($\Sigma n-6$) fatty acid content—and their ratio is useful to specify reliance on aquatic vs. terrestrial resources. Tissue samples from terrestrial and aquatic primary producers and higher-level consumers (e.g., insects, mollusks, crustaceans, fishes and birds) were

collected during the spring and fall of 2015. We show that the food webs are structured such that upper trophic levels couple separate energy channels (based on detrital, phytoplankton or marsh grasses), regardless of season or saltmarsh. For example, predatory fishes appear to derive their energy from phytoplankton and detrital sources. Although many consumers have a high degree of feeding plasticity, as the nature and availability of food can vary considerably both spatially and temporally, few species exhibited significant shifts in resource use. Finally, we compare the conclusions drawn from fatty acid profiles with simultaneously collected stable isotope ratio data in the same system.

Ixtoc Oil Spill Impact on Coastal Areas of the Southwest Gulf of Mexico

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Four push cores were collected in the Western area of the Yucatán Peninsula near Isla Arenas and Campeche (NE from the Ixtoc well) to assess the impact of Ixtoc-1 oil spill on benthic environment. Coastal foraminiferal assemblages were used as indicators of environmental change. Two of the cores were collected in salt ponds within the mangrove ecosystem (CP-04, IA-04), the third was retrieved 1-2m seaward of the mangroves (IA-03) and the fourth one (CP-05) in the marine area (1m water depth). The benthic foraminiferal assemblages in the marine cores showed relatively constant environmental conditions during the last 100-200 years based on short-lived radioisotope (210-Pb) chronologies. The two inland cores presented an environmental evolutionary trend from salt ponds in the mangrove swamp, towards a higher marine influence during the last century. This evolution could possibly be related to sea level rise. Three of the four cores showed a horizon with hydrocarbon remains in the sediments that could be related to the Ixtoc-1 oil spill, where benthic foraminiferal density decreased. Diversity did not show a clear trend, relating to the difference in sub-environment or environmental evolution at each site. The amount of hydrocarbon remains in the sediments is minor, and no damage to the morphology of the foraminifera was apparent. Above this horizon, neither the sediments, nor the foraminiferal faunas showed traces of hydrocarbon remains. This suggests that the amount of oil reaching the coastal environment in this region was not large enough to cause massive damage to foraminifera.

Preparing a Defensible Ecosystem Baseline for Coastal Marine Environments Using Mechanistic Models

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To elucidate perturbations to habitats and aquatic resources, the establishment of a defensible baseline for ecosystem productivity is an important criterion for assessment studies such as Natural Resource Damage Assessments (NRDA). Using this baseline within mechanistic models can help determine resulting impacts from interacting perturbations by providing a quantitative platform for

organizing disparate data into a meaningful system for testing representations of the extant ecosystem. Quantitative estimates for specific resources can then be compared to measured estimates of overall productivity. In order to establish the overall NRDA baseline productivity for the Deepwater Horizon Oil release, the open source EPA fate and effects ecosystem model AQUATOX, was calibrated to simulate effects on key estuarine habitats in Mississippi Sound and Mobile Bay. Secondary productivity of each of these habitats is represented by a food web for which each state variable represents a specific taxonomic or trophic group, and average trophic level is explicitly calculated within the model. Model-estimated productivity for each habitat compared well with published estimates and with generally accepted ecological observations. Variation in secondary productivity across similar habitats was responsive to environmental factors such as salinity and turbidity, and to physical site characteristics. Simulation of these habitat characteristics proved useful for bracketing the potential variation in ecological services for each habitat, and for establishing baseline productivity for NRDA purposes; it also can provide guidance for ecosystem restoration design initiatives. The simulated systems also proved to be useful for estimating injury from oil exposures and to distinguish loss of productivity due to oil from loss due to other stressors, such as freshwater diversions. The analysis demonstrates the effectiveness of the AQUATOX model as a tool to quantify levels of injury by comparing the results of a baseline ecological model, calibrated and verified with pre-oiling observations, with post-oiling results. This alternative approach to injury assessment can be used to validate single-species approaches and also to evaluate the injury to, and recovery of, an integrated ecosystem.

The Sea Level Rise Tipping Point of Delta Survival

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We estimated the sea-level rise (SLR) rate when thirty-six of the world's coastal deltas began forming in the last 10,000 years. These deltas are from a variety of environmental settings with regards, for example, to regional tides, geological subsidence, precipitation, and temperature. A common global influence that occurred then was a sharp reduction in the rate of SLR, which is, in general, attributed to be the cause of their formation. We corrected the age estimates for 36 delta ages that were originally based on uncalibrated C14 dating to arrive at an average age of $8,109 \pm 122$ BP and a median age of 7967 BP. The SLR at the average delta initiation is from literature estimates of the SLR rates determined from dating corals, molluscs and peats and was around 5 mm yr^{-1} in the Atlantic and 6 to 10 mm yr^{-1} in the Pacific. We argue that the tipping point for delta formation and regression are essentially similar. Two estimates of the upper threshold for coastal wetland accretion (survival), for example, are also at this tipping point. The SLR this century is accelerating to being several times higher than this tipping point and so we suggest that delta retreat and probable collapse appears highly likely within the next few decades.

Monitoring, Data Management, and Analysis

MDA-001: Northern Gulf of Mexico Marine Mammals: Baselines, Trends, Threats, and New Methodologies

Whale and Dolphin Action Plan for the Gulf of Mexico: A Five-Year Vision

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The Gulf of Mexico is a heavily utilized and industrialized ocean basin. It supports oil and gas development, commercial and recreational fishing, shipping, military operations, tourism, and a host of other human activities, all of which are increasing. The Deepwater Horizon oil spill -- the largest in U.S. history -- left ocean, coastal, and estuarine habitats permanently altered. The Gulf continues to experience natural perturbations caused by coastal erosion and extreme weather events. Knowledge is lacking as to how these human-caused and natural events are individually or collectively impacting marine mammals in the Gulf. Efforts to address damages resulting from the Deepwater Horizon oil spill have resulted in multiple sources of funding to restore Gulf marine species, including whale and dolphin stocks injured by the spill. The restoration priorities identified by the Deepwater Horizon Natural Resource Damage Assessment Trustees for oil spill-affected stocks overlap to a large degree with priority research and recovery actions for all 56 Gulf of Mexico whale and dolphin stocks. To leverage restoration efforts with ongoing research and monitoring efforts, a coordinated and cooperative approach is needed amongst Gulf entities. The National Marine Fisheries Service (NMFS), in partnership with other federal agencies working in the Gulf, has developed the Whale and Dolphin Action Plan to guide management, research, and monitoring activities across the Gulf. The primary audience for the Whale and Dolphin Action Plan is federal and state resource managers, Deepwater Horizon Trustees, academic and non-profit organizations, and funding entities. The plan provides a vision for priority actions that would restore and recover whale and dolphin stocks in the Gulf, both nearshore and offshore. The broad dissemination and use of this "go-to" guide amongst managers and funders will facilitate greater cooperation and assurance that high priority research needs for whales and dolphins in the Gulf are being met.

Developing Baselines Using Bottlenose Dolphins in St. Andrew Bay, Florida to Inform Restoration Efforts following the Deepwater Horizon Oil Spill

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Common bottlenose dolphins (*Tursiops truncatus*) in the northern Gulf of Mexico (nGoMx) are exposed to numerous environmental stressors, including harmful algal blooms, infectious disease, and chemical pollutants. Such stressors have caused at least four Unusual Mortality Events in the nGoMx over the past 2 decades. Three of these mortality events were attributed to harmful algal toxins and the other,

which was unprecedented in magnitude and duration, was linked to the Deepwater Horizon (DWH) oil spill. St. Andrew Bay (SAB), located in the Florida Panhandle, did not receive significant DWH oiling, and the majority of dolphin carcasses following the DWH spill were recovered from areas to the immediate west (Mississippi and eastern Louisiana coasts). However, dolphins in SAB and adjacent coastal waters have been exposed to many of the other stressors that affect nGoMx stocks. Thus, information on stressor exposure and health of SAB dolphins could be used as a comparative baseline for other dolphin populations that are still recovering from DWH impacts. We conducted small vessel, photographic-identification surveys and remote biopsy sampling during two seasons in both 2015 and 2016 in SAB and adjacent coastal waters. Dolphin abundance was relatively stable in SAB across seasons while an influx of coastal animals was observed during spring. For the 392 distinctive individuals in the SAB catalog, the majority (93%) were sighted exclusively in SAB or coastal waters. Contaminant concentrations differed significantly between SAB and coastal dolphins. These differences may be attributed, in part, to a Superfund site in SAB associated with DDT contamination. SAB male dolphins had mean DDT levels (67 µg/g lipid; 50 - 89, 95% CI) that are currently the highest in the southeastern U.S. Future research, e.g. health assessments and tagging projects, could build upon these initial results and inform future restoration efforts.

Examining the Effect of Multiple Disturbances on Population Persistence with Application to Marine Mammals

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Environmental disturbances such as oils spills, floods, and fires can have long-term effects on populations. Determining whether a population is able to recover from a disturbance is an important focus of conservation. However, the concept of recovery assumes that the effects of a disturbance eventually diminish while, in many situations, it is unlikely that a population will not experience future disturbances. When faced with reoccurring disturbances, focus often switches from population recovery to population persistence. We can model the occurrence of repeated disturbances mathematically using a two-state Markov chain to describe the effects of a disturbance on a population. In this model, there are two possible environmental states, either the undisturbed environment or a disturbed environment that has a detrimental effect on the population. Disturbances occur stochastically with their frequency depending on the average length of effect of a disturbance and the average time between disturbances. The effects of these disturbances are reflected in the population of study in the form of reductions in vital rates. Using such a model formulation, we examine the long-term (stochastic) population growth rate and address questions regarding the persistence of a population. An application to a stage-structured model for a sperm whale population will be presented to study the possible effect of oil spills on the persistence of sperm whales in the Gulf of Mexico.

Is Blubber a Suitable Matrix for Endocrine Assessment in Cetaceans?

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Cetaceans in the Gulf of Mexico exhibited many physiological changes following exposure to crude oil from the Deepwater Horizon oil spill, including altered endocrine function and impaired reproduction.

* Student presenter

Continued studies could help to better characterize these changes and monitor indicators of endocrine health as populations recover. Our research has focused on developing techniques for accurate and efficient assessment of endocrine function in cetaceans. Blood is commonly used for endocrine assessment in wildlife because circulating hormone values reflect systemic homeostasis; however, collection of blood from cetaceans is difficult due to legal and logistical limitations. This highlights a need for alternative matrices and methods for assessing endocrine status in cetaceans. Blubber is one possibility as it can be collected remotely by non-lethal dart biopsy, and blubber steroid hormone measurements have been used for qualitative assessment of physiological changes (i.e. pregnancy, sexual maturity, and stress). However, it is currently unclear whether steroid hormone concentrations in blubber quantitatively reflect circulating concentrations and systemic endocrine status. Thus, we used liquid chromatography-tandem mass spectrometry (LC-MS/MS) to simultaneously measure up to 11 steroid hormones in matched blood and blubber samples from bottlenose dolphins (*Tursiops truncatus*), and then modeled the relationships between blubber and blood hormone concentrations. We found that blubber steroid hormone measurements are moderately predictive of circulating concentrations of testosterone, androstenedione, and progesterone but not 17-hydroxyprogesterone, cortisol, and cortisone, suggesting that blubber is best used for qualitative assessments until further refining of these predictive models is possible.

A New Method for Estimating the Probability of Detection of Cuvier Beaked Whales from Passive Acoustic Data near Gulf of Mexico Oil Spill Site

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The probability of detecting a cue from marine mammal echolocation clicks is an important parameter for estimating the density of species in a certain geographical region. In this study, we consider data collected in years 2007, 2010 and 2015 in Gulf of Mexico in 2 locations, 9 miles (northern site) and 25 miles (southern site) away from the Deepwater Horizon oil spill site. A new method for estimating the detection probability using passive acoustic data is proposed. The detection process consists of two parts: 1) acoustic clicks are produced and travel to a hydrophone and 2) the clicks are recorded on a hydrophone then processed by a detection algorithm and classified as valid cue detections. Failure in either part of the process could result in an actual cue not being counted in the density estimation, which in turn yields lower density estimates. To account for the factors in either part of the process, we calculate the probability of detection by multiplying the probability of success of these events. We use the passive sonar equation to predict a synthetic set of signal-to-noise ratios (SNRs) of received clicks where the distributions for the source level, orientation, whale position and depth are obtained from literature. A detection and classification algorithm is used to process the data set to obtain the ground truth clicks from the manually detected clicks. A statistical distribution on these processed data sets is used to find the distribution of success probability for each of the SNRs of one of the events mentioned above. Application of a kernel probability distribution on the synthetic set of SNRs gives the distribution of the detection probability for the other part of interest. Finally combining the above information in a Monte Carlo simulation, we obtain the average probability of detection as a function of SNR. Our results suggest that, except for the northern site in 2007 where the average detection probability was around 16.94%, the average probability of detection varied from 12.36% to 13.72% for all other sites and years. Probability of detection obtained using this new method are within 0.16% to 0.43% of the estimates using the method followed previously by Kusel (2011). [This research was made possible by a grant from The Gulf of Mexico Research Initiative.]

* Student presenter

Trends in Deep-Diving Whale Populations in the Gulf of Mexico: 2010 to 2016

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The offshore Gulf of Mexico (GOM) provides habitat for a diverse array of deep-diving whales including: sperm whales, beaked whales and dwarf/pygmy sperm whales. As top predators, these animals are thought to be a significant component of the GOM marine ecosystem. Monitoring the status of these populations is challenging because they are primarily present in pelagic waters and often forage at depth. Passive acoustic methods have been developed that use sound produced by cetaceans to detect their presence and to estimate population densities. This study presents six years of acoustic monitoring data collected since 2010; animal density are estimated using two methods, one based on the number of echolocation clicks, and another based on the detection of animal groups during fixed time-bins. Sperm whales (*Physeter macrocephalus*) and pygmy and dwarf sperm whales (*Kogia breviceps* and *Kogia sima*) are present primarily in the northern GOM. Beaked whale species include Gervais' (*Mesoplodon europaeus*), Cuvier's (*Ziphius cavirostris*), Blainville's (*Mesoplodon densirostris*) and an unknown species of *Mesoplodon* sp. beaked whale. At sites in the northern GOM, Gervais' beaked whales were present throughout the monitoring period, but Cuvier's beaked whales were present only seasonally, with periods of low density during the summer and higher density in the winter. Both Gervais' and Cuvier's beaked whales have a higher density in the southeastern GOM throughout the monitoring period. Short and long-term trends in GOM deep-diving whale densities are examined for the period 2010 - 2016.

Study of Sperm Whale's Long-term Abundance Trends in the Northern Gulf of Mexico

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Passive acoustic monitoring is becoming a lead approach for assessing abundances of different species of deep-diving marine mammals. To estimate the regional population density variability for endangered sperm whales in the Northern Gulf of Mexico (GoM), we synthesized passive acoustic data, collected by the Littoral Acoustic Demonstration Center-Ecological Monitoring and Modeling (LADC-GEMM) consortium in the Mississippi Canyon area between 2001 and 2017 using a combination of fixed and mobile monitoring sensors. We compare the abundances of the sperm whales in different years before and after oil spill. The results show that sperm whales are present in the region between 2001 and 2017 but may have lower activity during winter months. The data processing results indicate the habitat preference shift for sperm whale after the 2010 oil spill with activities higher at the sites further away from the spill site. The results strongly advocate for continuous long-term spatially distributed acoustic observations to fully characterize sperm whale population variations in the Gulf of Mexico. and to understand how environmental disasters and stresses affect different species.

Comparisons of Sperm Whale Lengths in the Northern Gulf of Mexico

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Sperm whales (*Physeter macrocephalus*) produce short duration acoustical clicks while diving to search for food, each click composed of several pulses. The time interval between consecutive pulses, the

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interpulse interval (IPI), can be used to estimate the length of the whale. Whale length information can be useful in determining the age and predominate sex of the whale population in the Gulf of Mexico. Automatic measurements of IPIs using discrete wavelet transforms and autocorrelation-based methods are used in this work to obtain estimates of the IPIs. The Littoral Acoustic Demonstration Center - Gulf Ecological Monitoring and Modeling (LADC-GEMM) project collected underwater acoustic data in the northern Gulf of Mexico during the summer of 2015. Comparisons between sperm whale lengths at different EARS locations gives insight on effects of the BP oil spill on whales of different lengths and consequently of different age and sex. [This research was made possible by a grant from The Gulf of Mexico Research Initiative. Data are publicly available through the Gulf of Mexico Research Initiative Information & Data Cooperative (GRIIDC) at <https://data.gulfresearchinitiative.org>.]

Comparing the Performance of Bottom-moored and Unmanned Surface Vehicle Towed Passive Acoustic Monitoring Platforms for Sperm Whale Studies

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Passive acoustic monitoring (PAM) can complement visual observations to provide more efficient monitoring of the distribution and abundance of marine mammal species. Sperm whales are highly vocally active, produce wideband clicks in well-defined time patterns and can be easily distinguished from other marine sounds. Three different PAM platforms recorded data in overlapping time periods in the vicinity of the 2010 oil spill site: unmanned surface vehicle towed array, bottom-moored buoys, and Seaglider-mounted hydrophone. The detection rate of bottom-moored buoys and unmanned surface vehicle towed array were compared to investigate their relative efficiency in detecting sperm whales. Detection events were obtained using independent detectors for each platform and then compared by feeding data through a common detector. The results of this study aid in the development of cost-efficient PAM methodology for mitigation and environmental impact assessment purposes. [This research was made possible by a grant from The Gulf of Mexico Research Initiative.]

Species-Specific Density Estimation of Beaked Whales in the Northern Gulf of Mexico Using Long-term Passive Acoustic Monitoring

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The Littoral Acoustic Demonstration Center (LADC) has recurrently gathered passive acoustic monitoring data in the Gulf of Mexico (GOM) since 2001. From June to October of 2015, bottom-moored hydrophones collected recordings at a sample rate of 192 kHz in the pelagic zone at several sites in the northern GOM. Currently a primary goal of LADC is the development of population density estimates and behavioral studies of regional marine mammals for ecological model support. Beaked whales are of particular interest as they remain one of the least understood groups of marine mammals, and abundance estimates are lacking. In this study, a multi-stage detection and classification routine is implemented to mine the 2015 LADC data for echolocation transients from regional beaked whale species. Matched filtering and cluster analysis are applied to the results of a band-energy-based click detector to isolate signals from the beaked whale family. Species-specific biosonar clicks are then classified by spectral and geometric features using a feed-forward neural network. The results are

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statistically analyzed to estimate population densities in the northern GOM, and reveal temporal activity trends.

What we've learned about the health of Gulf of Mexico marine mammals: A retrospective

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MDA-002: Remote Sensing Assessment of Surface Oil and Related Ocean Observing

Where Did the Deepwater Horizon Surface Oil Go? -A Time Series of Advection and Fate, 24 April - 3 August 2010

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A now-cast surface oil advection model was developed to investigate the fate of the Deepwater Horizon (DWH) surface oil in the Gulf of Mexico (GoM). Inputs to the surface oil advection model included: 1) time-series of magnitude and distribution of surface oil in the GoM from the DWH discharge throughout the 102 day interval from 24 April 2010 to 3 August 2010, as quantified by 166 Synthetic Aperture Radar (SAR) images, 2) winds 10 m above the sea surface from the North American Mesoscale Forecast System (NAM), 3) ocean currents from the HYbrid Coordinate Ocean Model (HYCOM), 4) the oil's volatile fraction data estimated by the Oil Spill Contingency And Response (OSCAR) weathering model, and 5) daily magnitude and spatial distribution of aerial dispersant application and burning operations compiled by National Oceanic and Atmospheric Administration (NOAA). Every 12 hours, the surface oil advection model was initialized with the surface oil volume distribution data estimated from SAR images. The weathering and fate data were subtracted from the modeled surface oil volume at the end of 12-hourly time steps. Model results were compared to SAR estimates of the magnitude and distribution of surface oil in order to provide a quantitative and spatial estimate of where the oil slicks formed and dissipated in the GoM during the DWH event. Modeling indicated that the DWH surface oil predominantly dissipated in the Northeastern GoM. The preliminary results of the surface oil advection model regarding the extent of the shoreline oiling agrees well with previous studies.

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Tactical Oil Spill Observations with Drones, Satellites, and Drifters

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During oil spills, responders have relied on the crucial aerial support to guide recovery or containment maneuvers. Operations of manned aircrafts can be costly and take hours or even days to prepare. In contrast, Unmanned Aerial Systems (UAS) offer an alternative way for aerial surveys with the advantage of simple, fast operations. We have designed an aerial oil spill response system where remotely sensed images by a UAS are assessed through real time telemetry, which can then be used to direct fleet vessels to locations where skimming or containment will have the highest remediation values. The UAS system consists of a multi-rotor UAS rigged with high-resolution optical and thermal cameras. The system has been tested through experiments in the Gulf of Mexico at a site with recurring oil release. Results demonstrated that the system is capable of discerning different oil thicknesses in a qualitative way in real time with the optical and thermal cameras, although interpretation of the optical and thermal images is not straightforward (e.g., thermal signal of floating oil not only depends on its thickness but also depends on its equilibrium state with water, time of measurement, and light exposure history). The UAS system was also used extensively in support of drifter experiments at tactical locations to observe and model oil transport. Here we present the experimental results through integration of observations from the UAS system, drifters, satellites, and in situ measurements of oil thicknesses.

Assessment of Offshore Oil/gas Platform Status in the Northern Gulf of Mexico Using Multi-source Satellite Time-series Images

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With the further development of offshore oil/gas production, the environmental pressure from offshore platforms is ever-increasing. Understanding the detailed platform status is crucial to local ocean management. The records of platform status may be incomplete or even unavailable because offshore platform abandonment have generally not been properly planned, designed and executed. The daily-growing optical/SAR images provide an unparalleled record of the Earth surface and can be used to retrieve status of offshore platforms. However, the ubiquitous false alarms and the poor geometric accuracy of images acquired by early sensors, challenge the feasibility of assessing platform status from space. Here, we demonstrate a time-series remote sensing (TSRS) analysis approach, which adopts two strategies to overcome the above challenges: (i) a stepwise optimization strategy from individual image to time-series images; and (ii) a geo-correction strategy from qualified images to poorly geo-referenced images. The status of platforms are then determined based on both the high and poor geometric accuracy images along the whole temporal span. The TSRS approach has been applied to a data-well-documented area-the northern Gulf of Mexico based on more than 25,000 moderate resolution optical/SAR images acquired from eight satellites. A total of 9,260 platforms has been detected, and their status have been further determined. Comparing with BSEE platform database, we found 98.84% of active BSEE platforms (BSEE-AP) have correctly coincided with active platforms derived by TSRS, and total of 82.04% detected platforms by TSRS are confirmed by BSEE

platform database, BSEE pipeline database, Suomi-NPP NTL products and high resolution images. Further site-specific validation of results indicated that only 18 (4.44%) platforms are wrongly detected compared to the “true” data generated from high resolution images. Our findings suggest that TSRS approach is a simple, robust, and cost-effective way to assess the offshore platforms status. This approach may powerfully help enhancing the imperfections of the existing offshore oil/gas platform database and narrow down the future field investigation.

Design of Adaptive and Dynamic Offshore Oil Spill Wireless Sensor Networks

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Wireless Sensor Networks (WSN) is an emerging technology which consists of small, limited powered and low-cost devices that have the capability of computation, sensing and wireless communication. Sensor nodes deployed to detect and monitor oil-spill can collect and deliver data to the sink without requiring manual control. Remote Sensing is an alternative technology but has limitations like spatial & temporal resolution. We have developed the framework for an adaptive and dynamic WSN that will enable rapid detection and monitoring of oil-spill. We have considered various aspects of WSN that include routing, localization and data exchange. Routing and localization were given more consideration as their implementation becomes a challenge with non-stationary sensor nodes. Proposed WSN requires constant surveillance of the area of interest which needs proper routing of data. The routing strategy for dynamic WSN may introduce data overload, and our methodology is capable of controlling it, by adapting to the available resources and requirements. We have proposed a method that uses TDOA for sensor localization with the use of few anchors. Our protocol uses the proposed localization method for periodic accurate location detection of non-stationary sensors, which facilitates the prediction of sensor movement along the ocean with the use of predictor i.e. velocity drift. Architectural challenges for such system are also discussed considering the dynamics of the ocean.

Remote Sensing of Persistent Oil Slicks in Mississippi Canyon 20

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Persistent oil slicks have been observed in and near the MC-20 lease block, which is located approximately 20 km from South Pass Louisiana. The site is the former location of an oil production platform that was destroyed in 2004 by Hurricane Ivan. Possible sources for these slicks include ongoing releases from the complex of wells associated with the platform, residual oil pockets dispersed in the sediment that buried the site after the hurricane, and putative natural seeps. Aerial photographs of floating oil in MC-20 consistently show a distinctive, linear slick origin. Comparison of a georectified aerial photograph with a site plan of the seafloor wreckage indicates an origin directly over the fallen platform, as opposed to the well-bay. Analysis of over 158 synthetic aperture radar (SAR) images collected from 2006 to 2017 show oil slicks with an average area of 15.3 km² (stdev 15.13) originating an average distance of 890 m (stdev 1416) from the well-bay. Best evidence therefore indicates releases from the well complex rather than points of origin dispersed across the block. Hindcast modeling of oil slick length will be used to improve estimates of surface residence time for the oil and rates of discharge.

Monitoring Acoustic Signature of Deep-sea Hydrocarbon Seeps in the Gulf of Mexico

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The seepage of hydrocarbons released from marine seeps varies on time scales from decadal to sub-hourly. Monitoring the upward velocity of hydrocarbons over time contributes to understanding the gas bubble processes, including correctly modeling bubble sea-gas exchange, natural loading of hydrocarbons in the marine environment, and global flux to the atmosphere and oil on the sea surface. The seeps also form a natural test bed for development of sensors and techniques to measure the upward velocity component generated by the seep. Here, we report on an application of an AUV to identify natural seeps in the Green Canyon block 600 of the Gulf of Mexico during 2 days of June 2017. The survey site was 2200x1600 m² at a depth of 1200 m. Near-bottom multibeam backscatter, side-scan sonar mosaic and chirp sub-bottom profiles were collected using an AUV. The low fly altitude (40 m above the seafloor) allowed water-column profiles to be collected with high resolution by the Kongsberg EM2040 at 200 kHz frequency. A comparison of these results is made with acoustic backscatter collected in 2014 and 2015 using two shipboard multibeam echosounders (Kongsberg EM122 and EM302, respectively) for changes in number and location of seepage within the GC600 block. Seeps identified from the EM2040 backscatter intensity were also visited with a Comanche ROV for visual inspection. An oily plume was selected for further investigations with acoustic sensors deployed in September 2017 to monitor temporal variability over a period of 3 months. Concurrent measurements include a vertical array of conductivity/temperature instruments and two video (VTLC) cameras for identifying visual variability of the seep and will provide invaluable reference data for our acoustic measurements.

Satellite Mapping of Sea Surface Salinity in the Northern Gulf of Mexico: Near Real-time Data Products

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Sea surface salinity (SSS) is an important parameter to characterize physical and biogeochemical processes in the ocean. Yet its remote estimation in coastal waters has been difficult because 1) satellite sensors designed to “measure” SSS lack sufficient resolution and coverage, and higher-resolution ocean color measurements suffer from optical complexity when used to estimate SSS; and 2) algorithms developed for coastal oceans are not always applicable under all circumstances. In the northern Gulf of Mexico (GOM) this challenge was addressed through algorithm development and product generation. The former was focused on modeling, validation, and extensive tests in contrasting environments, and the latter was focused on classifying the ocean conditions where the model is applicable. Satellite remote sensing reflectance ($R_{rs}(\lambda)$) at 412- 667 nm were used to train the SSS model, and the developed model had root mean square error (RMSE) of ~1.2 and coefficient of determination (R^2) of 0.86. However, the model is not applicable for upwelling cases, because the implicit assumption between colored dissolved organic matter and salinity no longer holds true for upwelling case. Therefore, anomalies in sea surface temperature (SST) are used to delineate upwelling pixels in satellite imagery, which are masked in the satellite-derived SSS maps for near real-time applications. In addition, to increase the data quantity in the daily satellite SSS maps, we retrained and reevaluated the SSS model by relaxing the data quality control in the matchups between field SSS and

* Student presenter

satellite $Rrs(\lambda)$. Statistically, the effects of increased data quantity and reduced data quality in both model tuning and model application to satellites are compared and discussed.

Identifying Seasonal Trends in Physical -Biological Properties and Anomalies across the MS Shelf Waters between Coastal and Offshore Waters

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The seasonal variability in surface bio-physical properties across the Mississippi (MS) shelf is described using VIIRS satellite and ocean model products. Ten selected regions spanning east to west from the MS Sound to the shelfbreak were used to determine the seasonal chlorophyll, backscattering, euphotic depth, sea surface temperature, salinity and currents for both the nowcast and anomalous properties. The MS Shelf water properties vary both spatially between offshore waters and coastal MS Sound waters, and temporally fluctuate throughout the year. Seasonal variability in MS River discharge, as well as that of other rivers into the Mississippi Bight, offshore circulation and atmospheric conditions impact shelf water bio-physical cycles and relationships along the shelf. The seasonal relationships between the physical and biological properties were determined for different regions across the shelf and show the seasonal eastward movement the MS river plume. Results show correlation between salinity and ocean color, specifically chlorophyll and particle scattering. Seasonal trends of the MS Sound bio-physical properties are compared with the seasonal cycle of offshore Shelf regions. Seasonal dynamic anomalies bio physical products (DAP) were also determined for the ten shelf regions to identify how changes occur at these selected regions. Temporal anomaly products identify gradients of the seasonal trends which provide insight for operations associated with sampling and determining if abnormal seasonal changes are occurring in shelf waters. Additionally, results recognize seasonal MS River plume locations on the shelf and associated bio-physical properties. These results provide a method to determine the seasonal variability of marine surface properties, which can address questions of how events impact the seasonal interactions of biological and physical properties on the MS Shelf.

Evaluation of Episodic Events Using Satellite Bio-optical Observations and Circulation Model Output in the Northern Gulf of Mexico

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We present findings from efforts to determine marine system sensitivity to environmental events in the northern Gulf of Mexico and procedures to monitor regional surface property variability and anomalies. Bio-optical observations (chlorophyll and the diffuse attenuation coefficient) and anomalies derived from the Visible Infrared Imaging Radiometer Suite (VIIRS) and circulation model forecasts from the American Seas Model (AMSEAS) of surface temperature and salinity are used to evaluate three regional episodic events: 1.) the 2016 Bonnet Carré Spillway opening, 2.) the 2016 Flower Garden Banks bleaching event and 3.) Tropical Storm Cindy (2017). These events highlight the spatial and temporal scales of perturbations to the local marine system and provide insight to regional variation in sensitivity to oceanic events. For each event, observations are compared with climatological values across multiple locations showing the relative impact of the events to typical seasonal patterns and the

scale of spatial impact. These results further research efforts to resolve the influence of events on the region and can provide decision-making information to marine managers.

Assessing Coastal Marshes Biomass Using Spectroscopy

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Coastal marshes are important carbon sinks that face multiple natural and anthropogenic stresses. Optical remote sensing is a powerful tool for closely monitoring the biomass of coastal marshes. However, application of hyperspectral sensors on assessing the biomass of diverse coastal marsh ecosystems is limited. This study samples spectral and biophysical data from coastal freshwater, intermediate, brackish, and saline marshes in Louisiana, and develops parametric and non-parametric models for using the Compact Airborne Spectrographic Imager (CASI) to retrieve the marshes' biomass. Linear models and random forest models are developed from simulated CASI data (48 bands, 380-1050 nm, bandwidth 14 nm). Linear models are also developed using narrowband vegetation indices computed from all possible band combinations from the blue, red, and near-infrared wavelengths. It is found that the linear models derived from the optimal narrowband vegetation indices provide strong predictions for the marshes' Leaf Area Index (LAI; $R^2 > 0.74$ for ARVI), but not for their Aboveground Green Biomass (AGB; $R^2 > 0.25$). The linear models derived from the simulated CASI data strongly predict the marshes' LAI ($R^2 = 0.93$) and AGB ($R^2 = 0.71$) and have 27 and 30 bands/variables in the final models through stepwise regression, respectively. The random forest models derived from the simulated CASI data also strongly predict the marshes' LAI and AGB ($R^2 = 0.91$ and 0.84 , respectively), where the most important variables for predicting LAI are near-infrared bands at 784 and 756 nm and for predicting ABG are red bands at 684 and 670 nm. In sum, the random forest model is preferable for assessing coastal marsh biomass using CASI data as it offers high R^2 for both LAI and AGB. The superior performance of the random forest model is likely to due to that it fully utilizes the full-spectrum data and makes no assumption of the approximate normality of the sampling population. This study offers solutions for measuring coastal marsh biomass using CASI data with parametric and non-parametric models, thereby providing useful tools for assessing and monitoring the biomass of coastal marshes in Louisiana and similar coastal marsh ecosystems elsewhere.

Innovative Technologies used for Ocean Observing

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The Gulf of Mexico is important to the United States and all nations in the region for food security, energy, recreation, and fisheries and weather observation. Understanding the pulse of ocean life in the Gulf is vital to the region. The surface and undersea observation of the Gulf would improve our understanding of the region. Existing technologies can be brought to bear on this problem. Lessons learned, and technological advances used in the Ocean Observatories Initiative (OOI) could be applied to implement and increase under sea observations in the Gulf. The OOI manages and integrates data from the over 800 instruments deployed in the Atlantic and Pacific Oceans, in seven arrays. Instruments are located on a myriad of platforms including gliders, AUVs, surface buoys, profilers, inductive mooring cables, and seafloor junction boxes. Overall there are nearly 75 models of specialized instrumentation used throughout the OOI that collect over 200 unique data products. The

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types of instruments used in the arrays are Fluorometers, HD Digital Cameras, Acoustic Doppler Current Profilers, Bio-acoustic sonar and many more. The data collected from these instruments can be analyzed and used to support reef surveys and fisheries movement. The instruments and technologies can also be used to predict and analyze the impact of storms, seismic events and manmade events like oil spills, on our reef systems. Each year, instrument manufacturers improve their instruments, which in turn allows the OOI to increase its ocean observing capabilities, therefore, increasing data collection capability and our understanding of the Gulf of Mexico. The way we use ocean observing technologies, is just as important as the technologies themselves. Instruments deployed on moorings can be moved to collect information, in anticipation of seasonal events and migratory patterns of sea life. Underwater autonomous vehicles can travel long distances while collecting data.

Frontal Density of Northern Gulf of Mexico Derived from Satellite Ocean Color Measurements

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Ocean fronts are where two distinct water masses meet and where enhanced biological activities may be found. In the northern Gulf of Mexico, fronts may be formed under influence of remote (e.g., Loop Current) and local (e.g., river or non-point discharge) forces. Despite their importance in ecological studies, however, to date there are very few studies to document the statistics of their locations in space and time due to technical difficulties in using traditional satellite data products (e.g., inaccurate altimetry data in coastal waters, isothermal temperature during summer, frequent cloudcover in ocean color data products). Here, using a recently developed color index (CI) that is immune to perturbations by sun glint and thin clouds and therefore provides much improved data coverage as compared with traditional ocean color data products, we analyze medium-resolution (500-m) long-term MODIS data (2002 - present) to derive monthly and seasonal frontal density maps. These maps not only show seasonality in frontal boundaries but also interactions of coastal water and river plumes with eddies.

MDA-003: Innovative Mainstream Designs

Gulf of Mexico Collaboration on Long-term Data Management post-Deepwater Horizon

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Post-Deepwater Horizon, several data management entities have worked together to develop common standards, and best practices for collecting, storing and accessing data collected under the Natural Resource Damage Assessment (NRDA) process. In June 2017, NOAA and the Coastal Response Resource Center hosted a workshop on building a long-term data management collaboration. In this workshop, participants agreed to continue working together through ongoing working groups on data management standards, interoperability, and discovery/searchability of data from multiple sources. The presentation will highlight the recommendations from the workshop and the objectives and

outcomes to date from the working group. This effort builds on early work on Environmental Disasters Data Management and outcomes from that effort will also be highlighted.

Swimming Through the Data Deluge to Inform Oil Spill Prevention Needs

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Lessons from different offshore oil spills have highlighted that prevention needs are inherently big data problems. Scientists must wade through the breadth of physical, ecological, and socio-economic data to derive new insights to inform oil spill prevention efforts. To help cope with the data deluge, big data techniques, machine learning, and advanced spatio-temporal analytics can be used to help assess different prevention scenarios. Integrating these data and techniques led to the development of the National Energy Technology Laboratory's Spatially Weighted Impact Model (SWIM). Designed as a decision support tool, SWIM integrates these large data streams from various sources and new geo-data analytics to allow users to evaluate, rank, and compare different research, management and policy scenarios. In this presentation, we will discuss the underlying approach and technology behind SWIM and provide some example applications for offshore oil spill scenarios to demonstrate SWIM capabilities for evaluating different oil spill prevention strategies.

Managing Deepwater Horizon Restoration Project Information for Reporting and Public Access

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The April 2010 Deepwater Horizon (DWH) oil spill in the Gulf of Mexico was the largest offshore oil spill in U.S. history. The subsequent 2016 legal settlement initiated a massive restoration effort to address the natural resources injuries caused by the spill. Given the scale of the injury and the volume of restoration projects to be implemented, the DWH Trustee Council is relying on the DIVER (Data Integration, Visualization, Exploration, and Reporting) data management system to collect, aggregate, and distribute detailed restoration project information. This talk will focus on the types of restoration project data being collected and the ways that DIVER is being used to support public access to project information, data queries, reporting, monitoring, and long term decision making.

Louisiana's System Wide Assessment and Monitoring Program SWAMP

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Managing complex and highly degrading ecosystem of coastal Louisiana in which the natural and socio-economic systems are integrated is inherently difficult. In addition, deltaic environments are uniquely challenged due to the interdependence and delicate balance of water, land and economic systems and future uncertainties regarding the magnitude and rate of climate change impacts. This is further complicated as the strategies adopted for restoration are mostly first-of-their-kind, either in scale or

scope, and do not have well-established boiler plate/text book templates to follow. This necessitated Adaptive Management Program of coastal Louisiana which encourages an integrated and flexible approach to land and water management that considers risk and uncertainty. It promotes solutions that are sustainable even if conditions change by providing a mechanism for robust decision making. The Coastal Protection and Restoration Authority (CPRA) of Louisiana has developed the System-Wide Assessment and Monitoring Program (SWAMP) as an important component of CPRA's adaptive management strategy. SWAMP is designed in a nested fashion to facilitate the integration of project-specific data needs into a larger, system-level design framework. Monitoring and operation of restoration and protection projects will be nested within a larger basin-wide and coast-wide SWAMP framework and will allow informed decisions to be made with an understanding of system conditions and dynamics at multiple scales. This is being implemented on regional scale by monitoring natural system indicators in Barataria Basin as a Pilot implementation program and also in different parts of the state. This presentation intends to inform how the baseline conditions are being quantified and what methods to assess change in the biophysical and sedimentary environments developed to support the strategic implementation and evaluation of restoration projects.

DIVER Application: Accessing Project and Environmental Data and Developing Data Services

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The DIVER application is a data warehouse containing detailed environmental and project data including the majority of Natural Resource Damage Assessment (NRDA) data from the Deepwater Horizon Oil Spill which spans the Gulf of Mexico. The DIVER Explorer query tool was developed to support querying high level information describing organizing of environmental data (e.g. Workplan, Dates, Location) and also detailed information including analytical chemistry results, field measurements, and related information including field sampling forms and photographs. The DIVER Explorer query tool has two main ways for users to query data: Guided Queries and a Keyword Search. The Guided Queries provide users with queries that are developed for specific data types, with the detailed choices required to output results that can be used for further analysis and modeling. Keyword Search is newly developed functionality that supports users entering a fragment of text or whole word, with a result showing the texts occurrence within the 20+ million environmental data records. A user can further refine the result of a Keyword Search by a useful field (e.g. Collection Form or Matrix), and then choose to run a query which results in an output table. All query results in DIVER Explorer create a map with spatial data, a table with results that can be filtered and downloaded, charts showing facets of the data, and ISO-compliant metadata. Some data types include detailed study notes, photos, and the ability to link to unstructured information such as scanned forms or notes. An additional new way to access data is through data services built upon the ERDDAP data server, developed by NOAA. The ERDDAP data server implemented within DIVER provides direct, machine readable access to the data warehouse through a URL. DIVER also generates Web Mapping Services (WMS), which are map layers that can be consumed by mapping applications including NOAA's Environmental Response Management Application (ERMA).

Using Structured Decision Making in Development of a Gulf-wide Avian Monitoring Network

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Despite the importance of the GoM to North American avifauna, no comprehensive, Gulf-wide, bird monitoring program exists. This deficiency was highlighted post-DWH spill, when it became readily apparent that little to no baseline data were available to evaluate the potential effects of the spill on bird populations. To address the myriad of monitoring challenges and complexities across species, habitats, and region-wide the Gulf of Mexico Avian Monitoring Network (GoMAMN) was formed. Comprised of a diversity of conservation partners including state and federal agencies, NGOs, and academic institutions. GoMAMN's broad goal is to define a vision and process for developing the role of bird monitoring in achieving integrated, efficient, and effective GoM management of affected avian species. Utilizing a Structured Decision Making process, GoMAMN developed a set of fundamental objectives coupled with an explicit objectives hierarchy that reflects the goals, objectives, values, and information needs for an integrated Gulf-wide avian monitoring strategy. The fundamental objectives developed include: (1) maximizing the relevancy of monitoring data, (2) maximizing rigor of monitoring projects, and (3) maximizing integration of monitoring projects. In addition, the Network identified 3 over-arching data needs (sub-objectives under #1 above) including (A) maximizing the Network's ability to conduct population and habitat status assessments (i.e., baseline data RE status and trends of priority birds and habitats), (B) maximizing the Network's ability to understand effects of management and restoration actions on target species and their populations, and (C) maximizing the Network's ability to understand ecological processes and their respective effects on target species and their populations. GoMAMN's Coordination Committee and Community of Practice (i.e., the Network) are currently using this objectives hierarchy to: (1) facilitate communication and coordination regarding avian monitoring needs (e.g., Gulf restoration projects); (2) guiding the development of a comprehensive, Gulf-wide Avian Monitoring Plan; and (3) utilize the objectives and value models to develop a prioritization tool to assist potential funding sources in selecting among competing bird-focused restoration proposals.

Migratory Species Conservation Decision Support Tool: Tools for Planning and Risk Analysis

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Marine species migrate to fulfill essential needs: to find food, reproduce, or seek out a more habitable location. The Gulf of Mexico hosts a wealth of active biodiversity migration -70% of highly migratory fish, five sea turtles, one-third of the bird species in North America, and most of the North Atlantic's marine mammals migrate through this ecosystem. The Migratory Species Conservation project aims to identify these migratory pathways - blueways - in the Gulf to preserve migratory marine species and improve the health of large marine ecosystems. Since 2016, the Conservancy has led the development

of Migratory Species Conservation, a framework for their conservation and an online spatial tool to help address the knowledge gap of migratory pathways, threats, and opportunities for their conservation. The accompanying online Migratory Species Decision Support Tool (DST) provides support for planners, resource managers, government officials, and the ocean conservation community to understand marine species blueways, threats, and key stopovers. The DST is built from more than one-thousand animal satellite tracking data from over 100 researchers and institutions in the United States, Mexico, and Cuba to assess migratory pathways in the Gulf. The tool includes a visualization platform to highlight information about migration corridors, movement density, occurrence hotspots, and stopovers, along with marine environmental data, and human and climate-related threats and contains several apps that can be used for careful marine planning and resource management. The second tool - Migratory Species Risk Assessment app - helps users to identify potential risks to mitigate in activity planning for species migrating through federally designated oil and gas planning areas in the US and Mexican Gulf waters. These tools are a useful resource for scientists, resource managers, industry and policy-makers for reducing impacts of human activity in the Gulf.

Data Management of Environmental Monitoring Data from Mobile Bay Best Practices and Lessons Learned

L. Hu

Dauphin Island Sea lab, Dauphin Island, AL

Dauphin Island Sea Lab (DISL) started real-time environmental monitoring of Mobile Bay in 2003. Data from seven stations are accessible at www.mymobilebay.com 24/7. Data are also transmitted to the Gulf of Mexico Coastal Ocean Observing System and National Data Buoy Center within half an hour of data collection. Monitoring of Mobile bay has built a quality base-line database to support scientific research in climate change, ecosystem restoration, and decision-making in the events of natural and man-made disasters. This presentation will discuss the management system of DISL monitoring data, from its acquisition to archival. Topics will include:

1. Quality Control (QC) procedures: range check, missing data check, and stuck sensor check;
2. Easy access to real time data on www.mymobilebay.com, data transmitted to Gulf of Mexico Coastal Ocean Observing System (GCOOS) and National Data Buoy Center (NDBC);
3. Access to historical data with quality flags on DISL website, and data archival at National Ocean Data Center;
4. Visualization of historical data to allow user quick view into the database;
5. Efforts to enhance the software programs.

Also to be discussed are lessons learned: no matter how perfectly automated a system is, a human check is always needed to detect potential problems, and to respond to interruptions in the system caused by changes in technology, or by changes in the environment.

A Computational Aid Tool for Visualization of Acoustical Data in the Northern Gulf of Mexico

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Early in the summer of 2016 it became evident there was a need for an effective and efficient signal analysis toolkit for the Littoral Acoustic Demonstration Center-Gulf Ecological Monitoring and Modeling

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(LADC-GEMM) Research Consortium. LADC-GEMM collected underwater acoustic data in the northern Gulf of Mexico during the summer of 2015 using Environmental Acoustic Recording Systems (EARS) buoys. Previously the visualization of our acoustic data was handled through short scripts and executed through a command line, each time requiring the data to be loaded into working memory. In order to increase productivity of data analysis and processing a graphical user interface (GUI) was created. A working prototype has been developed with MathWorks matrix laboratory (MATLAB), an integrated development environment (IDE). The program has been named Banshee, as the mythical creatures are known to “wail”. The interface has been formatted to load raw data files from the EARS buoys in various file formats. Loaded samples can also be saved in various file formats with adjusted parameters. The GUI button array features a time series plot, a spectrogram, and a power spectral density graph as the analysis tools. All the graphs are included in the “All” button as a comprehensive overview of the loaded sample. Overall the prototype is now very modular and can accept new tools relatively quickly. [This research was made possible by a grant from The Gulf of Mexico Research Initiative. Data is publicly available through the Gulf of Mexico Research Initiative Information & Data Cooperative (GRIIDC) at <https://data.fulresearchinitiative.org>.]

DIVER Application: Using Common Data Models for Data Integration and Data Queries

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The DIVER application is a data warehouse and query tool containing detailed environmental and project data including the majority of Natural Resource Damage Assessment (NRDA) data from the Deepwater Horizon Oil Spill. Now National in scope, the DIVER application was initially created to address the unprecedented scope and magnitude of environmental data generated in response to the Deepwater Horizon Oil Spill in the Gulf of Mexico. NRDA data available in DIVER spans many disciplines and source organizations, and includes analytical and non-analytical sample results, field measurements and observations, toxicity test results, oceanographic sampling, photographs, and animal telemetry. In addition to NRDA data, the DIVER application contains chemistry and bioassay data from the DWH Response, and information from NRDA funded restoration efforts. The foundation of the DIVER data warehouse is the concept of common data models, which support data integration and querying across diverse datasets. Common data models are a collection of data standards, with common fields for high level information that allow querying across different data sets, and also supports complex data and detailed results. The DIVER team has recently created a Data Specification that is available for download, which provides users with detailed insight into how data are organized within the DIVER data warehouse, valid values, and data dictionaries. This presentation will focus on the NRDA data integration efforts across the Gulf of Mexico, data standardization approach, and newly collected data in support of restoration monitoring efforts.

Organizing Monitoring Data from the Bottom Up to Facilitate Answering Big Picture Questions

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The DWH natural resource trustees are undertaking a massive restoration program in the Gulf, applying an ecosystem restoration approach. The Trustees’ Monitoring and Adaptive Management

(MAM) work group develops systematic approaches to build monitoring plans, identify restoration objectives, and standardize monitoring parameters. The monitoring data from these projects will inform routine reporting on projects as well as drive overarching synthesis of the Gulf-wide impacts of the restoration program. NOAA's Damage Assessment Remediation and Restoration Program is gathering and sharing these data through the Data Integration, Visualization, Exploration and Reporting (DIVER) application. DIVER combines information sharing portals and querying tools with a sophisticated data ingest system to streamline the collection and distribution of monitoring data, while keeping the data in context with project information and historical assessment data.

Monitoring data consists of field-based assessments of habitat and resource restoration projects as well as other metrics like usage numbers for recreational projects and as-built information. These data provide a wealth of information to the general restoration community on the trajectories and expectations for different project types and restoration approaches. DIVER employs a system of flexible data templates to collect these field measurements and present them for querying and export in ways which can be rolled up to answer larger questions. To ensure a standard process, the data organization and categorization within the templates is based on the monitoring approaches identified by the MAM. Metadata and supporting documentation are collected for each project. These same data types and templates are relevant to field-based injury assessments, remediation evaluation, and routine monitoring.

Physical and Chemical Connectivity

PCC-001: Dispersants: Disruption or Facilitation of Oil Degradation?

Aluminosilicate Microstructured Dispersants Stimulate Proliferation of Ubiquitous Marine Bacteria and Production of Biosurfactant

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Aluminosilicate (AS) microstructures, including halloysite clay tubes and kaolinite clay sheets, can substitute for the surfactants found in chemical dispersants. Like chemical dispersants, AS microstructures decrease interfacial tension at the oil-water interface and break the oil into smaller droplets. AS microstructures form stable emulsions with crude oil that last more than a week and the increased surface area enhances the bioavailability for ubiquitous marine bacteria. AS microstructures can also be carbonized or surface-modified with pseudo-peptidic polymers, which increase surface hydrophobicity, further reduce interfacial tension and increase emulsion stability. *Alcanivorax borkumensis* is a Gram-negative species that blooms in the presence of crude oil and degrades straight-chain hydrocarbon components. We have shown that the growth rate of *A. borkumensis* increases in the presence of both pristine and modified AS microstructures. The presence of AS microstructures also increased the production of the biosurfactants that aid biodegradation. Carbonized kaolinite sheets were most effective at stimulating biofilm production after 3 and 6 days of culture. AS microstructures, which are an environmentally friendly alternative to chemical dispersants, can be applied close to the shore, thus enhancing crude oil biodegradation in areas where chemical dispersants cannot be deployed.

Surfactant Enhanced Bioremediation of Oil by *Alcanivorax borkumensis* Using Oil Dispersed by Food-grade Amphiphiles

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Dispersant mixtures containing the food grade amphiphilic molecules of soybean lecithin and Tween 80 have been shown to be effective emulsifiers and capable as substitutes for traditional surfactant mixtures in the design of new dispersant systems. When designing these systems, it is important to take into account the effects that they may have on the bacterial communities present. Past experiments have shown that the presence of polyethoxylated surfactants (such as Tween 80) and vesicles (such as those formed by lecithin) can have a dramatic increase on the rate of bacterial growth and therefore the rate of oil degradation. Combining the oil dispersion capabilities of lecithin/Tween 80 surfactant mixtures with the affinity of bacteria for polyethoxylated surfactants and nitrogen/phosphorus containing lipids, the utilization of surfactant enhanced bioremediation (SEB) with these dispersant mixtures seems promising. The research here describes the effects of these dispersant mixtures on the degradation rates of hexadecane by *Alcanivorax borkumensis* (AB) and compares them to degradation rates in the presence of Corexit (a commonly used dispersant; applied during the Deepwater Horizon oil spill). Experiments performed in microplate readers as well as

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Erlenmeyer (baffled) flasks allow for clear monitoring of growth patterns in an aqueous subphase below an oil layer as well as in dispersed oil in the absence of a surface oil layer. Detailed imaging of the oil/water interface using optical microscopy allows for visualization of the AB and their biofilms at the droplet interface as functions of surfactant composition and concentration, and oil concentration. Our results thus far have shown that (1) the bacteria adhere to oil/water interfaces and stabilize oil droplets in the absence of dispersant, (2) the bacteria form biofilms on oil droplets and lead to the formation of large oil-bacteria agglomerates that sediment, and (3) low lecithin/Tween 80 concentrations promote bacterial adhesion to droplet interfaces, while high concentrations limit adhesion and biofilm growth.

Corexit and Oil Alter Aggregation of Extracellular Polymeric Substances

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Corexit was used in unprecedented quantities during the Deepwater Horizon oil spill in the Gulf of Mexico (GoM) in 2010 to facilitate oil dispersion by emulsifying floating oil slicks into small droplets in order to accelerate the oil degradation rate. When Corexit was introduced in response to an oil spill, the marine environment was greatly impacted. Extracellular polymeric substances (EPS) are natural polymers of high molecular weight, primarily containing polysaccharides and proteins, released by microbial communities, including various bacteria and phytoplankton. In previous reports, EPS were found to emulsify spilled oil to enhance activities of carbohydrate and peptide degrading enzymes. The initial aggregation behavior of EPS plays a key role in the oil degrading process; however, this particular subject is still under-explored. Here we used dynamic laser scattering to monitor the initial aggregation process of EPS from three phytoplankton species (*Dunaliella tertiolecta*, *Thalassiosira pseudonana* and *Amphora* spp.) and one marine bacterium (*Sagittula stellate*) with water accommodated fraction (WAF) of Macondo oil, Corexit enhanced water accommodated fraction (CEWAF), and Corexit. We found that generally CEWAF is able to enhance EPS aggregation efficiency by up to 80-100%, which is consistent with our previous findings. Moreover, the amphiphilic EPS showed stronger resistance to Corexit dispersion while hydrophobic and hydrophilic EPS are more sensitive to Corexit dispersion. Both flow cytometric and scanning electron microscopy data confirmed these results. Overall, our results indicate that spilled oil and Corexit can significant impact EPS initial aggregation, which should be taken into consideration during an oil spill cleanup process.

Laboratory and Computational Fluid Dynamic Experiments on Oil Droplet Dynamics in the Presence of Dispersants

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Dispersants are commonly used to mitigate the devastating effects of oil spills by causing oil to fragment/coalesce into smaller droplets where microbe consumption, dissolution, and evaporation are quicker and more effective. In order to better understand how oil droplets behave in water and after

surfacing with added dispersants, lab experiments with oil droplets of various composition and sizes are injected into water with and without dispersants with and without wind. Numerical simulations are also implemented using Volume Of Fluid (VOF) computational fluid dynamics with multi-phase physics. The VOF model allowed the setting of interfacial tensions between oil, air and water. The results from numerical simulations are in general consistent with laboratory observations, using visual and infrared cameras. With crude oil droplets of various sizes injected into water without dispersant under light wind conditions (~ 5 m/s), oil droplets tended to form a ring-shaped feature. The numerical simulation showed the same effect, however, with a slightly more exaggerated ring feature. The same experiment for weathered oil (using machine oil as a proxy) showed no significant spreading in either the lab or the numerical simulation. When dispersants were added to crude oil, both the lab experiments and numerical simulations showed fragmentation, with the numerical simulations showing a pronounced effect. When dispersants were added to the weathered oil in both lab experiment and numerical simulation, minimal fragmentation was observed. Combined laboratory and numerical experiments are expected to help in developing more realistic subgrid-scale parameterizations and account for the missing physics in operational oil-spill transport and dispersion models.

Additional Evidence on the Effects of Chemical Dispersant on the Formation of Negatively Buoyant Oil-SPM Aggregates (OSAs)

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It is well established that aggregation between naturally dispersed oil droplets and suspended particulate matter (SPM), which leads to the formation of oil-SPM aggregates (OSAs), takes place in both freshwater and marine environments. However, the effects of the application of chemical dispersants on OSA formation are still not well understood. Further to the research conducted for the Coastal Response Research Center in 2006-2008, several new series of bench-scale experiments have been conducted to quantitatively assess the effects of Corexit EC9500A on OSA formation under various conditions. Results showed that negatively buoyant OSAs form readily with different crude oils under moderate mixing energy at 15 °C and freezing temperature of 0 °C. Application of Corexit EC9500A enhanced OSA formation, even at a small dispersant-to-oil ratio of 1:500. A key controlling factor for this OSA formation is fine content. Sediments rich in fines less than about 5 μm in size are superior candidates in forming OSAs. Water salinity was shown to have a strong influence on OSA formation when increased from 0 to about 10 ppt. Size distribution, settling velocity and density of negatively buoyant OSAs were measured using a newly developed settling column device and state-of-the-art high definition video camera. Results showed that OSAs formed at 33ppt have physical properties similar to sediment flocs. However, results showed that the presence of oil droplets in their structure enhances OSA resistance to shear due to the strong bonding between the sediment fines and oil droplets. The novelties of the methodology to conducting this research and the results obtained with different oils and native sediments will be discussed.

Health Risk Assessment of Exposure to Volatile Organic Compounds and Particulate Matter Emitted from Oily Seawater Treated with Dispersant

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Airborne toxic compounds emitted from seawater contaminated by oil spills may be transported to nearby workers and communities and ultimately inhaled. Inhalation of toxic compounds (e.g., benzene) and their deposition in the human respiratory system may cause serious pulmonary diseases, including lung cancer. Spraying of dispersants to enhance the entrainment of the crude oil slicks into the water column has been practiced extensively. Dispersion of the crude oil alters the emission rates of volatile organic compounds (VOCs) and aerosols that carry toxic compounds, and may alter exposure levels. This study compared the emission rates of major VOCs and airborne particulate matter for slicks of crude oil, crude oil and dispersant mixture, and pure COREXIT 9500 dispersant. Separate laboratory tests were performed above breaking waves and plumes of bubbles bursting on the water surface. In both cases, real-time monitoring was conducted using a photoionization detector for the VOCs, and particle sizing instruments for detecting 10 nm to 20 μ m droplets. The chemical composition of the emissions was determined using gas chromatography/mass spectrometry for air samples, and Fourier-transform infrared spectroscopy for the particles. Using the emission rates, a risk assessment model for short-term exposure to the toxic compounds was developed using the USEPA unit risk factors, and the well-established dosimetry model estimating particle deposition in different regions of the respiratory system. Results indicated a 2-4 times decrease in concentrations of VOCs, but up to 15 times increase in the total mass of aerosolized particles for the slicks with 1:25 dispersant to oil ratio (DOR) compared to slicks with crude oil only. Due to an increase in the total mass of particulate toxic compounds, particularly among small particles that would deposit in the alveoli region of the lungs, the total risk of lung cancer for the slicks with DOR 1:25 oil was ultimately elevated.

Macro-scale Hydrodynamics and Tip Streaming in the Presence of Dispersants during Subsea Blowouts

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Chemical dispersants are one of the most commonly considered non-mechanical techniques in spill response. The first large-scale application of dispersants in deep water is Deepwater Horizon blowout, where approximately 3 million liters of dispersants was applied at ~1500 m depth in the Gulf of Mexico to lower the interfacial tension between oil and water and to promote formation of small droplets. To study the movement of oil released underwater in the presence of dispersants, in this work, we conducted an experiment of horizontal release of oil without and with dispersant. The jet hydrodynamics and droplet size distribution were studied by the model VDROD-J and compared to the model JETLAG, a miscible plume trajectory model. Both models were found to reproduce the oil jet hydrodynamics for oil without and with dispersant. With the presence of surfactants in the fluid mixture, tip streaming phenomenon often occurs where daughter droplets of micron or sub-micron size are ejected from thin threads of the droplet poles; and our experimental results have shown evidence that tip streaming occurred. For this purpose, a new conceptual module was developed in VDROD-J to capture the tip streaming phenomenon and an excellent match was achieved with

observation. The new model development improves the capability of VDROD-J model in application to the cases when dispersants are used, which should have consequences on predicting the DSD when dispersant are used on an underwater oil release.

Bubble Bursting Aerosolizes Slicks of Crude Oil-Dispersant Mixtures

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Generation of marine aerosol by the bursting of bubbles has been studied extensively. However, little information is available about emissions of oily aerosol as bubbles burst in slicks containing oil-dispersant mixtures. This study examines the concentrations of aerosolized droplets in the micron (0.5-20 μm) and nano (10-380 nm) size ranges as bubble plumes rising in seawater impinge on oil slicks. These slicks consist of 50 and 500 μm thick layers of crude oil, pure Corexit 9500A dispersant, and mixtures with a dispersant to oil ratio (DOR) of 1:25. The bubble diameter distributions are centered around 86 μm (denoted as small), 178 μm (medium) and 595 μm (large). During analysis, emission factors per bubble are calculated to facilitate the use of the present data for assessing the oily aerosols in field conditions. The micro-aerosol concentrations increase during bubble bursting for all plumes and contaminants, but trends vary substantially among cases. For a given contaminant, the concentration decreases with increasing layer thickness. A striking two orders of magnitude reduction in micro-droplet concentration occurs when medium and small bubbles burst in the 500 μm thick crude oil slicks in comparison to the 50 μm layers or uncontaminated column. In contrast, the nano-aerosol concentrations increase by an order of magnitude only for cases involving large bubbles bursting in 500 μm thick layers of DOR-1:25 oil and 50 μm thick slicks of pure dispersant. This increase is not observed for cases involving smaller bubbles or slicks without dispersant. Plausible explanations for these differences might be associated with bubble bursting mechanisms, namely jet and film breakup, as well other physicochemical processes. Chemical analysis of the volatile and particulate emissions above the slicks as well as the materials found on filters used for collecting the total suspended particulate matter confirm the presence of airborne crude oil above the oil-containing slicks.

Effects of Water-Accommodated Fraction of Macondo Oil and Corexit on Oil Transport in Mesocosm Experiments

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Large amounts of mucous-rich oil containing marine snow formed in surface waters adjacent to the Deepwater Horizon spill; this marine oil snow (MOS) was implicated in oil delivery to seafloor. Whether the use of chemical dispersants (i.e., Corexit) increased or decreased MOS sedimentation remains controversial. We conducted mesocosm (M) experiments including four treatments in each: 1) a water accommodated fraction of oil (WAF), 2) a chemically-enhanced WAF with addition of oil dispersant Corexit (CEWAF), and 3) diluted CEWAF (DCEWAF); and 4) a control without any WAF or Corexit. The mesocosms mimicked different environmental contexts, including 1) coastal seawater seeded with natural phytoplankton and associated bacteria concentrate (M2); 2) oligotrophic seawater amended with f/20 nutrients (M3); 3) coastal seawater amended with f/20 nutrients (M4); 4) coastal seawater seeded with natural phytoplankton and associated bacteria concentrate for elongated duration (16-day) (M5). The purpose was to investigate 1) if the application of Corexit will enhance or reduce the

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transport of WAF to the depth via incorporation into MOS in a single system; 2) if there is a difference in the oil incorporation into sinking MOS in a coastal region (M4) versus an oligotrophic region (M3); 3) if there is any difference in the incorporation into sinking MOS in a more terrestrial-affected coastal region (M2) versus a less terrestrial-affected coastal region (M4); 4) the development (i.e., formation of sinking MOS and incorporation of petrocarbon into the sinking MOS) of the contaminated system in a short-term (M2) versus a long-term mesocosm (M5). Results obtained from the mesocosm experiments provide essential information for oil spill response and remediation planning, and long-term prediction of petroleum contaminants in the ocean.

Does Corexit Impact MOSSFA?

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The vertical transport of sinking marine oil snow (MOS) and oil-sediment aggregations (OSA) during the Deepwater Horizon spill contributed appreciably to the unexpected, and exceptional accumulation of oil on the seafloor. However, the role of the dispersant Corexit in mediating oil- sedimentation is still controversial. Here we review the different mechanisms involved in MOS formation and examine how Corexit impacts them. Experiments have shown that the production of exudates like TEP, which are involved in marine snow formation, is impacted by Corexit, both positively and negatively. This has consequences for the aggregation mechanisms. But the change in the behavior of oil in seawater due to the presence of Corexit also impacts marine oil snow formation and characteristics. The redistribution of oil has central ecological implications, and future decisions on mediating measures or damage assessment will have to take the formation of sinking, oil-laden, marine snow into account.

Comparing Microbial Community Responses to Oil and Corexit between Coastal and Offshore Waters of the Gulf of Mexico

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Marine microorganisms play a central role in the degradation, dispersion, and transport of oil after an oil spill. However, due to differences in the composition and functional potential of microbial communities in different ecosystems, the behavior and ultimate fate of oil after its release is difficult to predict, especially for oil spills which impact large areas containing a variety of environmental niches (e.g. offshore waters, coastal waters, estuaries, etc.). Here we present our investigation of how the microbial response to the water accommodated fraction of oil (WAF) with and without Corexit® differs between coastal and offshore waters of the Gulf of Mexico using 16S rRNA sequencing, meta-transcriptomics, quantitative petroleum-hydrocarbon analyses, and epifluorescent microscopy. Four mesocosm treatments were set up for each water type: (1) a seawater only control, (2) seawater with the water accommodated fraction of oil (WAF), (3) seawater with WAF and Corexit® in a 1:20 ratio (CEWAF), and (4) a diluted CEWAF treatment. In both water types, the WAF, CEWAF, and diluted CEWAF treatments led to an outgrowth of several putative hydrocarbon degrading bacterial taxa. In coastal water, this manifested as a decrease in community diversity. However, in offshore waters, community diversity instead increased over time. Furthermore, we also observed the formation of micron-scale aggregates of microbial cells around droplets of oil and dispersant and found that their rate of formation was directly related to the concentration of oil within the water column, regardless of

water type. These micro-aggregates are potentially important precursors to the formation of larger marine oil-snow particles and our observation that Corexit® significantly enhanced their formation suggests dispersant application may play a role in the development of marine oil snow sedimentation and flocculent accumulation (MOSSFA) events. Together, these data reveal how microorganisms differ in their response to spilled oil in coastal and offshore environments and also enable us to further evaluate the effect of chemical dispersants on these communities.

Experimental Investigation of Oil Behavior in Turbulent Flows: Effects of Dispersants and Gas Bubbles on Oil Droplet Formation

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With the present of dispersants, the interfacial tension between oil and water is reduced, and therefore the droplet sizes. Although the chemical processes by which dispersants work are generally well understood, the effects of dispersants on droplet formation under different application methods have not been thoroughly investigated. In this study, we conducted laboratory experiments using the EPA baffled flask to investigate the oil behavior in turbulent flows. A high-speed 1k×1k camera is used to record the droplet formation process. Two types of crude oils with high and low viscosity are used, along with the dispersant COREXIT 9500 at different dispersant to oil ratio. By adopting different dispersant application methods, we studied the mechanisms of droplet formation under the effects of dispersants. The turbulent mixing causes air bubbles to be trapped in the water column. The interactions between air bubbles and oil droplets and its effects on droplet formation are also studied. Results from this study enhance the knowledge of the fundamentals of droplet formation in the presence of dispersants and gas bubbles, which would provide insights in the development of oil remediation strategies during oil spill events.

PCC-002: Sedimentary Evidence for the Fate of Oil

Assessing Transformations of Oil Deposited on the Seafloor of the Gulf of Mexico Using Ramped Oxidation and ¹⁴C Analysis

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In 2010, the Deepwater Horizon blowout released 4.9 million barrels of oil into the Gulf of Mexico. Studies using radiocarbon and hopane concentrations estimate between 0.5-14.4% of the released oil sank to the seafloor. Over the last seven years, we have collected a time series of marine sediments contaminated with oil from the DWH. In addition, sediments from control/non seep sites (background) and sediments from natural seep sites were also collected. Bulk radiocarbon analysis of the sediment has shown an apparent recovery at the DWH affected sites, shifting from more depleted radiocarbon (2010 $\Delta^{14}\text{C} = -501\text{‰}$) towards less depleted (2014 $\Delta^{14}\text{C} = -177\text{‰}$) background-like radiocarbon values

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over time. The DWH affected time series was analyzed using ramped pyrolysis/oxidation paired with natural abundance radiocarbon and stable carbon isotope analysis to evaluate the relative importance of transformation-remineralization vs mixing of the petrocarbon in the apparent recovery observed at the DWH sites. Evolved CO₂ was collected from oxidation of sedimentary organic matter across 5 temperature intervals during the ramping process. The sediments from the 2010 DWH sites had more CO₂/larger peaks at higher temperatures with more depleted $\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$ signatures; the signatures were similar to oil ($\delta^{13}\text{C} = -27\text{‰}$, $\Delta^{14}\text{C} = -1000\text{‰}$). Sediments collected in 2014, lost the higher temperature CO₂ peaks and had more enriched $\delta^{13}\text{C}$ and $\Delta^{14}\text{C}$ signatures overall. The CO₂ profiles collected from the control and seep site sediments were markedly different from the DWH affected sites. The mega seep, GC600, had more CO₂ evolve (or a larger CO₂ peak) at higher temperatures, while the control had more CO₂ evolve (or a larger CO₂ peak) at lower temperatures. At the DWH sites we observed transformation in both the evolved CO₂ from the sediment and in the radiocarbon signatures over time consistent with remineralization of the oil at DWH affected sites.

Isotopic Composition of Sinking Particles: Oil Effects, Recovery and Baselines in the Gulf of Mexico, 2010-2016

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The isotopic values (^{14}C , ^{13}C and ^{34}S) of sinking particles captured within sediment traps moored at 120m above the seafloor were determined at 3 sites to gauge the recovery and post-spill baseline conditions in the northern Gulf of Mexico following the 2010 oil spill. Near the well, we observed ^{14}C depletion starting in October 2010 (-140 to -80‰) and a systematic increase at a rate of $0.07 \pm 0.02\text{‰}$ until July 2013, when there was a change point and values reached a baseline ($-3.2 \pm 31.0\text{‰}$). These baseline ^{14}C values were similar to those of sinking particulates at a reference site further East ($3.8 \pm 31.1\text{‰}$). There was no significant temporal trend in $\delta^{13}\text{C}$ near the well (mean $-21.9 \pm 0.5\text{‰}$), similar to the reference site ($-21.9 \pm 0.9\text{‰}$). Between October 2010 and September 2011, the $\delta^{34}\text{S}$ values near the well were much lower than at the reference site (mean $7.4 \pm 3.1\text{‰}$ compared to $16.2 \pm 3.1\text{‰}$) but became significantly enriched from November 2012 to March 2015 (mean $16.9 \pm 2.0\text{‰}$), consistent with an increase in input from petrocarbon to marine production. At a natural seep site, our analysis indicated a period of significant isotopic depletion (a “trough”) in the ^{14}C and ^{13}C data from 8/2012 to 1/2013. During this trough, $\Delta^{14}\text{C}$ was on average $-109 \pm 29\text{‰}$. Before and after values were considerably enriched ($\Delta^{14}\text{C}$ of $-22 \pm 46\text{‰}$). Isotopic depletion coincided with increased input of lithogenic material, suggesting that interaction of petrocarbon released from the natural seeps with lithogenic particles and marine snow to cause the sinking of ^{14}C and ^{13}C depleted particulates. Following the perturbation of the oil spill, the Gulf recovered to equilibrium; ^{34}S indicates a recovery of 1 to 2 years, ^{14}C indicates 3 years, while PAH composition (Giering *et al.*, 2017) indicates a recovery of 2 years. These differences are driven by the sensitivity of the indicators, and the indicators may be reflecting recovery of different processes. Our results indicate that under baseline conditions, the carbon inputs to sinking particulates in the northern gulf are dominated by surface marine production (78-86%) and riverine inputs (12-19%).

Structural Insights into Weathered Deepwater Horizon Oil on Coastlines Using Ramped Pyrolysis GC-MS

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The chemistry of crude and weathered oils remains key to understanding its impact on coastal environments after an oil spill. There are limitations, however, whereby singular analytical techniques cannot always identify the wide breadth of petroleum and petroleum-derived compounds. We explore the analytical capabilities of ramped pyrolysis - gas chromatography - mass spectrometry (Py-GC-MS) to evaluate environmental samples of petroleum hydrocarbons from the Deepwater Horizon oil spill. We show that bulk flow Py-GC-MS can quantify the overall degree of petroleum hydrocarbon weathering. Furthermore, thermal slicing Py-GC-MS can quantify specific compounds in the “thermal desorption zone” from 50-370°C, as well as pyrolyzed fragments from non-GC-amenable petroleum hydrocarbons in the “cracking zone” from 370-650°C. These data, together with laboratory simulation experiments, suggest an increase in thermochemical stability, oxygenated products and complexity of high molecular weight and/or polar components with advanced weathering largely due to photochemical oxidation.

A Preliminary Synthesis of Recent Sediment Accumulation Rates in the Southern Gulf of Mexico

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The Gulf of Mexico (GoM) is one of the large marine ecosystems most threatened by oil spills and other anthropogenic pressures, but there is limited knowledge on recent (< 100 yr) sediment accumulation rates, the period when most anthropogenic impacts have occurred. During the last decade, sediment cores were collected throughout the southern GoM in order to develop sediment chronologies and sediment accumulation rates by using the ²¹⁰Pb dating method. In this work, we i) present the analytical methodologies used, ii) describe the assumptions, validation, uncertainties, limitations and accuracy of the dating models, iii) present a regional synthesis of sediment accumulation rates during specific time periods, iv) discuss the potential problems to provide accurate chronologies and sediment accumulation rates, and v) suggest strategies to improve recent chronologies at the basin scale. Determination of regional and basin-scale sediment accumulation rates will advance our understanding of factors forcing changes in sedimentation and provide accurate reconstructions of local to regional in sediment accumulation rates throughout the Southern Gulf of Mexico.

High-Resolution Sedimentary Record of the Deepwater Horizon Event: Impacts and Recovery

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A rapid sedimentation pulse in the northeast Gulf of Mexico in 2010 provided a unique opportunity to investigate a depositional event at high resolution. Multicores were collected annually (2010-2016) from numerous sites and sampled at 2 mm resolution. Geochronology was established using $^{210}\text{Pb}_{\text{xs}}$ and $^{234}\text{Th}_{\text{xs}}$. Although $^{234}\text{Th}_{\text{xs}}$ is conventionally used to measure bioturbation depth, it is used here as a geochronological tool due to the absence of bioturbation, unusually high sedimentation rate, and exceptionally high sampling resolution. Sediment texture and composition were performed on discrete samples, and whole cores were analyzed for elemental composition at mm-scale by scanning XRF. $^{234}\text{Th}_{\text{xs}}$ mass accumulation rates (MAR) and inventories show that the 2010 sedimentation pulse was short lived (<1 yr). Apparent increases in MAR at some sites beginning as early as three years following the event, are not supported by $^{234}\text{Th}_{\text{xs}}$ inventories, and likely reflect the re-establishment of bioturbation and not an increase in MAR. Silt content varied significantly in cores collected immediately following the event, but relaxed in subsequent years to near pre-event values. $^{210}\text{Pb}_{\text{xs}}$ profiles of cores collected 2014 - 2016 begin to resolve the sediment pulse by $^{210}\text{Pb}_{\text{xs}}$ dating methods. Surficial sediments in the NE GoM have recorded and preserved the initial depositional event, short-term impacts and rapid preliminary recovery of the sedimentary system. Detection of the event by $^{210}\text{Pb}_{\text{xs}}$ allows for continued evaluation of the preservation of the event signature, and the recovery of the sedimentary system over the next several decades.

Mechanisms of Sediment Attachment to Oil in Turbulent Flows

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The environmental significance of oil-sediment interactions on the fate and transport of spilled oil has been recognized in the last two decades; that is, interactions between oil and sediment particles mediates the physical transport of spilled oil in the shoreline and enhances oil dissolution and biodegradation. Oil-particle interactions can result in oil particle aggregates (OPA), which move differently from oil droplets or particles alone. This may alter drastically the fate of oil. Using confocal microscope imaging techniques, we obtained detailed 3D structures of OPAs formed in turbulent flows. A new mechanism of particle attachment to oil was discovered, whereby the particles behave as projectiles penetrating the oil droplets to depths varying from ~2 to 10 μm due to the hydrodynamic forces in the water. This mechanism results in higher attachment of particles on oil in comparison with adsorption, as commonly assumed. The projectile mechanism could also explain the decreased sediment uptake by a weathered oil. Contrary to the stable OPA under quiescent condition, we demonstrated that a continuous decrease in the size of the droplet over time in presence of turbulence and high particle concentration, and massive OPA networks (or clusters) were formed after long hours of oil-particle interactions, which could be explained by the projectile hypothesis. This finding has significant environmental implications, as the small droplets have large interfacial areas, thus

enhancing oil dissolution and biodegradation. A large interfacial area enables additional particles to attach to the droplet, promoting oil sedimentation. The effects of particle hydrophobicity and shapes were also studied. The findings from this study revealed a new pathway for the oil fate in environments containing non-negligible sediment concentrations.

Elevated Rates of Biogenic Silica Deposition in the Sediment from the Northern Gulf of Mexico during the Deepwater Horizon Oil Spill

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The Deepwater Horizon (DWH) oil spill resulted in a widespread Marine Oil Snow Sedimentation and Flocculent (MOSSFA) event that is characterized by increased deposition of surface-derived components (i.e., petrogenic and pyrogenic hydrocarbons, phytoplankton and zooplankton, and clay-sized mineral fraction) and dramatic changes in post-depositional chemical (redox) and biological (mass mortality of benthic meio- and macro-fauna) conditions. In an effort to constrain the amount of surface-derived MOSSFA-related biological inputs, biogenic silica concentrations and mass accumulation rates were determined from sediment cores utilizing a wet-alkaline extraction method modified from DeMaster (1981). Sedimentary biogenic silica is distinct from mineral-bound silica and has been used as a proxy record of diatom production and surface water primary productivity. Biogenic silica concentrations and mass accumulation rates increased by 2 ~ 3-fold during the 2010-2011 interval. This suggests that a significant portion of the surface biological materials entrained during the MOSSFA event was sourced by diatom production. Elevated sedimentary biogenic silica coordinate perfectly with earlier 16S-RNA measurements of diatom-derived materials in the sediments. Biogenic silica results also corroborate existing records of other surface derived MOSSFA materials in 2010-2011 including planktonic foraminiferal tests, pyrogenic hydrocarbons, and other petroleum-derived biomarkers. Moreover, our biogenic silica results confirm sediment trap studies that document significant increases in the numbers of diatom frustules settling through the water column during the DWH oil spill (Beizhan *et al.*, 2016). Overall, biogenic silica concentrations and accumulation rates provide an independent and corroborative proxy for MOSSFA related surface material deposited and diatom production during the DWH.

Changes in Sedimentary Redox Conditions Following the Deepwater Horizon Blowout and Ixtoc-I Events: Geochemical and Ecological Implications

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Marine sediment cores reveal a region wide organic rich sedimentation pulse following the Deepwater Horizon blowout event, which resulted in significant changes to sedimentary redox conditions. We use redox sensitive metals to constrain the temporal evolution of reducing conditions. Microbial respiration of the carbon rich marine snow deposited to sediments resulted in decreased pore-water

oxygen concentrations and a shoaled redoxcline, which produced two distinct solid Mn peaks. Associated with the Mn minimum, an enrichment of Re consistent with reducing sediments typically exists. The subsurface Re enrichment increased 3-4 times for the first two years, suggesting more reducing conditions, then remained relatively constant or decreased, indicating a return to pre-impact conditions. A dramatic reduction of benthic foraminiferal abundance is coincident with reducing conditions, demonstrating the important consequences of changing redox conditions on benthic ecosystems. Next generation sequencing reveals a noteworthy relationship between microbial community structure and redox metal data at millimeter scale resolution. The other major sub-marine blowout in the southern Gulf of Mexico (Ixtoc-I; 1979-80) also released a large volume of crude oil below the surface. Down core profiles of redox sensitive metals (Mn, Re, Cd) constrain the record of changing redox conditions after this event; they reveal multiple Mn oxide peaks associated with a shoaling redoxcline and Re maxima associated with more reducing conditions. Non-steady state behavior in both northern GoM and sites near Ixtoc is consistent with a MOSSFA (Marine Oil Snow Sedimentation and Flocculent Accumulation) event.

Assessing the Weathering of Residual Oil Deposited in Mexico Coastal Environments 37 Years after the Ixtoc-1 spill Using Novel Techniques

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On June 3rd of 1979 the Ixtoc-1 oil platform in the Bay of Campeche (Mexico) blew out releasing about 3 million barrels of oil during 9.75 months. In the aftermath of the spill (1979-1980) a survey conducted by Texas A&M University-Corpus Christi indicated oil reached and impacted several areas, including mangroves, reefs and rocky beaches. Previous visual surveys and observations from locals confirmed the coastal areas were not impacted by oil before the Ixtoc-1 spill. In 2016, C-IMAGE II researchers conducted a similar survey with the additional goal of collecting oil-containing samples to investigate (1) the chemical composition and concentration of residual petroleum hydrocarbons, (2) buried oil weathering products, (3) photo-oxidation vs degradation weathering processes, and (4) fate and potential toxicological impacts. Mangrove samples indicated the presence of oil on branches as tar, and buried in sediments as a semiliquid layer of crude oil or mixed with sediment detritus. Samples from rocky beaches had thick tar accumulations that bounded pebbles, cobbles and boulders together ("targlomerates") and, when cracked opened, released liquid oil resulting in an oil-sheen when submerged in sea-water. ¹⁴C was analyzed in vegetation and bacterial composition identified in sediments to determine if petrocarbon was incorporated into the trophic web of the forests. Sediment samples were analyzed for aliphatics (C10-C37 *n*-alkanes, isoprenoids), biomarkers (hopanes, steranes, and diasteranes), polycyclic aromatic hydrocarbons (2-6 ring PAHs including alkylated homologues and biogenic compounds), and PAH oxygenated products (hydroxy-, nitro-, oxy-PAHs) using GC/MS/MS in MRM mode to determine the weathering of petroleum hydrocarbons. A comparison of all compartments and analyses conducted will be discussed to help improve our understanding of the fate of spilled oil in coastal environments.

A Sedimentary Comparison of MOSSFA Events from the Ixtoc-1 (1979) and Deepwater Horizon (2010) Sub-marine Oil Well Blowouts in the Gulf of Mexico

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To date, there have been two major sub-marine blowouts in the Gulf of Mexico: the Ixtoc-1 event (Bay of Campeche) in 1979-80 and the Deepwater Horizon (DWH) event in 2010. The Ixtoc-1 event occurred at a depth of 56 m. and released ~530 million liters of oil over a 10-month interval while the DWH event occurred at a depth of 1500 m. and released ~760 million liters of oil over a 3-month interval. Comparative sediment studies of the Ixtoc-1 and DWH events show that significant quantities of oil were deposited on the sea floor from both blowouts. In both cases, the mechanism for the sedimentation of oil was a Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA) event. High resolution sampling of both Ixtoc-1 and DWH sediments documents a region-wide increase in the deposition of fine-grained materials that is synchronous with increases in bulk sediment, organic-carbon and hydrocarbon (PAH- petrogenic and pyrogenic) accumulation rates- all substantially higher than pre-blowout background conditions. In both regions, increases in algal biomass are associated with the pyrogenic PAHs indicative of a surface-derived MOSSFA event attributed, in part, to spill mitigation strategies of surfacing oil. Post-depositional impacts during the Ixtoc-1 and DWH incidents include an intensification of low oxygen conditions, cessation of bioturbation and a region-wide mass mortality of benthic foraminifera. In spite of the contrasting blowout scenarios, the Ixtoc-1 appears to be a viable analog that can be used to predict how DWH oil degradation and recovery of the benthic ecosystem will evolve. Determining how response strategies facilitate MOSSFA events and subsequently influence long-term hydrocarbon exposure and controls offshore benthic recovery rates is fundamental to predicting the spatio-temporal distribution of spilled oil, planning response strategies that account for impacts to offshore vs. coastal ecosystem, and developing quantitative oil budgets.

Is the Gulf of Mexico Uniquely Primed for Hydrocarbon Degradation?

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The Deepwater Horizon spill fueled blooms of bacteria that rapidly respired labile components of Macondo oil in the water column. Microbes also depleted oil that reached the seafloor, leading to surprisingly short half-lives of compounds often considered recalcitrant, such as hopanes and dibenzothiophenes. Previous exposure to natural seeps and anthropogenic oil releases in the northern Gulf of Mexico may have primed microbial populations, enabling their rapid response to the influx of hydrocarbons. A competing hypothesis is that seed populations of hydrocarbonoclastic microbes, widespread across oceanographic provinces, are poised to proliferate when oil compounds become available. Here, we address this issue by querying publicly available metagenomic datasets from diverse marine environments including the Gulf of Mexico, Antarctic straits, the Sargasso Sea, the North Sea, the Mediterranean Sea, coastal California, and the North Pacific Subtropical Gyre. We ask whether known hydrocarbon-degrading bacteria such as *Alcanivorax*, *Colwellia*, *Oceanospirillales*, and

Cycloclasticus, are enriched in the Gulf of Mexico relative to other sites. We then take a functional approach, investigating the relative abundances, distributions, and taxonomic affiliations of key genes for aerobic hydrocarbon biodegradation across sites. This “big data” approach yields data that may be useful in predicting the capacity for rapid oil spill attenuation by microbes in different marine environments. It also offers a means of testing Baas Becking’s ecological tenet, restated by Fenchal and Finlay (2004) as: “habitat properties alone are needed to explain the presence of a given microbe, and historical factors are irrelevant.”

Geochemical Connectivity in the sGoM: Old and New Organic Proxies for the Ixtoc-I Spill

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The 1979 spill caused by the blowout on the Ixtoc-I platform in the Bay of Campeche (southern Gulf of Mexico, sGoM), released more than 3 million barrels of oil, some of which was transported as far as the coast of Texas. However, there is a very limited knowledge of the subsurface fate of spilled oil, including its weathering, transformation and benthic deposition. We present the results of a comprehensive study into dissolved organic matter (DOM), suspended particulate matter (SPM), and seafloor sediments collected across the sGoM. The objective was to elucidate the biogeochemical connectivity within this marine system, and potentially determine whether an identifiable fingerprint of Ixtoc oil is still present. We combined traditional tools, such as GC-MS, and knowledge of petroleum geochemistry of the Campeche basin, with the new, state-of-the-art methods, namely FTICR-MS, to arrive at a more robust interpretation of hydrocarbon inputs to sGoM, and related biogeochemical processes. The analyses of SPM and sediments, showed a spatially and temporally ubiquitous signals of hydrocarbon input, possibly due to chronic contribution of natural oil seeps, a common geological feature of sGoM. Some biomarker ratios of terpanes, and dibenzothiopenes show excellent potential for the discrimination of different oil families from the Campeche basin. Comparison of sediment extracts and Ixtoc-I reference oil, showed indicative similarities of characteristic petroleum compound classes, such as hydrocarbon and sulphur containing heteroatom groups. The presence of oxygen containing compound classes, is suggestive of parent oil transformation. On the other hand, the analysis of DOM revealed complex oxidative transformation (biogenic and/or abiogenic) of organic matter, including possible ultimate products of oil degradation. This study can help to assess the potential long-term fate of the oil released after the Deepwater Horizon blowout.

PCC-003: Hydrocarbon Transformation Processes and Products at the Sea Surface

In Search of the Missing Macondo Oil: A Case for Photochemical and Biological Solubilization *en route* to Refractory Dissolved Organic Matter

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Natural organic matter (NOM) is a complex mixture predominately comprised of oxyhydrocarbons. Dissolution of some NOM is a result of biogeochemical degradation processes that transform plant and animal detritus into low molecular weight (< 2 kDa), oxygenated compounds. This pool of dissolved organic matter (DOM) is one of the most cycled reservoirs of organic matter on Earth. Labile DOM is consumed as part of the microbial loop, whereas chromophoric DOM (CDOM) can be removed directly by sunlight or photodegraded into lower molecular weight, bio-labile compounds. Ultimately, the reactivity and fate of DOM is dependent on its composition and structure, as well as its environment. Crude oil is comprised largely of a complex mixture of low molecular weight (< 2 kDa) hydrocarbons. Once released into aquatic environments, non-volatile hydrocarbons can be transformed into oxyhydrocarbons by similar biogeochemical processes that produce DOM from NOM. Therefore, it is plausible that a significant fraction of the “missing” 11-30% of Macondo crude oil (MC252) is in the process of integrating into the DOM pool. We present data suggesting that with time, photo and biological solubilization are pathways for removal, transport and degradation of MC252. Nearly 4% of the mass of a thin film of MC252 is converted to DOM when exposed to sunlight. Moreover, sand patties comprised of 10-15% residual oil exhibit a two-fold increase in DOM production when exposed to simulated sunlight relative to those in the dark. Reports from decades of study of *in-situ* biodegradation of an inland crude oil spill in glacial sediment show that, fermentation and methanogenesis convert crude oil into DOM. Although the oil spill occurred nearly four decades ago, the concentration of DOM in the aquifer adjacent to the subsurface oil only began to exhibit a steady increase in the last ~15 years. Finally, an exponential decrease in the concentration of petroleum-derived DOM is observed when it is exposed to photochemical and biological degradation. Analysis of this DOM by complementary analytical methods such as optical spectroscopy, NMR spectroscopy and mass spectrometry all indicate that with time, the composition of this degraded DOM produced from petroleum tracks toward carboxyl-rich alicyclic molecules (CRAM), the major refractory component of DOM.

Partial Photochemical Oxidation was a Dominant Fate of Deepwater Horizon Surface Oil

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Following the Deepwater Horizon (DWH) blowout in 2010, oil floated on the Gulf of Mexico for over 100 days. Controls on the fate of this surface oil are poorly constrained, but in the aftermath of the blowout substantial accumulation of oxygenated petroleum residues have been reported. Here we provide five quantitative lines of evidence demonstrating that oxidation by sunlight accounts for the oxygenated petroleum residues. First, residence time on the sunlit sea surface, where photochemical reactions occur, was the strongest predictor of partial oxidation. Second, two-thirds of the partial oxidation from 2010-2016 occurred in less than 30 days on the sunlit sea surface, prior to coastal deposition. Third, constancy of the diagnostic biodegradation ratio - octadecane:phytane - indicates that partial oxidation of oil on the sunlit sea surface was driven by abiotic processes. Fourth, O₂ consumption from oil photo-degradation experiments greatly exceeded CO₂ generation, consistent with partial, but not complete oxidation. Fifth, estimates of partial photo-oxidation calculated with photochemical modeling overlap with observed oxidation. We suggest that photo-oxidation of surface oil has fundamental implications for the response approach, damage assessment, and ecosystem restoration plan in the aftermath of an oil spill, and that oil fate models for the DWH spill, other spills, and natural seeps should be modified to accurately reflect the role of sunlight.

A Comparison of the Optical and Molecular-Level Composition of Photodegraded Macondo Well Oil in the Presence of Dispersant

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Oil spilled in aquatic systems is exposed to sunlight, resulting in important photochemical processes. Photochemistry likely plays a major role in the fate of oil spilled in areas with sunlight exposure, especially since high molecular weight aromatics are readily photodegraded but are resistant to biodegradation. Dispersants have been widely used in aquatic spills, but the effect of dispersant on photochemistry is not well understood. Here, we present data that show enhanced photodegradation of oil in the presence of dispersant (Corexit EC9500A). In order to gain a clearer understanding of these changes, we utilized excitation emission matrix spectroscopy (EEMs) to identify the fate of the irradiated oil in the presence and absence of dispersant. The composition of dissolved organic matter (DOM) was similar in the presence or absence of dispersant. A more dramatic change in the composition of the oil was observed in the presence of dispersant. Notably, the optical properties obtained by EEMs show an enhanced blue shift in the presence of dispersant which is indicative of the degradation of aromatic rings to more aliphatic-like compounds. The molecular-level information obtained by Fourier transform ion cyclotron resonance mass spectrometry corroborates the EEMs data by showing a decrease in the unsaturated, low oxygen with a corresponding increase in the aliphatic-like compounds. These results indicate that Corexit enhances photodegradation of Macondo crude oil.

Understanding how the use of dispersant affects photochemical transformation of oil is critical to understanding the fate of oil in aquatic systems.

Photoproducts in Gas Phase of Solar Irradiated Crude Oil-Seawater Systems Determined by SPME-GC-MS

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Crude oil is often exposed to sunlight when it is released into environments. Many photoproducts could be produced during the natural photochemical degradation process of spilled oil. The high molecular weight photoproducts will remain in the aqueous phase or oil phase, while the low molecular weight photoproducts will be more likely to partition into the gas phase. We report here an investigation of photoproducts observed in the gas phase from solar irradiated crude oil. Oil samples were spread over seawater in a jacketed beaker held at 27°C and exposed to simulated sunlight. The photoproducts in gas phase were collected with a solid phase microextraction fiber SPME and analyzed using gas chromatography-mass spectrometry GC-MS. Several types of oxidation photoproducts such as aldehydes, ketones, and alcohols were formed in the gas phase of irradiated crude oil. These results will provide a definitive understanding of the mechanisms and photoproducts released into the gas phase when oil is exposed to sunlight.

Molecular-level Insights into the Biotic / Abiotic Compositional Changes of Weathered Oils Exposes the Importance of Photo-Oxidation

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Once released into the environment, petrogenic species undergo oxidative transformation that further increases the already complex crude oil matrix by at least an order of magnitude. The transformation dramatically alters native petroleum chemistry through addition of ketone, hydroxyl, and carboxylic acid functionalities, and subsequently affects toxicity, solubility, tendency for emulsion/mousse formation, aggregation, and ultimately, bioavailability. Despite the challenge, recent advances in analytical methodology and instrumentation now allow molecular-level insight into these complex systems irrespective of initial (unaltered) or transformed-product boiling point. Here we use microcosms to differentiate between photo- and bio-oxidation products for Macondo well oil (MWO) and a heavy crude oil. The molecular-level results are compared to field samples collected over a 7-year time period. Analysis by Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR MS) exposes the compositional differences between the unaltered and transformed oil samples and exposes species that are unique to both biotic and photo-transformation. The unique species are significant, as MicroTox results reveal that MWO water-soluble photo-oxidation products are more toxic than the unaltered oil, and that the level of toxicity is dependent on irradiation time. Furthermore, photo-oxidation generates 20-30 times the amount of dissolved organic carbon (DOC) as bio-oxidation, and most importantly, photo-ox generates interfacially active species that promote emulsion formation (mousse). Molecular-level changes for all experiments are provided by FT-ICR MS, and offer a unique explanation for the increased toxicity and emulsion formation. Work supported by

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Photoperiod, Exposure Duration, Timing, and Latent Mortality: Effects of Photo-induced Toxicity on Aquatic Organisms

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The Deepwater Horizon oil spill in 2010 introduced millions of barrels of crude oil into the Gulf of Mexico, potentially exposing a wide range of aquatic biota to polycyclic aromatic hydrocarbons (PAHs). Exposure to ultraviolet radiation (UV) can exponentially increase the toxicity of photodynamic PAHs, leading to adverse outcomes well below the threshold of other mechanisms of toxicity in a phenomenon known as photo-induced toxicity. Because the embryos of many marine fishes develop rapidly, natural light-dark cycles can result in differential UV exposure. Here, we report the results of experiments in which early lifestage fish and zooplankton were exposed to a range of PAH and UV exposure scenarios. Toxicity was UV and PAH dependent in all species. Toxicity was also dependent on the developmental stage of the fish, the rate/intensity of UV exposure, and the availability of recovery periods. Taken together, these data suggest that short-term transient exposure to low concentrations of PAHs, common during spill events, can result in acute toxicity in aquatic organisms. Furthermore, effects may be exacerbated during sensitive windows of development, and may be manifested outside of standard bioassay durations. This research was made possible by grants from NOAA and The Gulf of Mexico Research Initiative.

New Methods to Determine the Toxicity of Oxygenated Oil Transformation Products in Weathered Deepwater Horizon Oil Residues

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It has been shown that weathering of surface oil after the Deepwater Horizon spill led to the formation of oxygenated oil products within weeks, that these products persist for years, and potentially exhibit toxic effects. Here, we investigated the long-term persistence and toxicity effects of these oxygenated hydrocarbons (OxHC). To this end, we analyzed oiled samples collected on the sea surface and beaches between 2010 and 2017 for petroleum hydrocarbons and OxHCs. We identified 1-alkanols, 2-ketones, and n-alkanoic acids in weathered oil residues as OxHC marker compounds. We furthermore investigated the acute toxicity of these OxHC compounds. To do so, we calculated baseline toxicity of petroleum hydrocarbons and oxygenated products using quantum chemical tools and calibrated our model with data from toxicity assays. Overall, we found that toxicity levels caused by OxHCs are comparable to that of PAHs for slick oil, and are surpassing that of PAHs in heavily weathered oil. Our results suggest that for weathered oil, the toxicity of OxHC should not be neglected in oil spill risk and damage assessments.

Novel Techniques for Exposure and Analysis of Effects of Airborne Toxicants from Crude Oil in Terrestrial Animals

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Airborne toxicants are of special concern for humans following an oil spill, due to the toxicity of several volatiles present in crude oil. Despite the risk of spilled oil on air quality, few studies assess the effects of airborne oil toxicants on terrestrial organisms. A potential difficulty in such studies is the translation of the exposure scenario in the lab to conditions in the field. Here, we describe new methodologies and results that pair organismal response to airborne toxicants from crude oil, with sensitive real-time analytical chemistry using a portable mass spectrometer that can be used in either the lab, *or* in harsh field environments. Embryos of birds (*Gallus gallus*) and teleosts that incubate in air (*Fundulus grandis*) were exposed to sublethal levels of volatile organic compounds from Deepwater Horizon crude oil during embryonic development. Real-time quantification of light weight aromatic compounds was performed during exposures using a laboratory-grade linear quadrupole mass spectrometer with membrane inlet and an electron ionization source, built into a military-grade, portable system. Embryos of *G. gallus* exposed to oil vapors showed a decrease in platelets, and increase in blood osmolality; and molecular biomarkers of exposure (i.e. CYP1A), which increased in the lung epithelia shortly after the first breaths. Air-incubated embryos of *F. grandis* exposed to oil vapors had an overall decrease in developmental rate, evident in a decrease in growth, pigmentation and rate of cardiovascular development. These experiments galvanized the effectiveness of this experimental approach for detecting volatiles from crude oil in air (or water) in both laboratory experiments and in the field at parts per trillion resolution, without the need for extensive sample preparation or training. Ongoing experiments will integrate exposure effects in vertebrate models with onsite analytical chemistry for spatial and temporal mapping of toxicity risk to humans.

Examining Inputs of Biogenic and Oil-derived Hydrocarbons in Surface Waters following the Deepwater Horizon Oil Spill

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Laboratory and field studies indicate that the production of hydrocarbons by cyanobacteria in the surface ocean is more quantitatively significant than the combined inputs from oil spills and natural oil seeps. The predominant hydrocarbons that are produced by a wide range of phytoplankton and algae in surface waters are pentadecane (C15-n-alkane) and heptadecane (C17-n-alkane). The relative abundance of C15 and C17 n-alkanes in surface waters is due to their specific biogenic origin, but can also reflect the differences in physicochemical properties and therefore the environmental fate of the two compounds. Oil-derived hydrocarbon compounds including C15-n-alkane and C17-n-alkane are known to persist in the environment for extended periods of time, yet there is no evidence that biogenic hydrocarbons accumulate in the surface ocean. This study aims to obtain insight into the coexistence of hydrocarbons from both biogenic and oil-derived sources by examining publicly available data from the National Oceanic and Atmospheric Administration (NOAA) repository for environmental data related to the Deepwater Horizon Natural Resource Damage Assessment (NRDA). We examine hydrocarbons collected from both surface (< 200m) and subsurface (>200m) water samples. Analysis of this dataset will provide more robust information regarding the presence, source,

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cycling and fate of biogenic and oil-derived hydrocarbons as well as insight into the relationship between these two different sources of hydrocarbons.

The Effects of Sunlight on the Composition of Exopolymeric Substances Affecting Aggregate Formation during Oil Spills

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During the Deepwater Horizon oil spill, a large amount of marine oil snow, which consists of a matrix of microbial colonized on exopolymeric substances (EPS), was formed in surface waters of the Gulf of Mexico (GOM). Secretion of EPS maybe one microbial defense strategy against harmful or stressful environment situations. The toxicity of oil can be enhanced by elevated oxidative stress through UV radiation. To test the effects of sunlight on the composition and secretion of EPS and the subsequent aggregation process, we conducted short-term irradiation experiments in three treatments, i.e., control (GOM coastal seawater), water accommodated fraction of oil (WAF), and chemically-enhanced WAF (CEWAF). EPS composition (mainly carbohydrates and proteins) was quantified in the colloidal and aggregate fractions. In addition, bacterial abundance, live/dead cell ratio, particle size distribution, and the ambient •OH formation rate were measured under these conditions. We found that in the presence of oil, natural sunlight stimulated polysaccharide secretion, coinciding with increased ROS (i.e. •OH) production. Moreover, formation of larger sized aggregates was observed in the irradiated WAF treatments. The results support the hypothesis that sunlight plays an important role in marine oil snow formation during an oil spill.

Microbial Analysis of the Sea Surface Microlayer with a Focus on Surfactant-associated Bacteria and Applications to Satellite Oceanography

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Under low wind speed conditions, surfactants accumulate on and enrich the sea surface microlayer (SML) to form natural, biogenic sea slicks. Surfactants are products of life processes of various marine organisms, such as bacteria, phytoplankton, and seaweed. These natural, biogenic slicks are detectable visually and in synthetic aperture radar (SAR) imagery due to the damping of short gravity capillary (Bragg) waves. In this study, *in-situ* sampling was coordinated with TerraSAR-X, RADARSAT-2, and Sentinel-1B satellite overpasses. Using an innovative technique developed at Nova Southeastern University, the SML and associated subsurface water (SSW) were sampled during a Gulf of Mexico Research Initiative (GoMRI/CARTHE) research cruise, LASER, on the R/V F.G. Walton Smith in February 2016. A second dataset was collected during the SPLASH experiment from a small boat in April 2017. During SPLASH, sampling was also conducted in the slick in an oil seep near the Louisiana coast. Analysis of this second dataset will be complete shortly. Results of the DNA analysis of microlayer samples by real-time PCR (qPCR) and sequencing via Illumina MiSeq in the natural biogenic slicks indicate that more surfactant- and oil-associated bacteria, such as *Bacillus* and *Pseudomonas*, reside in the SSW compared to SML in low wind speed conditions. This suggests that surfactants are produced in SSW and are transported to the SML via physical processes, such as advection, turbulence, and bubble

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scavenging. Therefore, surface slicks can be indicators of the presence of organic material, such as a dissolved oil spills, in the water column.

Partitioning of Oil into Marine Waters is Influenced by the Interaction Between Oil Type and Season

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Oil products transported through pipelines and on ships have the potential to spill in coastal systems. Products vary from refined fuel products to diluted bitumens, which represent a composite of heavy bitumen diluted with lighter oils. The fate and behaviour of spilled oil is driven by the chemical and physical properties of the oil itself, as well as the environmental conditions during the spill, which vary with season. To characterize the importance of seasonal influences on the fate of oil following a coastal surface spill, simulated spills were carried out in spring and summer. Fresh oil, including diesel and three diluted bitumens (AWB, WCS and Synbit), were spilled in triplicate in 200 L enclosures and sampled over 2 weeks to characterize the distribution of oil in the water column as well as the microbial response to oiling. AWB spills resulted in highest water column concentrations of volatile hydrocarbons, although levels were 40% lower in summer compared to spring. Peak concentrations were 50% lower for diesel and WCS, and 80% lower for Synbit in summer. This is likely due to higher evaporation in summer, which decreased volatile compounds in the water. Variation in the composition of diluents accounts for the different responses of the diluted bitumens between seasons. Total hydrocarbons were highest for diesel spills, while lower concentrations were observed for diluted bitumens. Total hydrocarbons peaked after 48 h for diesel, but increased throughout the experiment for diluted bitumens, suggesting the diesel more readily dissolved in water and was more available for biodegradation. This was supported by higher bacterial cell abundances after diesel spills and higher inhibition of microbial activity compared to diluted bitumen spills. Bioluminescence by a bacterial indicator was inhibited 60% with diesel, but only 10-15% by diluted bitumens, with no difference between spring and summer, suggesting dissolution of responsible compounds was not affected by temperature. Partitioning of diesel showed limited seasonal differences, while the diluted bitumen AWB showed significant seasonal differences, highlighting the importance of oil type in determining the fate of oil in the environment.

PCC-004: Currents, Winds and Waves: Moving Oil in the Gulf of Mexico

The Movement of Deepwater Horizon Oil to Northern Gulf Beaches

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Surface oil of Deepwater Horizon origin sullied the northern Gulf of Mexico marshes and beaches from Louisiana to Florida. The Mississippi to Florida beaches were particularly impacted during the month of June 2010. We review the evolution of the surface oil as it approached the beach and then consider the mechanisms of transport. Both the ocean circulation and ocean waves are found to be important. The circulation appears to control the transport of surface oil in deep waters and over most of the

continental shelf. But as oil approaches shallow water the wave orientation may become more conducive than the circulation orientation for transporting oil to the beach. In essence it is found that the circulation gets the oil to the vicinity of the beach, whereas the waves, via Stokes drift, are responsible for the actual beaching of oil. A combination of observations and numerical model simulations are used to demonstrate this.

Effects of Near-Inertial Wind Forcing on Baroclinic Instabilities over the Texas-Louisiana Shelf

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The Mississippi-Atchafalaya river system creates a large region of fresh water influence over the Texas-Louisiana continental shelf. Baroclinic instabilities occur along the plume front, and these instabilities are a significant source of variability in currents and water properties over the shelf. The instabilities enhance dispersion of materials such as surface oil slicks, and can modulate bottom oxygen causing patchiness in the seasonally hypoxic bottom waters over the shelf. Although a large, regional high-pressure system reduces the occurrence of strong atmospheric fronts during summer, when the instabilities are thought to be most energetic, there is still a persistent land-sea breeze that can excite strong inertial currents. These inertial currents have been observed to reach an amplitude of over 0.60 m s^{-1} - the strongest currents observed on the shelf not associated with a storm event. Recent theory suggests that these near-inertial motions can interact with the geostrophically balanced flow in the plume front and associated eddies to cause a forward cascade of energy toward smaller scales. We use an idealized model of unstable, buoyancy driven flow over a continental shelf, similar in character to the Mississippi-Atchafalaya plume region, and force this model with a range of near-inertial winds in order to quantify the effect these winds have on the bulk mixing and salinity structure of the plume.

Analysis of the Lagrangian Flow in the Top Centimeter of the Water Column Using the GISR Drift Card Data Set and a New Surface Drift Model

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During 2013 and 2014 the Gulf Integrated Research Consortium (GISR) released 1800 drift cards into the water, 10 at a time, at many locations in the northern Gulf of Mexico. About 287 of the cards (16%) were retrieved. The retrievals showed that there was little dispersion as cards from the same release point were often found relatively close together; on average the distance apart of the retrieved cards from the same release was less than 21% of the distance travelled. 219 cards were retrieved on land & 68 were picked up at sea. The time of arrival was known for the sea retrievals and so these cards provided 68 estimates of the average Lagrangian flow in the top centimeter of the water column. This observed very near-surface Lagrangian flow was used to test the accuracy of a new model of Lagrangian flow based on a sum of the surface Stokes drift and the Eulerian flow approximated by a high-resolution numerical model. This comparison suggests that the Stokes drift makes a major contribution to the transport of surface particles to the coast, and that higher frequency short waves make a major contribution to the Stokes drift.

Dispersion and Clustering Experiments in the Gulf of Mexico

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Two recent experiments performed in the Gulf of Mexico addressed one of the most perplexing questions in ocean physics: What are the processes that cause matter on the ocean surface to cluster while also producing turbulent dispersion? These experiments utilized cutting-edge technology resulting in an unprecedented wealth of synoptic data, ranging over scales from 1 to 10^6 meters. The first experiment, the Grand Lagrangian Deployment (GLAD), was conducted during July 2012 in the eastern half of the Gulf of Mexico. Approximately 300 GPS-tracked drifters were deployed to determine whether the relative dispersion of an initially densely clustered array was driven by processes acting at local separation scales or by mesoscale shearing motions. The second experiment was a component of the Lagrangian Submesoscale Experiment (LASER), conducted during the winter of 2016. Here thousands of bamboo plates were tracked optically from an Aerostat, to supplement another deployment of almost 1000 GPS-tracked drifters. Statistics from pair separations, structure functions, and scale dependent relative diffusivities showed: an inverse energy cascade for scales above 10 km and a forward energy cascade at scales below 10 km with possible energy input at Langmuir circulation scales. In addition, the analysis found evidence of surface flow convergence at scales less than 10 km that account for material clustering at the ocean surface.

Study on Langmuir Turbulence Based on Wave-Phase-Resolved Simulations

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The mixing and transport of mass and species (including oil spills), momentum, and heat in the ocean surface mixed layer are significantly influenced by Langmuir turbulence, a type of turbulent flows induced by the interaction between wind-driven currents and surface waves. In this work, we use two advanced wave-phase-resolved simulation approaches to study Langmuir turbulence. The first method is large-eddy simulation (LES) on a dynamically evolving wave-surface-fitted grid, so that wave motions are directly simulated with turbulence motions. Not only the phase-averaged Stokes drift, but also the instantaneous effect of waves on the turbulence is resolved by our simulations. We show that the generation and evolution of Langmuir cells and Langmuir turbulence are successfully captured. Further analyses of the vorticity and turbulence kinetic energy production indicate that both the phase-averaged wave effect and the correlation between turbulence and wave phases are important to the dynamics of Langmuir turbulence. The second approach is wave-directly-forcing simulation based on the Helmholtz's decomposition. The flow field is decomposed into irrotational and rotational parts, representing wave field and turbulent flow, respectively. The wave field is solved using the high-order-spectral method that can capture nonlinear wave interactions in complex wave systems. The turbulent flow is solved by LES, with an addition of a vortex force representing the instantaneous wave forcing on turbulence. We further simplify boundary conditions of the turbulent flow using Taylor expansions of the wave height at the undisturbed mean water surface, and thus Cartesian grid can be used to increase the computational efficiency. This method can accurately and efficiently simulate Langmuir turbulence under realistic ocean conditions with broadband waves. The surface streaks generated by Langmuir cells are captured, and they agree with those observed by marine radars deployed in field.

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Clustering, Deformation, and Dispersion of Buoyant Material

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Oil at the ocean surface, like other floating material, is constantly redistributed by the ocean currents. On average, such material disperses. However, tight clustering is also commonly observed, especially along fronts. Understanding the dynamics of these opposing processes would dramatically improve the predictive capability for the evolution of oil slicks and similar pollutants in the ocean environment and thereby increase the effectiveness of clean-up operations. To this end, we analyze several dense arrays of drifters released nearly simultaneously during the LASER experiment (in the DeSoto Canyon, winter 2016) and the SPLASH experiment (in the Louisiana Bight, spring 2017). In each case, over 100 surface drifters were launched in a regular grid that was quickly deformed by the ambient currents. Nevertheless, we obtained estimates from several different algorithms of horizontal divergence, shear, and vertical vorticity accompanying the clustering and dispersion. Limitations on such estimates due to drifter alignment along fronts are discussed. We also compare the drifter group evolution along the coastal, shelf-break, and deep-water fronts.

The Dynamical Role of Horizontal Divergence in Submesoscale Frontogenesis

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Oceanic surface submesoscale currents have recently been shown to have a dominant role in the dispersion of surface drifters in the Northern Gulf of Mexico and, presumably, in oil dispersion as well. Submesoscale currents are characterized by anisotropic flow structures with large magnitudes of lateral buoyancy and velocity gradients. Realistic numerical simulations of the Northern Gulf of Mexico and surface drifter observations are used to investigate the horizontal advective enhancement rate of these fields, i.e. frontogenesis. We derive and verify an asymptotic regime for the flow evolution during frontogenesis and demonstrate that in contrast with the early stages, when the along-front velocity is much larger than the cross-front velocity and when deformation may play a governing role, in the late stages cross-front and along-front velocities have similar magnitudes and gradient sharpening is primarily governed by horizontal convergence. This implies that the divergence field, an easier quantity to measure than frontogenetic rates, may provide a valid assessment for frontogenesis in oceanic field observations.

Topographic Enhancement of Diapycnal Diffusivity on the Continental Slope in the Northern Gulf of Mexico and Its Application to the Oil Droplet Dynamics

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A tracer release experiment (Ledwell *et al.* 2016) has indicated that mixing was greatly enhanced over the slope in the northern Gulf of Mexico compared to the interior of the Gulf. To characterize the diapycnal diffusivity on the slope, we have conducted two research cruises specifically to measure turbulence in 2016 and 2017 and revisited the historical data collected during the Gulf Integrated Spill Response (GISR) cruises between 2013 and 2015. Diapycnal diffusivities are inferred from free-fall

vertical microstructure profilers (VMP) that measure the rate of dissipation rate of turbulent kinetic energy and give an independent measure of the small-scale turbulence that controls diapycnal mixing. The mixing generated is quantified in terms of a turbulent diapycnal diffusivity, k , which measures the rate at which the turbulence spreads a tracer across density surface over time. Indirect references of bottom mixing are also from the CTD tow-yo sections by estimating the buoyancy flux and from current meters on bottom-mounted moorings. Bottom enhanced mixing is found from both microstructure profiles and ctd tow-yos, which is likely associated with the local complex topography on the slope. We also relate turbulent velocity to the size and density of oil droplets by estimating the rising velocity of different size oil droplet due to balance between buoyancy and drag force.

APEX-EM Float Performance Measuring Ocean Structure

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Technology for measuring the deep ocean currents (including temperature and salinity) is now possible using the recently developed APEX floats with electromagnetic sensors (APEX-EM) developed by Teledyne-Webb. The float acquires temperature and salinity profiles using a Seabird sensor. In addition, the APEX-EM profiling floats were equipped with chemical and bio-optical sensors: Aanderaa Optode sensor measuring dissolved oxygen, and the WET Labs ECO puck sensor which combines measurement of chlorophyll fluorescence (proxy of phytoplankton abundance), measurement of backscatter (as proxy of particle concentration) and CDOM fluorescence (incl. fluorophoric oil components). The ECO puck has been specifically designed to minimize space and power requirements for applications in autonomous measuring platforms, and is rated for sampling to 2000 m depth. We will discuss the performance of these floats that were deployed in May 2017 north of the Loop Current eddy complex as part of a GoMRI sponsored technology development. As part of the deployment, this new technology has been exercised to understand the float response when exposed to various stressors such as atmospheric frontal passage, hurricane passage, Loop Current intrusion, severe rain events and excess fresh water from the Mississippi River. Sampling rates were changed between profiling once every five days to depths of up to 2000 m as well as continuous profiling between 40 to 400 meters for higher temporal sampling by changing the piston counts on the missions. On the surface, data were transmitted over Iridium system including the GPS position, enabling investigators to update mission profiles to adaptively sample ocean processes.

Numerical Simulations of Oil Droplet Breakup in Homogeneous Isotropic Turbulence

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The distribution of oil droplet sizes produced by very near field turbulent stirring is a fundamental input for the subsequent environmental modeling of oil fate and transport. Droplet size distributions directly determine droplet rise velocities and dissolution rates and are significantly modified by the application of chemical dispersants. Here we examine the atomization of initially spherical, immiscible liquid droplets immersed in sustained, homogeneous, isotropic turbulence using an adaptive grid volume-of-fluid of method to track dynamic droplet interfaces. A series of experiments specifically investigates

the effects of changing oil viscosity, interfacial surface tension, and initial droplet size on the evolution of the droplet size distribution. For all parameters values investigated, droplet breakup is highly non-local in space and time. Droplets of linear size d_0 are predominantly stretched by larger scale turbulent structures to l/d_0 order 5-10 before breaking. The size distribution of daughter droplets changes dramatically with local Weber number. At large Weber numbers, breakup typically proceeds from highly elongated filamentation producing decidedly unequal sized daughter droplets. For smaller sized drops, or larger interfacial surface tension, breakup into equal-sized daughter droplets is more likely. As a result, the droplet size distribution at intermediate times is bimodal. Increasing the oil/water viscosity ratio both increases the production of small-scale droplets and reduces the breakage frequency of droplets with near-critical Weber numbers. Notably, the size of the largest surviving droplets shows power law scaling with the interfacial surface tension coefficient that is consistent with standard Kolmogorov-Hinze arguments, despite the fact that the largest droplets are considerably smaller than the smallest inertial sub-range scales of the turbulence.

Numerical Study of the Variation of Upper-ocean Light Field Induced by Oil Plumes

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Crude oil plumes can be dispersed over a wide surface area in the aftermath of a large subsea blowout. Upper-ocean flows such as turbulence and Langmuir circulations may provide sufficient forcing to keep a considerable amount of oil suspended as droplets and disperse them over the water column in the upper-ocean mixed layer. Clouds of suspended oil droplets can cause significant light absorption and scattering, strongly affecting the sunlight penetration in the ocean euphotic zone where photosynthesis occurs. In this study, the turbulent dispersion of suspended oil droplets and the resultant variations of upper-ocean light field are studied using numerical simulations. In particular, the dispersion of the oil plume is simulated using large-eddy simulation, the sea-surface wave field is simulated using a high-order spectral method, and the sunlight transport is simulated using a Monte Carlo radiative transfer model. The simulation results show that oil plumes of different droplet sizes are dispersed very differently in the upper ocean, resulting in different inherent optical properties for the mixture of oil droplets and seawater. As a result, the ocean light field can vary significantly for different ocean flow and oil plume conditions. This research is made possible by a grant from The Gulf of Mexico Research Initiative. D.Y. also acknowledges the financial support from start-up funds at the University of Houston.

Spatiotemporal Oil Droplet Size Distribution Datasets Generated by Breaking Waves in Supporting New Oil Spill Fate Models

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Many oil spill fate models in use rely on a dataset obtained by Delvigne and Sweeney (*Oil Chem. Poll.*, 4, 281-310, 1988) for the subsurface droplet size distributions under ocean waves. Comprehensive as it is, this study does not provide information about the effects of dispersant or time on the size distribution of oil droplet. The present systematic laboratory study examines the temporal evolution of the crude oil droplets' size distribution generated as breaking waves entrain oil slicks. The measurements are performed for varying wave energy, as well as a broad range of oil viscosities and

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oil-water interfacial tension, the latter achieved by premixing the oil with COREXIT 9500A at dispersant to oil ratios (DOR) of 1:500, 1:100 and 1:25. The subsurface droplet number size distributions (NSD) from 2 s to 5 hrs after wave breaking are measured *in-situ* using digital holography. The corresponding temporal evolution of the wave-generated turbulence is measured using Particle Image Velocimetry (PIV). The early (2-10s) NSD have two distinct size ranges with different slopes. For all the low DOR oils, the transition between them scales using a turbulent Weber number in the 2-4 range. For smaller droplets, the NSDs have a power law with exponent of about -2.1, similar to prior observations, and for larger droplets, the exponent decreases to well below -3. Conversely, for the DOR 1:100 and 1:25 oils, the early transition size decreases from ~1mm for non-treated oils to 46 μ m and 14 μ m respectively, and can no longer be predicted using the Weber number. Furthermore, the magnitude of the NSD exponent increases with increasing DOR. The NSDs of all the droplets steepen over time. The measured temporal evolution of the NSDs are predicted effectively using a one-dimensional advection-diffusion model accounting for buoyant rise and turbulent diffusion of the droplet, the latter determined from the measured turbulence level.

PCC-005: Microbial Processes at Oil-Water Interfaces

Cargo-Carrying Bacteria at Oil-Water Interfaces

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Bacteria adhere to and restructure oil-water interfaces as they secrete polysaccharides and surfactants, change phenotype to become immobile, and build elastic films. We have studied this restructuring in prior research for various strains of *Pseudomonas aeruginosa* at the hexadecane-water interface. We have found, however, that certain strains do not restructure fluid interfaces. Rather, they remain motile in interfaces that remain fluid over hours. We exploit this fact to study the manner in which these bacteria interact with microscopic passive materials, i.e. colloids, at these boundaries. Typically, colloids are thought to have enhanced, random displacements owing to indirect interactions like hydrodynamic interactions as bacteria swim near them. We find, however, that colloids at interfaces of suspensions of *Pseudomonas aeruginosa* Δ pelA move along nearly deterministic paths that are not consistent with this mechanism. Direct observation of bacteria at interfaces reveals new modes of transport owing to direct adhesion of the bacteria to the colloids. We discuss the manner in which we model these interactions. Our work contributes to a better understanding of the transport of passive microscale objects with actively swimming bacteria at oil-water interfaces, and opens important questions about bacteria-mediated micromixing in other settings.

Hydrodynamic Interaction of Marine Bacteria and Oil Droplets

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We discuss the hydrodynamic interaction of marine bacteria with soluble and insoluble hydrocarbons (HCs). We present direct numerical simulations of a continuum framework involving conservation equations for motile and chemotactic marine bacteria, the corresponding *soluble* HCs, and the multi-

phase fluid flow characteristic of rising oil drops. The rising oil drops' main contribution is the generation of a 'pseudo-turbulent' flow. This pseudo-turbulence results in the distortion of any HC fragment into thinner filaments that have high HC-concentrations in their core. Chemotactic species profit from the distortion and seek out these HC-rich regions, thus obtaining a 'motility benefit' over non-motile/non-chemotactic species. We reveal that motility can result in ~30% faster instantaneous consumption by motile bacteria compared to the non-motile ones. The results of this study are expected to provide vital information and fertile ground for research in the field of bacterial bioremediation in subsurface oil spills.

Accumulation of Marine Bacteria on and Near Oil-Water Interfaces

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During the Deepwater Horizon spill, hydrocarbon-degrading bacteria interacted with surfactant-laden oil-water interfaces during biodegradation. Here, we characterize the effects of chemical dispersants on the ability of bacteria to move near and adhere to oil/water interfaces as a first step using microfluidics, optical microscopy, and image processing. We make monodisperse oil-in-water emulsions using co-flow glass microfluidic devices; by varying the size of inner and outer microfluidic channel and the flow rates of the oil and water, we are able to generate oil droplets of diameter 35 - 100 μm . The oil droplets are stabilized using dioctyl sulfosuccinate (DOSS), the primary component of the Corexit EC9500 used in oil spill response. Dispersant-stabilized oil drops are then introduced into aqueous media containing marine bacteria, including *Marinobacter hydrocarbonoclasticus* and *Alcanivorax borkumensis*. We characterize the accumulation of bacteria on and near the oil/water interface as a function of time using microscopy and cell-tracking methods. Information on how dispersants modify the ability of bacteria to accumulate at interfaces is expected to inform the development of models that predict the rate of degradation in an oil-spill scenario.

Monitoring Morphological Changes of Crude Oil Microdroplets Exposed to Different Bacteria Species and Consortia

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Biodegradation is considered an effective way of degrading marine oil spill and cleaning of the ecological marine environment due to its low cost, environmental friendliness, and absence of additional pollution. A variety of bacteria with specific metabolic abilities are able to consume oil. We conducted laboratory experiments to determine the effectiveness of the size of the oil microdroplets on the bacteria-oil interaction and biodegradation. Further study was done to explore the interaction of different bacteria species on stationary oil microdroplets versus microbial interaction of oil degrading consortia containing six different bacteria species. The study was performed by monitoring the morphological changes of the microdroplets in real time for one week as well as the instantaneous flow field. To attain the results, we developed a micro-bioassay containing an enclosed chamber with bottom substrate printed with stationary oil microdroplets and a digital holographic interferometer (DHI). The results were also examined with atomic force microscopy at the end of each experiment. The experimental results indicated that droplets smaller than 20 μm in diameter are not subject to bacterial degradation and their volume change beyond the dissolution was not observed. It was also

observed that different bacteria species have diverse appetite for oil. The experiments of consortia and various flow shears on biodegradation and dissolution are ongoing and will be reported.

How Does Marine Oil Snow Initiate on a Rising Micro-Scale Crude Oil Droplet?

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An estimated 40% of the released hydrocarbons following the Deepwater Horizon oil spill are still unaccounted for. Contrary to the expectations of some, bioconsumption is estimated to only account for a third of the hydrocarbons. Making matters more complicated, up to 15% of the oil unexpectedly settled to the sea floor in sticky mucous-rich flocs i.e. marine oil snow (MOS), adding a previously unconsidered route for the fate of the oil. Significant quantities of MOS were observed at the sea surface following the spill, and many laboratory experiments have demonstrated MOS formation using microbial communities sampled from the field. A number of factors are considered to have led to the large scale MOS event including the Deepwater Horizon's proximity to discharge from the Mississippi River, elevated particulate concentrations, and increased microbial mucous in the vicinity of the spilled oil. However, the initiation of a MOS aggregate is not yet well understood. Here we present results from ongoing investigations on the aggregation of bacteria on a single micro-scale crude oil droplet. Using a microfluidic bioassay we perform microcosm experiments simulating the rise of the droplet through a bacteria suspension. We demonstrate that microbes can form aggregates directly on an oil-water interface and these aggregates can grow into tails more than 10 drop diameters in length. With high speed microscopy and particle tracking velocimetry (PTV) we measure the hydrodynamic impact of these attached aggregates which includes significant increases in drag i.e. the aggregates would drastically slow down a rising oil drop. These results suggest a pathway to MOS formation by way of microbial aggregation on an oil drop resulting in a reduction in rising velocity allowing for increased microbial and particulate accumulation. Ongoing experiments are elucidating the effects of the rising velocity, drop size, microbial community, temperature and dispersant on the initiation of MOS.

Time Evolution of Surface Oil Layers and Surfactant Stabilized Droplets - Bacterial Colonization, Biofilm Generation and Biodegradation

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Oil dispersion by chemical dispersants is a primary spill response method applicable to deep sea spills and surface spills. Such methods are expected to increase hydrocarbon availability for oil-degrading microbial communities. Many such organisms produce biofilm that contributes to the formation of marine oil snow. In the context of oil degradation and potential sedimentation it is especially important to understand the characteristics of the produced biofilm and its interaction with surface layers and surfactant stabilized crude oil. We examine biofilm formation both under dispersant free oil layers and on dispersant containing oil droplets. As a model, we use a key hydrocarbonoclastic agent, the biofilm-producing *Alcanivorax borkumensis*. In relatively static surface layers, there is a strong proliferation of biofilm which forms pendent layers below the oil. Detailed cryogenic electron scanning microscopy reveals that the biofilm forms an interfacial mat which increases the interfacial viscosity and inhibits

* Student presenter

dispersion. Over a period of a week, we observe sedimentation of a portion of the biofilm mat together with oil, leading to verification of the marine oil-snow sedimentation concept. Essentially similar observations are seen with high concentrations of oil dispersed with Corexit 9500A, where bridging between droplets due to biofilm occurs. The use of cryo electron microscopy is crucial to understand the nanoscale aspects of such bridging and the creation of aggregated droplet based sedimentation. The results of our study also indicate that repeated dispersant addition to exopolymer containing oil layers and droplets reduces dispersant efficacy. Alkane biodegradation is significant over a week of biofilm formation, with cryo electron microscopy showing sequestration of bacterium in the biofilm at the oil-water interface.

Bacterial Proliferation on Clay Nanotube Pickering Emulsions for Oil Spill Bioremediation

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Halloysites (tubular aluminosilicate) are introduced as inexpensive natural nanoparticles that form and stabilize oil-water emulsions. Pickering emulsification can proceed with energies low enough to be afforded by ocean turbulence and the stability of droplets extends over more than a week. The oil/water interface is shown to be roughened and bacteria, which are added for oil degradation, are better attached to such oil droplets than to droplets without halloysites. The enhanced proliferation has been illustrated with the presence of *Alcanivorax borkumensis*, an alkanotrophic bacteria widely distributed in marine environments, on halloysite Pickering emulsions. The presence of halloysite around the oil-degrading bacteria has been shown to increase the metabolic activity of *A. borkumensis* in addition to enhanced proliferation. A halloysite-based dispersant system is therefore environmentally friendly and promising for further optimization. The key elements of the described formulations are natural clay nanotubes, which are abundantly available in thousands of tons, thus making this technology scalable for environmental remediation.

Flat-sheet Clays Sequester Oil-degrading Bacteria and Stabilize Oil Dispersions Providing Insights on Marine Snow and Oil-Mineral Aggregates

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Amphiphilic particles inherently adsorb on oil-water interfaces creating effective surfactant-free emulsions. We report the ability of flat sheet natural clays such as kaolinite to stabilize crude oil-in-seawater emulsions. The sheet-like structure adsorbs at the oil/seawater interface creating armored droplets that form an effective steric barrier to droplet coalescence. These systems mimic the behavior of oil-mineral aggregates but can also be engineered to enhance adsorption at the interface and optimize emulsion stability, thus leading to environmentally benign oil dispersion technologies. Our work examines the fundamental thermodynamics of these emulsions and additionally examines the role of bacterial attachment to the particles and growth at the interface. There is significant

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colonization of kaolinite stabilized oil droplets by *Alcanivorax borkumensis*, an oil-degrading bacterial species that uses alkanes as the carbon source. We find that colonization is rapid with proliferation of biofilm over the particles and bridging of the clays induced by the microbial exopolymer. This phenomenon leads to sedimentation of the oil-particle-biofilm complex and provides insight into the oil-sinking concept. A unique aspect of the research is the use of cryo-electron microscopy to understand bacterial sequestration, growth of biofilm, and eventual sedimentation. The degradation of the alkanes in a model crude oil (Anadarko) is also measured in the system containing particle and biofilm stabilized emulsions. The results indicate that degradation is rapid with about 80% alkane reduction over a period of a week.

Antibody-based Assays to Monitor Polycyclic Aromatic Hydrocarbon Degradation by Marine Bacteria

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Among the various constituents of crude oil, polycyclic aromatic hydrocarbons (PAHs), which consist of several fused benzene rings, are among most important pollutants. Benzene rings are very stable, and therefore persistent in the environment. In addition, many PAHs have toxic, mutagenic and/or carcinogenic properties. We used a purified recombinant antibody to PAHs available in our laboratory (Y. Sun (2016) *Anal. Chem.* **88**:9181) to develop immunoassays that can monitor degradation of PAHs by the genus *Cycloclasticus*, a group of marine bacteria that participate in bioremediation of PAHs. The type strain *C. pugettii* was adapted for growth in minimal medium (ONR7a) with crystalline biphenyl or phenanthrene as the sole carbon source. The organism grew much slower in phenanthrene, most likely because of this PAH's low solubility (~1000-fold less than biphenyl). Addition of 1% DMSO to ONR7a allowed us to increase the solubility of phenanthrene up to 500 μ M, and *C. pugettii* then grew to much higher densities. Fluoranthene and fluorene at 500 μ M did not support growth alone in DMSO-ONR7a, but were degraded if the medium was supplemented with biphenyl. When we combined our immunoassays for phenanthrene, fluoranthene and fluorene (IC₅₀'s 8, 1.5 and 15 μ M, respectively) with a fluorescent viability assay, we could monitor cell growth and time-dependent PAH disappearance in the same culture. This novel method is now being employed to monitor bacterial degradation of PAH's spiked into crude oil samples and to study the effects of dispersants on bioremediation of PAHs in spiked oil samples.

Influence of Associated Bacteria on Phytoplankton Oil Response

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Studies show that both phytoplankton and prokaryote communities significantly change after an oil spill, with important consequences for carbon fluxes and food webs. The phytoplankton species-specific bacteria community, and the strong interactions between the bacteria and algae, might be one of the factors responsible for the resistance of some phytoplankton species and the decline of others. To test this, we looked at the sub-lethal effects of dispersed and undispersed crude oil on xenic (with bacteria; X) and axenic (without bacteria; AX) cultures of *Peridinium sociale* (armored dinoflagellate),

* Student presenter

Amphidinium carterae (non-armored dinoflagellate) and *Skeletonema* sp. (small diatom). Oil alone did not impact phytoplankton physiology. However, with dispersed oil, growth rate and photosynthetic efficiency of the three strains significantly decreased for both X and AX cultures. *Skeletonema* was the most impacted, with a negative growth rate in the presence of dispersed oil, and a 20% decrease in growth with dispersant alone. Surprisingly, phytoplankton physiology was similar with and without bacteria. This may be due to the youth of the AX cultures, which were established only four months before the experiments. 16S rRNA gene analyses showed that the absence of oil degradation in *Skeletonema* cultures is explained by the absence of oil degraders in its phycosphere before and after the addition of oil. In contrast, oil degraders were present in the free-living fraction of the dinoflagellate phycospheres, and their relative abundance significantly increased with dispersed oil. Oil degradation by free-living bacteria, along with the resilience of the attached bacteria, contribute to dinoflagellate oil resistance. Metatranscriptomics of both bacteria and an oil-resistant phytoplankton would give more insights into specific interactions that can help some eukaryotes to survive to oil spill.

The Interaction between Phytoplankton and Bacteria Responding to Oil and/or Dispersants

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Microbial communities play an important role at the base of the food web cycling both carbon and nutrients. Phytoplankton fix inorganic carbon, providing both dissolved and particulate organic matter during photosynthesis for larger organisms, while bacteria recycle nutrients and carbon. Although there is some research on the interaction between phytoplankton and bacteria, there are knowledge gaps on the effects of environmental stressors like oil spills. Mesocosm experiments were conducted with surface microbial communities in order to investigate the impacts of the Deepwater Horizon (DWH) Oil Spill in the Gulf of Mexico. Natural microbial communities collected from the Flower Garden Banks (FGB) and the Louisiana coast (LC) in the Gulf of Mexico were incubated in mesocosm tanks with four treatments: (1) a control treatment (seawater only), (2) Water accommodated fraction of oil treatment (WAF), (3) chemically enhanced water accommodated fraction of oil and dispersant (Corexit 9500) treatment (CEWAF), and (4) a diluted CEWAF treatment (DCEWAF). Samples for both phytoplankton and bacterial community analysis via 18S and 16S rRNA sequencing were taken every 12 hours for 4 days. The presence and relative abundances of known oil degrading bacterial taxa varied significantly between FGB and LC. Some taxa were exclusive to the nutrient poor FGB samples (e.g. *Polycyclovorans*) while other genera (i.e. *Marinobacter*, *Oleibacter*, *Methylophaga*) were represented in both waters, but by different OTUs respectively. Eukaryotic heterotrophs were abundant in samples from the LC from the first time point, but after 72 hours *Bacillariophyceae* abundance was higher in both control and WAF treatments compared to treatments with dispersant. Community network analysis was used to correlate changes between bacterial and phytoplankton operational taxonomic units. The results from this analysis will further elucidate the relationships between microbial communities responding to oil spills like that of the Deepwater Horizon.

Regulation and Dynamics of Microbial Oil Degradation in Nearshore and Offshore Waters

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The degradation of hydrocarbons by individual microorganisms or by groups of microorganisms working cooperatively is regulated by a complex and varying suite of variables, including microbial community composition, availability of nutrients and trace elements, availability of oxygen and temperature. We examined the impact of adding chemical dispersants and crude oil - either individually, together, or sequentially - on rates of microbial activity, including oxidation assays for specific oil components, and on microbial community structure in surface water samples from a nearshore oil-contaminated site and in offshore surface waters near the location of the Deepwater Horizon Accident. At the nearshore site (Taylor Energy), the concentration of nutrients and oil played key roles in regulating oil degradation rates and, as such, oil degradation rates varied seasonally. The addition of chemical dispersants did not stimulate oil biodegradation rates at this site. At the offshore site, oil degradation rates were also strongly regulated by both nutrients and the presence of chemical dispersants. Nearshore and offshore surface oil degrading populations were different and exhibited different responses to oil versus dispersant addition. The addition of oil versus chemical dispersants individually had interesting and unexpected effects on oil degradation rates at both sites. Together, these data underscore the important role that nutrient (nitrogen and phosphorus) availability play in regulating oil biodegradation rates in the environment. The data also suggest that chemical dispersants may not always stimulate oil biodegradation in surface ocean waters.

PCC-006: Marine Snow -- Formation, Chemistry, Impacts

Formation Mechanisms and Sedimentation of Marine Oil Snow: New Insights Through an Oil Compound-Specific Approach

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MOSSFA (Marine Oil Snow Sedimentation and Flocculent Accumulation) processes were extensively investigated during and after the Deepwater Horizon oil spill. However, the partitioning of specific oil compounds into marine oil snow (MOS) and the mechanisms of oil incorporation have not been identified. We incubated phytoplankton in roller tanks in the presence or absence of Macondo oil and the dispersant Corexit. We documented MOS formation and sampled MOS, the dissolved water phase and the unaggregated particles separately. Samples were analyzed for targeted oil compounds, namely *n*-alkanes and polyaromatic hydrocarbons, as well as for organic carbon content. Different mechanisms for oil incorporation into MOS were identified as depending largely on the physiochemical properties of the oil compounds. Hydrophobic molecules were incorporated into MOS within entire oil droplets that were scavenged by the phytoplankton. In contrast, the water-soluble fraction of the oil absorbed to cells from the water. The presence of the dispersant Corexit significantly increased the amount of oil in MOS and caused it to be enriched with toxic, high molecular weight oil compounds. These results allow predictions as to which oil compounds preferentially sediment via MOS under different

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circumstances. Furthermore, our results imply that the compound-specific incorporation of oil into MOS needs to be considered when estimating the amount of sedimented oil based on biomarker concentrations in sediments.

The Effect of EPS Composition on the Aggregate Formation on a Crude Oil Drop Interface

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After the Deepwater Horizon oil spill up to 15% of the released oil unexpectedly settled to the sea floor in sticky mucous-rich flocs i.e. marine oil snow (MOS), an oil fate not considered when calculating initial oil budgets. MOS formation as a significant mechanism for sedimentation of oil has been corroborated by observations of MOS formation at the sea surface, numerous laboratory experiments, and data from sediment traps. Several factors contributed to the production of MOS including elevated particulate concentrations, proximity to the Mississippi River Delta, and increased microbial release i.e. extracellular polymeric substances (EPS). EPS is a complex mixture of carbohydrates, proteins, nucleic acids and other compounds, and their composition can vary significantly based on the microbial community and environment. The composition of the EPS plays a significant role in the ability to form aggregates. For example, abundant amphiphilic proteins can provide additional adsorption sites for aggregation. In this collaboration between the GoMRI-funded research consortia DROPPS and ADDOMEx we present ongoing research into the ability of EPS with varying protein/carbohydrate ratios to produce aggregates on a single drop of crude oil. We use a microfluidic bioassay to perform “ecology-on-a-chip” experiments to simulate a microscale oil drop rising through a suspension of EPS and other particles. Time lapse microscopy lasting several days captures the growth and morphology of EPS aggregates. We demonstrate that a higher protein to carbohydrate ratio leads to larger and more rapid formation of MOS likely due to increased stickiness of the EPS. Additionally, we show that EPS in the absence of particles is unable to form aggregates in the time scale of our experiments, while the addition of particles can induce rapid aggregation. The protein composition of the EPS as determined by liquid chromatography mass spectrometry-based proteomics will be also presented. Ongoing work is considering the influence of different microbial communities and temperature on the formation of EPS aggregates.

Long Term Marine Oil Snow Mesocosm Experiment

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In order to understand the driving factors that lead to marine oil snow formation after the Deepwater Horizon Oil Spill, we conducted a long term (16 day) mesocosm experiment. Eighteen 110L capacity glass mesocosm tanks were filled with Gulf of Mexico seawater (25 PSU) collected 8 km offshore south of Galveston (TX) that had been pre-treated with a charcoal filter to remove large particles and debris. Plankton ($\geq 63 \mu\text{m}$) were collected using a net and transferred into polycarbonate bottles after being prefiltered (115 μm) to remove zooplankton, jellyfish and debris. Six replicates mesocosms each for the

controls, water accommodated fraction of oil (WAF high energy) and a diluted chemically enhanced water accommodated fraction of oil (DCEWAF) were prepared using Macondo Surrogate oil and Corexit 9500 (oil to Corexit at 20:1). The estimated oil equivalents (EOE) were determined using the same Macondo surrogate oil used for dosing and as the calibration standard by fluorescence analyses (Horiba Scientific Aqualog Fluorometer). Samples for EOE analyses were collected at the start (time 0) and every 24 hours to 360 hours and plots for WAF and DCEWAF mesocosms indicate exponential decay rates. The average EOE at time zero for the control, WAF and DCEWAF were 0.02 (0.00 to 0.04), 2.15 (1.47 to 2.58) and 2.62 (range 2.28 to 3.10) mg/L, respectively. The average EOE after 360 hours for the control, WAF and DCEWF were 0.02 (0.00 to 0.04), 0.31 (range 0.25 to 0.41) and 0.25 (0.24 to 0.27) mg/L, respectively. The average exponential decay rates for the control, WAF and DCEWAF were -0.0003/hr, -0.0054/hr and -0.0066/hr respectively. Control had only a low rate (near zero) of EOE loss. The loss rate of EOE from the DCEWAF was higher than the loss rate from the WAF mesocosms. This indicates the Coxeit use enhances oil removal rates. Additional analyses will provide information of whether this was due to formation of marine oil snow, biodegradation or some combination of these processes.

Does Oil Aggregate or Emulsify with Colloidal EPS? Importance of Protein/Carbohydrate Interactions in Oil and/or Dispersant Experiments

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Oil interacts with amphiphilic substances in the water to form either emulsions or aggregates, influenced by the chemical composition of exopolymeric substances (EPS) that aid in their formation. Here we investigated mechanisms governing the self-assembly and phase separation for protein-polysaccharide-oil interactions through measurements of surface tension, Fourier-Transform Infrared Spectroscopy (FTIR), and microscopy. Colloidal EPS fractions from treatments of WAF (water accommodated fraction of oil), CEWAF (chemically enhanced WAF), and control were analyzed. Comparisons of these EPS were made between coastal and open ocean mesocosm environments as well as interfacial surface and bulk water column distributions. Also, data from short term (4 day) mesocosms are compared to that of long term (16 day) mesocosms. Results from experiments using EPS model proteins and polysaccharides provide insights into the underlying mechanisms in mesocosms. Two major mechanisms were proposed that promote aggregate growth: 1) ionic bonding through anionic EPS bridging to cationic metals; and 2) hydrogen bonding through EPS amide functional groups. After aggregate growth was induced in cultured natural marine particle containing systems, the effect of varying dosages of EDTA and of urea in different treatments was documented through potential changes in aggregate size to determine if and when ionic or hydrogen bonding predominate. Mechanisms of protein-polysaccharide interactions at the oil-water interface with WAF determined emulsion stability or aggregate formation were investigated with electrophoresis and molecular size measurements. Results from these studies provide critical mechanistic insights into the fate and distribution of oil in the ocean, and may thus offer valuable information to both the science and management of oil spills.

Role of Micron-scale Aggregates in Hydrocarbon Oxidation

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The Deepwater Horizon oil spill in April 2010 introduced an estimated 650,000-780,000m³ of crude oil into the Gulf of Mexico (GoM). To mitigate the impact of this oil to the coastal environment, the dispersant Corexit® 9500 was applied to the surface oil slick, promoting the incorporation of oil droplets into the water column. During the spill, the formation of oil associated flocculants was observed within the contaminated surface waters which aggregated and sank over time, leading to the sedimentation of oil-rich marine snow. Mesocosm experiments were conducted to better understand the role of such microbial aggregates in hydrocarbon degradation and transport. Using GoM coastal water, three mesocosm treatments were set up consisting of a seawater only control, seawater amended with the water accommodated fraction of oil (WAF), and seawater with Corexit® dispersed oil. It was observed that, in addition to the formation of marine oil snow, smaller micron-scale microbial aggregates were also present in all treatments. Visual inspection of these microaggregates revealed that within the WAF and Corexit® amended treatments, ≥90% were associated with oil droplets. The abundance of these aggregates was greater in the WAF and Corexit® treatments as compared to the control and their peak abundance occurred on day 3, followed by a gradual decline. This peak abundance coincided with the maximum rates of biological hydrocarbon oxidation as estimated by the mineralization of ¹⁴C labeled hexadecane and naphthalene. To elucidate the potential of these microaggregates to serve as hotspots for hydrocarbon degradation as well as their involvement in marine oil snow formation, microaggregates were collected throughout the 16-day experiment via gravity filtration, enabling preservation of their structural integrity. We present here initial analysis of the microbial assemblages within the aggregates as characterized with 16S rRNA gene sequencing and fluorescent in situ hybridization (FISH).

Marine Snow Aggregates are Enriched in Polycyclic Aromatic Hydrocarbon (PAHs) in Oil Contaminated Waters of the Gulf of Mexico; Insights from a Mesocosm Study

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Polycyclic aromatic hydrocarbons (PAHs) are of great environmental concern because of their toxicity, and mutagenic and carcinogenic potentials. Marine snow can transport PAHs from the sea surface to the seafloor, but we have a limited understanding on the distribution of PAHs in marine snow aggregates. We determined the concentration and distribution of PAHs in marine aggregates sampled after four days of incubation from the bottom of mesocosm experiments. The mesocosm tanks contained 100 L of surface water from the Gulf of Mexico (Control), amended with oil in a water accommodated fraction (WAF), or with diluted chemically enhanced (with dispersant Corexit) WAF (DCEWAF). Compared to the control tanks, the total PAHs in aggregates in WAF and DCEWAF tanks were 3.5 and 10 times greater, respectively. The 3-ring phenanthrene and anthracene, and 4-ring fluoranthene and pyrene, were the most dominant PAHs comprising about 70% of the total PAHs in the oiled tanks. The oiled aggregates were also highly enriched in 4-5 ring PAHs (dibenzo [a,h] anthracene, indeno [1,2,3-cd] pyrene, benzo [k] fluoranthene, benzo [ghi] pyrene), which were not detected in the surrounding seawater. This suggests that marine snow could be a major contributor of high molecular weight PAHs to the seafloor sediment following an oil spill. Moreover, the concentration of PAHs in the aggregates is enhanced by 2.8-fold in the presence of Corexit compared to WAF. The

exoenzyme activities, and alkylated PAHs and alkane concentrations in the aggregates will be also presented. Our results provide insight on the role of marine snow in the transport of petroleum hydrocarbons from the surface to the deep-sea following the Deepwater Horizon oil spill where an estimated 10% of released oil was deposited to the seafloor of the northern Gulf of Mexico.

Rapid Degradation of Marine Snow-associated Oil during Mesocosm Simulations of the Deepwater Horizon Oil Spill Event Revealed by FTICR MS

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Significant amounts of marine snow made up of dead/living plankton/bacteria and their exopolymeric polysaccharide substances were found to have been stimulated by the Deepwater Horizon oil spill in the Gulf of Mexico. Natural marine snow interacted with both oil and the dispersant Corexit to form marine oil snow (MOS) that was rapidly removed from the water column and incorporated into sediments in and around the well site. Mesocosm simulations of this process demonstrated that Macondo-like oil can become incorporated into marine snow. Solid-state ¹³C NMR of marine snow aggregates performed by a new low-volume sample container and a quantitative pulse sequence readily distinguishes the MOS from natural marine snow. The polar fractions of marine snow and MOS aggregates, were isolated via extraction with dichloromethane (DCM) then analyzed by Fourier transform ion cyclotron resonance mass spectrometry (FTICR MS). FTICR MS analyses demonstrate that DCM extracts of MOS have distinct molecular compositions relative to both marine snow in control treatments (no oil) and Macondo oil. Specifically, the number of oxygens and double bond equivalents (DBE) in relatively abundant (as determined by relative mass spectral signal) CHO (C_xH_yO₂₋₄, DBE₈₋₁₅), CHON (C_xH_yO₁₋₄N₁, DBE₁₀₋₁₉), and CHOS (C_xH_yO₁₋₄S₁, DBE₈₋₁₄) molecular formulas assigned to MOS differed from those found in the control (CHO: C_xH_yO₂₋₈, DBE₁₋₈, CHON: C_xH_yO₂₋₅N₁, DBE₁₋₆ and C_xH_yO₅₋₉N₂, DBE₁₀₋₁₄; CHOS: C_xH_yO₆S₁, DBE₁₋₃ and C_xH_yO₄, DBE₆₋₇). The MOS molecular distributions also differed from that of Macondo oil and are consistent with the transformation of high DBE oil components that were unobservable by FTICR MS until being oxygenated, presumably via biological degradation processes. The results of this work provide insight into rapid oil transformation mechanisms that result from oil/marine snow/dispersant interactions and the identification of potential oil degradation marker compounds.

Establishing Gulf-wide Baselines and the Spatial Extent of Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA) from Contemporary and Past Oil Spills Using ²¹⁰Pb

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Short-lived radioisotopes in the sediments of the Gulf of Mexico (GoM) have shown to be useful tracers of marine oil snow sedimentation and flocculent accumulation (MOSSFA) following the Deepwater Horizon (DWH, 2010) and Ixtoc (1979-80) oil spills. Using excess ²¹⁰Pb (²¹⁰Pb_{xs}) inventories, the spatial extent (12,805 to 35,425 km²) of MOSSFA on the seafloor of the northern GoM was determined

following the DWH oil spill. These results have implications for the long-term preservation of oil spills and assessing the magnitude of sedimentary fluxes associated with MOSSFA. Work is ongoing to identify the spatial extent of MOSSFA in the Southern GoM associated with the Ixtoc oil spill utilizing $^{210}\text{Pb}_{\text{xs}}$ inventories and fluxes. Finally, Gulf-wide (US, Mexico, Cuba) maps of $^{210}\text{Pb}_{\text{xs}}$ activities, fluxes, and inventories are being developed in an effort to provide a contemporary overview of the current baseline sedimentation characteristics, which would be useful quantitatively assess changes in sedimentary flux and deposition following any future oil spills.

Numerical Modeling of the Interactions of Oil, Marine Snow and Riverine Sediments in the Ocean

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Natural or spilled oil in the ocean can interact with marine snow and sediment from riverine sources and form marine oil snow (MOS) aggregates. The MOS formed are fractal aggregates that can transport the oil on the surface layer to greater depth in the ocean, eventually settling on the sea floor. Recent studies of the Deepwater Horizon spill have identified this as one of the main mechanisms for transporting oil vertically in the water column. We have modified a stochastic, one-dimensional coagulation model developed for the biological pump to incorporate aggregation of marine particles with oil droplets. The model simulates the formation, size distribution, and vertical fluxes of MOS in the water column from the surface to the sea floor. Here we present the model development, calibration and validation with measured MOS field data in the Gulf of Mexico during and after the Deepwater Horizon spill, and discuss data gaps that need to be filled to improve the model accuracy and performance. The model can be used during response and planning activities associated with oil spills in the marine environments.

Transport of Dispersed Oil to the Seafloor by Sinking Phytoplankton Aggregates: A Modeling Study

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The formation and sinking of oil-containing marine snow aggregates (Marine Oil Snow - MOS) was found to be one of the primary mechanisms for vertical transport and sedimentation of oil during and after the Deepwater Horizon oil spill. Immediately following the spill, a large sedimentation event dominated by oil-containing diatom aggregates was recorded by a sediment trap deployed very near to the spill site. Here, we present a coupled one-dimensional aggregation-degradation-sedimentation model that aims to simulate the processes that led to this event in an effort to further understand the critical mechanisms involved and to evaluate the usefulness of such a model in cases where many parameters are unknown. The model is calibrated using detailed experimental data on diatom aggregates as well as field data collected during the event. Results are compared to sediment trap measurements. We evaluate model performance and assess its sensitivity to varying input parameters.

The Fractal Dimension of Marine Oil Snow Aggregates: Changing Aggregate Characteristics

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Oil in the water column can aggregate with marine particles to form Marine Oil Snow aggregates. The sedimentation of these aggregates leads to MOSSFA events, where marine particles sink through the water column to the ocean floor, carrying oil with them. Understanding the role of the fractal dimension in determining MOS characteristics is critical for predictive modeling of MOSSFA in terms of estimating oil budgets and predicting the fate and vertical transport of oil in the water column. The geometry of these aggregates is characterized by the fractal dimension which in turn affects important properties such as particle aggregation rates, particle porosity, and more crucially, aggregate sinking speeds. Predictive models of aggregate formation and sinking flux usually use a single fractal dimension for all particles, but measured fractal dimensions of marine aggregates vary from 1.2 to 2.9, leading to changes in predicted flux by as much as a factor of 7. Adding oil to aggregates may change the fractal dimension in many ways depending on how the oil interacts with the aggregates; does oil coat particles or do oil droplets fill the pore space in aggregates? We present a combination of size distribution modeling results with results from models of the formation of individual aggregates from multiple source particle types to assess the effects of oil on aggregate structure and properties such as settling speed and flux.

Insights in the Consequences of MOSFFA Events for the Benthic Community

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The MOSFFA event that caused the deposition of substantial amounts of oil contaminated marine snow on the seafloor probably was not unique for the Deepwater Horizon oil spill. A better insight in the consequences of such a MOSFFA event on the fate and effect of the oil is therefore needed to assess the potential environmental impact of future oil spills. This presentation reviews the results from a series of consecutive aquarium experiments, each increasing in complexity and providing a more realistic scenario that were conducted during the recent years within the C-IMAGE consortium. The results show how the effects of oil contaminated marine snow that settles depends on the traits of the benthic species as well as the MOSFFA accumulation rate. An important added adverse effect resulted from local oxygen depletion caused by the microbial degradation of the marine snow. This oxygen limitation in the top layer of the sediment also hampers the biodegradation of the oil. Species that consumed marine snow also did so when this was oil contaminated. A MOSFFA event may thus increase the impact of an oil spill on the benthic community by i) bringing oil to the sediment floor; ii) adding oxygen depletion as an additional stressor to the oil exposed community; iii) prolonging the impact by hampering oil degradation; iv) facilitating introduction of the oil contamination into the food chain.

PCC-007: Impact of Freshwater Discharge on Coastal-Deep Ocean Connectivity

The Impact of River Plumes and Winds on Cross-Isopycnal Transport in the Northern Gulf of Mexico

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River plumes affect coastal ecosystems by bringing nutrients and biological matter from inland sources to the ocean. The eventual fate of these constituents is dictated by currents which primarily advect water horizontally and by turbulence which mixes water masses and transports constituents vertically across isopycnals. In this study, a week-long shipboard survey was performed in the northern Gulf of Mexico near the mouth of the Mobile Bay in water that was 12-18 m deep as part of CONCORDE, a GoMRI consortium that focuses on the impact that oil spills have on coastal river-dominated ecosystems. Surface-to-bottom temperature, salinity, velocity, optical backscatter, fluorescence, and turbulence microstructure were all measured along a repeated 26 km, arc-shaped transect located about 15 km south of Mobile Bay. Resolution of the measurements ranged from 0.1 to 1 m vertically and from 10 to 150 m horizontally. Shipboard radar was used to track plume fronts as they propagated and evolved. Throughout the survey, numerous river plumes were encountered under both weak and strong wind conditions. Under low wind conditions, river plumes were found to increase turbulence in deeper waters by adding vertical shear. Conversely, under high wind conditions, river plumes were found to decrease turbulence by insulating deeper waters from wind forcing. The combination of turbulence and velocity measurements help us to quantify and map transport pathways of Mobile Bay water and its associated chemical and biological constituents in the coastal waters of the northern Gulf of Mexico.

The Role of Freshwater Discharge on Coastal Transport

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Tidal propagation is damped by fresh water discharge and has an important impact on system-wide transport, limiting the potential landward advancement of oil. Here, the role of discharge on spatial variability in the dynamics of tidal rivers is investigated in Mobile Bay and Delta, a microtidal diurnal system where discharge ranges multiple orders of magnitude. Long-term observations at 7 velocity stations and 20 water level stations, ranging over 260km along the system, were analyzed. Observations of the tidal extinguishing point in both velocity and water level were highly variable with significant shifts in location covering a distance over 140km. The velocity stations also allowed for measuring the extent of flood (i.e. point where tidal flow is arrested by discharge) shifting 100km. With increased discharge, flow characteristics at station locations can transition from an estuary (i.e. bidirectional tidal flow) to a tidal river to a traditional fluvial environment. This revealed systematic discharge induced damping and an increase in phase lag. Interestingly, before damping occurs, the tide amplifies (~15%) seaward of the extent of flood. Another consistent pattern is the higher sensitivity of the velocity signal to discharge than water level. This causes the velocity to lag more and create progressive tides. In a microtidal diurnal system, the signal propagates further inland than a semidiurnal tide due to its lower frequency but is easily damped due to the small amplitude, creating large shifts. Previous research has focused on environments dominated by semidiurnal tides with

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similar magnitudes to discharge using water level observations. For example, the well-studied Columbia and the St. Lawrence rivers have small shifts in their tidal extinguishing point O(10km) (Jay 2016, Matte 2014). These shifts are not large enough to observe process like discharge-induced amplification and damping at the same site like in the Mobile system, but they may indicate a decoupling of the water level and velocity signal by discharge. Throughout the world, shifts in tidal rivers are created by seasonal discharge patterns, but large storms can quickly disrupt a system and move it over 140km in a few days.

Cross Shelf Transport During a Mississippi River Plume Event in December 2015

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A well-defined Mississippi River (MSR) offshore plume event was observed in December 2015 during a NOAA funded project to study shelf-slope interactions and occurring within the time frame of the observational studies conducted in the region by the Consortium for oil spill exposure pathways in COastal River-Dominated Ecosystems (CONCORDE), funded by the Gulf of Mexico Research Initiative. The resources of both programs were brought together to study the shelf-slope transport of water and constituents such as colored dissolved organic matter (CDOM), dissolved inorganic carbon (DIC), and chlorophyll-a, during this event. During the event the MSR plume was detected approximately along the 500-m isobath to the east of the MSR delta by moorings located on the slope and a Sailldrone traversing back and forth between the moorings and in a line perpendicular to them. At the western-most mooring a NOAA/PMEL Moored Autonomous Dissolved Inorganic Carbon (MADIC) buoy measured salinities that dropped from near 35 to 18, temperatures that dropped approximately 5°C, and DIC that dropped by 150 µM/kg. The Sailldrone measured salinities as low as 10, temperature drops of more than 5°C, enhanced CDOM and chlorophyll fluorescence, and dissolved oxygen. A profiling mooring to the west captured the low salinity event as well. Sea surface topography during the event indicated a cyclonic feature in the region that began on the inner shelf, and could be responsible for some of the plume transport to the east. The event illustrates cross shelf transport driven by shelf eddies and winds, with associated transport of important biogeochemical constituents, such as DIC and CDOM.

Episodes of Offshore Export of Coastal Waters from the Mississippi Delta and Campeche Bank in the Gulf of Mexico: Characterization Based on Satellite Imagery

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In this study, satellite imagery from the Sea-Viewing Wide Field of View Sensor (SeaWiFS) and Moderate Resolution Imaging Spectroradiometer (MODIS-Aqua) sensors was used to quantify episodes of the export of coastal waters from the Campeche Bank and Mississippi Delta. Daily 1-km resolution images of chlorophyll-a concentration were individually analyzed for evidence of the transport of

highly-colored waters from these two locations. Three types of events were characterized: advection of highly colored water southward from the Mississippi Delta region to the Florida Keys region, northward export from the Campeche Bank to the deep Gulf, and direct entrainment from the Campeche Bank to the Florida Keys region by the Loop Current. Based on the analysis of each daily image, a histogram of transport events was compiled to quantify these export episodes. The transport of water northward from the Campeche Bank was observed on a regular basis and was visible in monthly climatologies, while the transport of water southward from the Mississippi Delta into the Florida Keys region exhibits a seasonal cycle with transport episodes mainly occurring during late summer and fall. Two factors which act in concert to facilitate the transport of water from the Mississippi Delta to the Florida Keys were identified: above normal discharge from the Mississippi River and a northern extent of the Loop Current above approximately 27.5°N. These export episodes can potentially influence the biological activity in the deep Gulf of Mexico and in the Florida Keys. Moreover, they illustrate pathways for long-distance connectivity at the basin scale.

Tracking Mississippi River Plume Using MODIS Color Index Imagery

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River plumes are highly dynamic systems that are important for transporting and transforming terrestrial materials in coastal margins. To track the spatial and temporal evolution of large river plume, an empirical river plume color index (RPI) was developed from MODIS/Terra images to track the Mississippi River plume in the Gulf. The river plume color index is tolerant to thin clouds, thick aerosols, and most sun glint. The river plume color index successfully detected Mississippi River plumes in the Gulf of Mexico, and tracked their transport pathways from the Louisiana shelf to the Florida Straits. The distribution of Mississippi River plumes revealed significant spatial and seasonal variations, which was primarily regulated by local circulation and loop-eddy current system in Gulf of Mexico. The plumes generally switched from a westerly, down-coast direction shelf in non-summer seasons to southeasterly and offshore in summer season due to remote and local forcing.

A Multi-platform Observational Study on Hydrocarbon Transport under the Influence of River Induced Fronts

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The transport and fate of hydrocarbons released during the 2010 Deepwater Horizon (DwH) oil spill was influenced by fronts created by rivers, especially from the Mississippi River (MR) plume. An unprecedented observational study took place in April 2017 to better understand the related processes, using an existing release of hydrocarbons near the MR Delta. Surface oil patches have been persistently observed around the Taylor Energy Site (TES) since 2004, when an oil platform was destructed by Hurricane Ivan. Although this is a release of much smaller scale than DwH, the related processes of river plume influence on hydrocarbon pathways are remarkably similar. A collaboration among different GoMRI-funded projects allowed the leverage of a broad range of expertise and resources to successfully carry out the field work and data analyses. The objective was to explore the

pathways of oiled waters, to document how they were influenced by the river induced fronts (in the context of other circulation characteristics) and to examine differences due to the variability in oil thickness. Drifter deployments, oil thickness characteristics, ship-borne radar measurements of currents and vertical transects were combined with high resolution imagery from satellites (down to 1.5 m) and an Unmanned Aerial System to document frontal positions and oil patch spreading. Two kinds of drifters were deployed to test the hypothesis that drogued/undrogued drifters would follow thick/thin oil. Results indicate that the MR plume extension over TES, in combination with local circulation, prevailing winds and broader regional dynamics (Loop Current system) determine the hydrocarbon transport. The multi-platform observations efficiently described three major pathways of waters originating at TES, under a “natural barrier” role of fronts: downstream/upstream moving westward/eastward of the MR Delta (coastal, river induced circulation) and offshore (basin-wide circulation).

In-situ Observations of Stratification and Circulation on the Louisiana Bight Shelf

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The Submesoscale Processes and Lagrangian Analysis on the Shelf (SPLASH) experiment was conducted on the Louisiana Bight shelf west of the Mississippi River Delta 20-28 April 2017. During the experiment, a combination of shipboard, towed, and autonomous surveying was used to investigate the vertical and lateral structure of the low-salinity Mississippi River plume. These new detailed observations reveal the variable circulation pathways and intricate thermohaline layering created by strongly-sheared buoyancy- and wind-driven flows on the shelf. The observed complex vertical water mass structure in the area may have serious implications for local biogeochemistry and cross-shelf dispersion.

Water Column Stability and the Role of Velocity Shear on Shelf Stratification in the Mississippi Bight, the Forgotten Region of Freshwater Influence

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Water column stability is a critical component of marine systems, regulating the vertical exchange of momentum, mass, and biogeochemical constituents. Observations of multi-year (2010-2016) summer time satellite-derived sea surface salinity (SSS), in conjunction with an in-situ sampling program of shelf CTD surveys and mooring-based measurements of the water column velocity and hydrographic conditions, are used to investigate aspects of the region of freshwater influence (ROFI) east of the Mississippi River Delta. Time series of SSS data indicate that the shelf region impacted by the seasonal eastward advection of freshwater can be as extensive as the region west of the delta, where the “Dead Zone” is extensively monitored every summer. CTD surveys south of Mobile Bay and extending ~50 km offshore indicate strong stratification with buoyancy frequencies commonly on the $O(0.1-0.01 \text{ s}^{-1})$ across the shelf. Despite this strong stratification, mooring data from the 20 m isobath during the summer of 2010 indicates that the bulk Richardson Number (Ri) can span 3 orders of magnitude $O(1-100)$. Examination of the high frequency (hourly) shear and buoyancy frequency time series reveals

that downwelling conditions and near-inertial oscillations are primarily responsible for generating instances of marginal stability (Bulk Ri ~ 1). Periods of intense near-inertial oscillations can intermittently drive gradient Ri numbers to critical or near-critical levels within the pycnocline. Interestingly, 'shear spikes' in the bulk squared shear (S^2) associated with the near-inertial oscillations are artifacts produced by an interaction with upwelling circulation that alters the depth of the shear peak. Due to the role of water column stability in coastal hypoxia events, the finding presents the possibility that the "Dead Zone" in the northern Gulf of Mexico has the potential to be larger than what has been observed to the west of the Mississippi River Delta

Assessing the Effects of Mississippi River Diversions on Estuarine-Shelf Exchanges and Oil Transport Pathways in the Northcentral Gulf of Mexico

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Freshwater diversions in the Mississippi River Delta region play a central role in the proposed 50-billion, 50-year strategy for restoring the Louisiana's coast. Under the proposed 2017 Coastal Master Plan, four large-scale sediment diversion projects are being considered for Barataria Bay and Breton Sound estuaries that would convey an order of magnitude more water compared to existing Davis Pond and Caernarvon diversions. The effects of existing and proposed future diversions on surface oil transport in the Mississippi River Delta region were investigated using a prognostic, three-dimensional, Finite-Volume Coastal Ocean Model (FVCOM). The numerical model domain covers most of the Alabama-Mississippi-Louisiana-Texas continental shelf with very high horizontal resolution (on the order of 20 meters) in Barataria Bay and Breton Sound. The model was driven by tidal and subtidal forcing at the open Gulf of Mexico boundary, freshwater discharge from the diversions, and surface wind stress. A number of different diversion scenarios were assessed, including a concurrent operation of six diversions (Davis Pond, mid-Barataria, lower-Barataria, Caernarvon, mid-Breton Sound and lower-Breton Sound) with a combined flow of 6,500 cubic meters per second. Numerical modeling results indicate that, depending on the scenario considered, the proposed sediment diversions have a potential to strongly influence hydrodynamics, estuarine-shelf exchanges and oil transport pathways in the Northcentral Gulf of Mexico.

The Seasonality of Submesoscale Mixing across the Mixed Layer in the Northern Gulf of Mexico

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Submesoscale circulations associated with vorticity structures of kilometer size and local Rossby number ~ 1 are characterized by a horizontal scale of 0.1-10 km and a vertical scale as much as 100 m/day. Their intensity in the northern Gulf of Mexico is primarily modulated by oceanic frontogenesis, influenced also by riverine inflow, and by mixed-layer instabilities, controlled by the available potential energy of the mixed-layer. Submesoscale circulations impact the transport of biological tracers such as nutrients and plankton across the upper mixed layer where air-sea exchange occurs. In this project, we evaluate their role using the Regional Ocean Modeling System (ROMS) at two horizontal resolutions. About 50000 Lagrangian tracers are deployed at different depths (at the surface, 50 m and 100 m) and tracked for 30 days to investigate the seasonal variations of the impacts of submesoscale processes on

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the horizontal and vertical transport across the mixed layer. Results indicate that overall both seasonality and model resolution have little impact on lateral transport at all depths while vertical dispersion increases significantly and is strongly modulated by submesoscale activities near the surface. The role of riverine input from the Mississippi-Atchafalaya River system is also discussed.

Modeling and Observations of Oil Drift in the Northern Gulf of Mexico: The Role of River Induced Fronts

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The presence of both shelf and open sea dynamics make the Northern Gulf of Mexico (NGoM) a topographically and dynamically complex study area, in the presence of intense oil exploration. Interactions of the Mississippi River plume and the Loop Current system were found important on the transport and fate of oil during the 2010 DeepWater Horizon (DWH) incident. An open source Lagrangian oil drift code, OpenDrift, has been used to simulate real oil spills in NGoM, with a focus on the role of river induced fronts on hydrocarbon transport. OpenDrift is developed at the Norwegian Meteorological Institute, is coded entirely in Python and is available at www.github.com, as part of GoMRI funded research. It is coupled to the NOAA oil chemistry database with nearly 1000 oil types and is now the main model for oil spill preparedness and search and rescue operations in Norway. In the cases presented here, high resolution HYCOM simulations with daily river discharge (Univ. of Miami 1/50 degree GoM-HYCOM model) are used as forcing, together with wind and wave analysis from ECMWF (European Center for Medium-Weather Forecast). We focus on the DWH spill and simulations based on recent observations of oil slicks around the Taylor Energy platform. Simulations are initiated from NOAA shape files, field surveys and point sources. The effect of using two different oil droplet spectra formulations on horizontal drift and vertical mixing is also discussed. Both study cases showcase how NGoM oil pathways are influenced by river plume circulation and fronts.

Exchange at Tidal Inlets: Numerical Modeling of Idealized Laboratory Experiments for Tidal Jet Vortices and Coherent Structures

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Many bays on the coastal Gulf of Mexico are protected by barrier islands, and exchange of material, including suspended and surface oil, between the bay and open coast depends on fine-scale processes at the tidal inlet to the bay. We present results of a numerical modeling study compared to existing laboratory experimental data for tidal exchange through an idealized inlet. The tidal flow creates large coherent structures (LCS) as starting jet vortices attached to the tidal inlet and as instabilities of the ensuing tidal jet. Starting jet vortices engulf fluid and can dominate exchange patterns at inlets. We develop a three-dimensional hydrodynamic model of the laboratory experiments using the Fine Resolution Environmental Hydrodynamics (FREHD) model. Comparison to the laboratory data demonstrate that the starting jet vortices can be accurately resolved, but require a high-order advection scheme to minimize numerical diffusion of the sharp velocity gradients at the tidal jet boundary and the edges of the LCS. The model uses the hydrostatic pressure assumption. Simple one-

equation turbulence closure using the k -equation with constant values of the standard model coefficients is adequate to capture the horizontal and vertical variation of the eddy viscosity. A uniform bed friction coefficient for a quadratic-law friction term is also acceptable for these laboratory experiments. The model predicts well the size of the starting jet vortices, their total circulation, and their advection in the tidal current. Because tidal starting jet vortices are coherent (barriers to transport across their boundaries) and because they can significantly alter the tidal flow through the inlet during reverse tides, their behavior is critical to predict exchange between Bays and the coast at narrow tidal inlets.

Science for Response

RSP-001: Oil Spill Modeling from Droplet Formation to Risk Assessment

Fundamental Prediction of Oil Droplet Sizes During Blowout

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During a deepwater oil and gas blowout, the initial droplet size distribution is a controlling factor in assessing whether the droplets will rise to the surface or remain sequestered in the deep ocean. Since the Deepwater Horizon blowout, there has been a global effort to experimentally characterise crude oil droplet size distributions through a variety of mixing geometries and operating conditions. However, the effort to capture these measurements in a model has relied solely on semi-empirical methods, typically involving the Reynolds or Weber numbers. In this presentation, we demonstrate that such semi-empirical methods are unable to explain the comprehensive data collected in this field; furthermore, these methods require extrapolation when scaling to field conditions. We propose a new relationship to predict crude oil droplet sizes, based on the fundamental properties of turbulence: kinetic energy and dissipation rate. This study demonstrates that these two properties are able to explain the entirety of the droplet size data reported thus far, and do not rely on engineering approximations. More importantly, we demonstrate that field conditions are within the validation range of this fundamental model, such that prediction of the Deepwater Horizon oil droplet sizes is an interpolative activity. The results demonstrate that turbulence plays a critical role in assessing whether droplets may rise to the surface. In cases of severe turbulence, chemical dispersants may not generate a significant shift in the droplet size distribution; this result suggests this fundamental predictive model may be used as an assessment criterion to determine whether dispersant application is warranted in the field.

Integrating the Dynamics of Jets and Plumes for the Prediction of the Oil Droplet Size Distribution

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The hydrodynamics of miscible jets and plumes has been well studied. However, that of immiscible liquids has gained prominence since the Deepwater Horizon spill. We contrast the hydrodynamics of both systems illustrating the similarity and differences. In particular, we rely on the hydrodynamics to explain the processes underlying the formation of oil droplets and gas bubbles. Our investigation revealed that the usage of dispersant causes the hydrodynamics of immiscible jets to behave similarly to those of miscible jets. We also address primary breakup of oil due to shear and secondary breakup due to turbulence. We also present experimental and numerical results on the formation of microdroplets due to the presence of dispersant. We finish the presentation by addressing the impact of gas on hydrodynamics and oil droplets. We show in particular that while gas bubbles tend to reduce the size of oil droplets in the absence of dispersant, they could result in larger oil droplets when dispersant is used due to scavenging.

Large-eddy Simulation of Nearfield Hydrocarbon Plume with Gas Dissolution

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Understanding the dynamics of the multiphase hydrocarbon plumes in the nearfield of subsea oil well blowouts is crucial for predicting the oil dispersion and planning for remediation. After being released from the oil well, the initial flow momentum is quickly dissipated over a relatively small distance, and the hydrocarbon flow continues to rise as a plume driven primarily by the buoyancy force induced by the gas bubbles. In the case of a deep-sea blowout, the gas bubbles can have sufficient time to interact with the surrounding seawater during their long journey rising towards the ocean surface, resulting in considerable gas dissolution that causes continuous reduction of the upward driving force of the plume. Therefore, it is crucial to consider the gas dissolution in order to obtain accurate predictions of plume peel and trap heights to track the fate of the oil. In this study, a new modeling strategy is developed to efficiently incorporate gas dissolution effect into a fast Eulerian-Eulerian large-eddy simulation (LES) model. In this approach, the evolutions of both the Eulerian mass concentration (C_b) and number density (N_b) fields of the gas bubbles are simulated using LES. In each local LES computational cell, the relation between C_b and N_b provides an estimation of the cell-averaged mass per bubble (M_b). Then by considering the local fluid pressure as well as applying a gas dissolution microphysics model, the local gas mass dissolution rate (D_m) and bubble slip velocity (W_b) can be calculated, which are then fed back to the LES plume solver to compute the evolution of C_b and N_b to the next time step. In this presentation, some preliminary results for LES of deep-sea hydrocarbon plume release are discussed to show the effect of gas bubble dissolution on the macroscopic plume characteristics. This research is made possible by a RFP-V grant from The Gulf of Mexico Research Initiative. D.Y. also acknowledges the financial support from start-up funds at the University of Houston.

Large Eddy Simulation Including Population Dynamics Model for Polydisperse Droplet Evolution in Turbulence

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Previous studies have shown that dispersion patterns of oil droplets in the ocean following an oil spill depend critically on droplet diameter. Hence predicting the evolution of the droplet size distribution is of critical importance for predicting macroscopic features of oil dispersion in the ocean. We adopt a population dynamics model of polydisperse droplet distributions for use in Large Eddy Simulation. We generalize a breakup model from Reynolds averaging approaches to LES in which the breakup is modeled as due to bombardment of droplets by turbulent eddies of various sizes. The breakage rate is expressed as an integral of a collision frequency times a breakage efficiency over all eddy sizes. An empirical fit to the integral is proposed in order to avoid having to recalculate the integral at every LES grid point and time step. The fit is tested by comparison with various stirred tank experiments. As a flow application for LES we consider a turbulent jet emanating from a source where oil droplets are released. The advected velocity and concentration fields of the droplets are described using an Eulerian approach. We apply this LES model to study the change of the oil droplet size distribution due to breakup, caused by interaction of turbulence generated by the jet with the oil droplets.

Numerical Simulation of the Hydrodynamics of the Deepwater Horizon Blowout: Impact of the GOR, Dissolution, and Temperature

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The Macondo 252 well blowout was studied using Computational Fluid Dynamics (CFD) method with Large Eddy Simulation (LES). We considered the effect of different gas to oil ratio (GOR) on the hydrodynamics of the subsurface oil plume. We also considered the influence of gas dissolution from oil into the surrounding water and the local temperature. Both were implemented using User Defined Functions (UDF) in the FLUENT software. The plume hydrodynamics were then compared under different conditions. The results show that the plume hydrodynamics at the near-to-orifice region can be significantly affected by GOR, oil plume with a higher GOR spreads the gas across the plume, and thus concentrates the oil in the center. This could challenge when applying dispersants on the periphery of the plume, as the dispersant might get scavenged by the gas. The study also substantiates the need for a comprehensive numerical model, including the consideration of GOR, gas dissolution, and temperature to evaluate the oil plume hydrodynamics during Deepwater Horizon Blowout.

The Unobserved Behaviors of Petroleum Bubbles and Droplets During Ascent Towards the Sea Surface: Lifting a Corner of the Veil with Simulations

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Despite the unprecedented sampling effort accomplished during the Deepwater Horizon, little is known about the behaviors of droplets and bubbles throughout their ascent in the water column, from the broken wellhead to the sea surface, due to limited field observations within the response zone. We developed a multiphase buoyant plume model, TAMOC, that we validated against key field observations in both the sea and atmosphere (Gros et al., PNAS, 2017). The model predicts the independent behaviors of hundreds of petroleum compounds and simulates the effects of the changing pressure, temperature, and compositions of droplets and bubbles on their properties. Here, we focus on an aspect not discussed in detail in the previous study: what insights these simulations bring regarding the coupled evolution of densities, thermodynamic states, and compositional changes during dissolution of the ascending droplets and bubbles. When released at the wellhead, the petroleum fluids were assumed to spontaneously partition into a gas phase composed mostly of light, methane to pentane (C₁-C₅), hydrocarbons, and an equilibrated liquid phase containing the bulk of the heavier petroleum compounds. However, the tremendous pressure encountered at 1500-m depth is predicted to have initially brought >50% of the mass of C₁-C₅ compounds within the equilibrated petroleum liquid phase. The behaviors of these droplets and bubbles during their subsequent ascent is a mystery: their compositions changed due to the simultaneous effects of aqueous dissolution and decreasing ambient pressure, leading to effects that can only be investigated by simulations. We studied the dependence of bubble and droplet behaviors on their initial sizes and other parameters. For example, we report on changing densities, predicted condensation of gas bubbles, and possibility of ebullition of liquid droplets during ascent. These simulations encompass the range of initial droplet and bubble sizes that have been proposed.

Modeling Subsurface Exposure Concentrations Resulting from the Deepwater Horizon Oil Spill, with and without Subsea Dispersant Application

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Subsea dispersant injection (SSDI) is a new oil spill response method that was first deployed during the Deepwater Horizon (DWH) incident in 2010. The objectives of SSDI use include reducing human and wildlife exposure to volatile organic compounds; dispersing oil into a large water volume at depth; enhancing biodegradation; and reducing surface water, nearshore and shoreline exposure to floating oil and entrained/dissolved oil in the upper water column. However, the tradeoffs include the potential for increased oil exposures of biota at depth. Oil spill modeling of the 2010 Deepwater Horizon discharge was performed to evaluate the fate and concentrations of the oil and its components in subsurface waters of the Gulf of Mexico, including consideration of the time-varying applications of SSDI. The oil fate model Spill Impact Model Application Package (SIMAP) was used to estimate rise rate of oil droplets, dissolution of oil constituents, movements of oil droplets and dissolved components, and degradation of hydrocarbon components in the deep-sea. As sampling during April-July 2010 was primarily performed within 20 km of the spill site, model predictions were compared to field data from within a 25 km by 25 km box centered on the wellhead. Concentrations of soluble and semi-soluble hydrocarbon components predicted by the model agreed well with chemical measurements when compared as frequency distributions within varying depth zones of the water column. The results showed that the soluble hydrocarbons primarily dissolved near the release depth, while semi-soluble compounds were partially dissolved at depth and as droplets rose. The effects of SSDI are evident in the results, when contrasting periods where no SSDI was applied (April) with those when SSDI was most effective (late June to early July), as well as when comparing the model simulation of the actual event with a simulation without SSDI.

Wind-based Lagrangian Parameterization for Near Surface Flows during LASER

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During the Lagrangian submesoscale experiment (LASER) in 2016, a thousand surface drifters were launched, measuring the upper depth-average 60 cm flow in the NGoM and the GoM interior. As a result of half dozen strong winter storms due to El Nino winter, a significant number of drifters lost their drogue. This unintended situation facilitated documentation of very near surface (5 cm) flows as well as deeper (60 cm) flows. These depths are relevant to oil spills transported at different depths. LASER thus provided valuable information on the kinetic energy transfer from the wind and waves and vertical shear near the surface, which is not well captured by coastal ocean models. In this study, we attempt to improve the surface Lagrangian transport prediction by combining a state-of-the art ocean forecast model using wind and wave data. The surface velocities are from the Navy Coordinate Ocean Model (NCOM) at 1 km horizontal resolution, while the wind and wave fields are obtained from the UWIN-CM coupled ocean-atmosphere-wave model. Two Lagrangian parameterizations are tested: one based on the Ekman transport, and the other directly on the surface winds. The LASER data-set is then used to assess their performance. It is found that wind and wave data can lead to significant improvement with respect to ocean model alone, over the first 48 hours for all conditions, which is an important period for oil spill response.

Modeling of Oil Droplets Transport Subject to Breaking Waves: Coupling Eulerian RANS with Lagrangian Particle Tracking

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We describe a new method of modeling oil droplets transport under breaking waves by coupling computational fluid dynamics (CFD) with Lagrangian particle tracking. The Reynolds-averaged Navier-Stokes (RANS) equations were solved within the CFD code FLUENT to reproduce the movement of breaking waves in the absence of wind stress and large-scale turbulence. The RANS velocity field were then exported to the Lagrangian particle tracking code NEMO3D to predict the transport of buoyant particles representing oil droplets, and the droplets kinematics were simulated by solving the equation of motion accounting for comprehensive forces under breaking waves. We found out the deepest depth droplets can entrain, and the z-centroid of oil droplets under breaking waves are independent of the droplets diameter, but related to the wave breaking height. In addition, our simulation results indicated that the effect of inertia and added mass force on small size droplets (diameter smaller than 200 μm) can be neglected, and the transport of these oil droplets just follows the velocity of the carrier fluid, which behaves as passive tracers. Furthermore, we found out that large size oil droplets (i.e. 300 and 400 μm) might have a larger entrainment than small size droplets (i.e. 200 μm) under breaking waves, but resurfaced much faster. Lastly, the simulation results showed that the air trapped in the bore of breaking waves generated many bubbles, and subsequently the floating of these bubbles significantly enhanced the resurfacing of oil droplets. The successful coupling of FLUENT and NEMO3D models for oil droplets transport under breaking waves unlocks many potential investigations such as prediction of oil concentration through the transport of oil droplets and subsurface droplets breakup and diffusion under breaking waves.

Applying Real-Time Atmospheric Science Verification Techniques to Spill Trajectory Models

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Traditionally, oil spill trajectory model forecast validation has been qualitative in nature. During the event, trajectory forecast results are compared to available surface oil observations by the modeler who subjectively adjusts the model parameters for future predictions. After the event, assessment of the model is done by comparing predicted and recorded shoreline impacts that may or may not include time of impact. More sophisticated validation tools are common in weather forecasting. The authors describe a method, used by meteorologists to check prediction of spatial rainfall above a prescribed amount against field measurements, that can be adapted to oil surface coverage that exceeds a set level. The presumptions of the validation method are the increased availability of high resolution synoptic volume estimates of the oil slick and the use of ensemble modeling by the spill forecaster. By calculating prediction error over spatial grid scales that vary in size from the whole area of interest down to the level of response equivalence (error does not affect response), it is possible to select model runs that forecast oil location neighborhoods that are closest to actual observed locations. The best subset of individual model runs (smallest forecast error) are used to objectively re-initialize model parameters such as local wind drift and horizontal dispersion for subsequent runs, and to quantitatively estimate forecast uncertainty based on past location errors. The approach lends itself to automation as

a non-linear adaptive filter, allowing the modeler to concentrate on underlying oceanographic and meteorological model estimation.

Dispersant Application Simulation with BLOSOM

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The Blowout and Spill Occurrence Model (BLOSOM) is an open-source 4D fate and transport model that simulates the events immediately following a deep-sea blowout or surface spill, and is part of a suite of risk analysis tools developed at the National Energy Technology Lab (NETL). Through a collaborative research effort with the Pacific Northwest National Lab (PNNL) and funding from the Bureau of Safety and Environmental Enforcement (BSEE), a dispersant module has been added to BLOSOM's capabilities. Namely, the user can now select droplet size distributions to represent oil treated with dispersant. These settings can be coupled with a relationship between dispersant application efficiency and oil viscosity that has been derived from a literature review to simulate treatment efficiency over time as a function of (weathered) oil viscosity. Alternatively, the dispersant treatment efficiency can also be directly selected by the user. Dispersant can be applied at different locations as specified by the modeler, enabling dispersant application at both the surface and within the water column. At present, BLOSOM is the first open-source 4-D blowout and oil-spill occurrence model capable of simulating the application of dispersant at any location, including at the blowout. BLOSOM is maintained on Github and as new research on dispersants in offshore systems emerges, the model will continue to evolve with the community's state of knowledge. In this presentation we demonstrate some of BLOSOM's current dispersant capabilities and discuss directions for future development.

Oil-Spill Risk Analysis for the Liberty Development and Production Plan in the Beaufort Sea

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The oil spill risk analysis (OSRA) is conducted by scientists at the Bureau of Ocean Energy Management (BOEM), an agency in the U.S. Department of the Interior, to estimate the likelihood and timing of contact between hypothetical spills from prospective oil and gas development in the U.S. Outer Continental Shelf and environmental resources such as shoreline, marine habitats, recreational areas and other areas of biological, social and economic importance. The OSRA model provides important information for the analysis required by the National Environmental Policy Act and for oil spill response plans. The OSRA model delivers three major products: 1) the probability of large oil spill occurrence (defined as greater than or equal to 1,000 barrels); 2) the probability of contact to environmental resources from hypothetical oil spill locations (Conditional Probability); and 3) the probability of one or more large oil spills occurring and contacting environmental resources (Combined Probability). In this presentation, we will present the OSRA results used in BOEM's Draft Environmental Impact Statement for the Liberty Development and Production Plan in the Beaufort Sea, Alaska. Hilcorp Alaska, LLC proposes to develop the Liberty Prospect by constructing a drilling and production island approximately 5.6 miles offshore, and transport the oil to shore by pipeline. We will discuss how the oil-spill occurrence rate applicable to the project is estimated given that there are little or no historical

large oil spill data in the offshore U.S. Arctic. We also will demonstrate how 18 years of wind, current and ice data are used to simulate 32,400 hypothetical oil spill trajectories from the Liberty Island and pipeline, and how the contacts of these trajectories to hundreds of environmental resources are tabulated for six time intervals (1, 3, 10, 30, 90, and 360 days) and three seasons (annual, summer, winter). Finally, we will discuss how the Combined Probability is generated from the spill occurrence rate, Conditional Probability, and estimated volume of oil to be produced and transported.

RSP-002: Laboratory and Field Experiments and Measurements

Testing at the *in-situ* Burn Pan at Joint Maritime Test Facility (JMTF), Mobile, AL, USA

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Fire research has been performed at the US Coast Guard Research & Development Center (RDC) Joint Maritime Test Facility (JMTF) since 1972, mostly on vessels moored at Little Sand Island. In cooperation with many other Federal agencies a burn pan was built at the JMTF and a series of burns was completed in 1998 that resulted in the development of an ASTM standard for fire-resistant booms. Since November 2015, RDC has collaborated with the Bureau of Safety and Environment Enforcement (BSEE) to refurbish the facility and perform three series of test burns, using diesel fuel and crude, to address issues identified during reviews of the *in-situ* burns conducted during the Deepwater Horizon Response. A wave-making capability has recently been installed on the JMTF burn pan. This is the only large outdoor facility in the U.S. that can provide maritime *in-situ* burn research that meets the minimum ASTM guidelines for testing fire-resistant boom. This paper will describe the facility's capabilities, the recent work and future potential work.

Experimental Investigation of the Rise Behavior of Gas-Saturated Crude-Oil Droplets under High Pressure

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A quick and scientifically sound response in case of deep submarine oil well blowouts like the Deepwater Horizon accident in 2010 and the development of mitigation strategies for future oil spills are important to avert major damage to people and the environment. The success of these measures hinges on the accuracy of the used models several of whom have been developed in order to simulate the fate of accidentally released crude oil and natural gas masses. The high pressure in the deep sea as well as in oil reservoirs influence the physical properties and behavior during drop formation and drop rise of the crude oil due to the high amount of dissolved natural gas. These "live-oil" properties must be taken into account when simulating deep-sea oil spills numerically or experimentally. The buoyancy-driven ascent of oil droplets through the water column during a blowout is an important input parameter for modeling the fate of the oil masses since it determines the residence time of the oil in the water column. Thus, dissolution, biodegradation and the horizontal transport of oil due to currents depend on the droplet sizes and rise velocities. As the gas-in-oil solubility is highly pressure-dependent

* Student presenter

and the pressure decreases from the reservoir to the deep ocean and further to the sea surface, the amount of dissolved gas in the live oil changes dramatically. This promotes degassing from the oil droplets by bubble formation which in turn affects the sizes and rise behavior of the oil droplets. Different experimental approaches using high-pressure facilities are applied for simulating the behavior of gas-saturated oil droplets under artificial deep-sea conditions. The experimental results are presented and the influence of pressure-related supersaturation and gas bubble nucleation is discussed. This research was made possible by a grant from the Gulf of Mexico Research Initiative (GoMRI), C-IMAGE II.

High-Pressure Oil-in-Water Droplet Size Distribution Measurements

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During offshore blowout, the distribution of crude oil droplet sizes has been shown to be a critical governing parameter in predicting the extent of the surface slick. However, there remain only a few experimental datasets reported worldwide on this topic, with a limited understanding of the effect of the dispersed phase thermophysical properties or the reduction of interfacial tension through chemical dispersants. In this study, we have deployed a high-pressure sapphire autoclave apparatus to visually measure the droplet size distribution for multiple liquid hydrocarbon phases, over a range of oil phase viscosities and densities. Furthermore, we have studied the effect of Corexit 9527A addition on the droplet size distributions, under a variety of concentrations. The droplets are captured using a high-resolution 1000 fps camera, which can typically detect droplets of at least 30 microns in diameter. The results demonstrate that mean droplet size varies indirectly with both the addition of chemical dispersant and the degree of turbulence in the system. However, in the limit of high turbulence, the addition of dispersant may have minimal impact on the DSD. The results are compared to both previous-generation Weber and modified Weber number models, alongside the current-generation turbulent kinetic energy and dissipation rate models.

Experimental Study of Oil Droplet Size Distribution of Deep-Sea Blowouts: Effects of Reservoir Pressure and Phase Changes

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In subsea oil spill modeling, the initial droplet size distribution formed at the spill site is one of the most crucial parameters. It affects horizontal and vertical transport as well as biodegradation and the formation of marine snow. During deep-sea oil spills such as Deepwater Horizon short-chained hydrocarbons (mainly consisting of methane) emerge from the wellhead alongside the liquid oil as a free gaseous phase as well as dissolved in the liquid oil. When oil and gas enter the water column at the wellhead, their physico-chemical properties change quickly and significantly due to the pressure and temperature drop at the vent. In the past years, many experiments and numerical simulations have been conducted in order to determine the oil droplet size distribution of a deep sea blowout. While there is today a sound understanding of the formation processes of small-scale, liquid-liquid jets, the drop formation processes of such a multiphase oil/gas mixture entering into seawater in a deep-sea blowout is still under controversial debate. To investigate the effect of these extreme and dynamic

* Student presenter

conditions on drop formation, downscaled jets of different “live” (i.e. gas-saturated) oils were generated under artificial deep-sea conditions (hydrostatic pressure up to 150 atm) in a high-pressure autoclave. The oil droplet size distributions in these jets are determined for different combinations of ambient and reservoir pressures in the single- and multiphase regime. Results show a strong influence of the gaseous components dissolved in the crude oil and the pressure drop at the wellhead on the droplet size distribution. Median drop diameters change significantly due to dissolved gas. Even a small pressure drop at the vent leads to oversaturation of the oil and thus the formation of additional gas bubbles immediately above the wellhead. In this work, droplet size distributions and characteristics of the experimentally generated jets are compared regarding the influence of gas presence, phase changes and pressure. Possible mechanisms of drop formation influenced by these factors are discussed. This research was made possible by a grant from The Gulf of Mexico Research Initiative/C-IMAGE II.

Polarimetric Lidar Measurements of Aquatic Turbulence - Laboratory Experiment

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Most oceanic flows are turbulent and therefore characterized by a wide range of coexisting scales of motion and temperature gradients and as small as few millimeters in size. Turbulent fluctuations of temperature in water cause fluctuations in its refractive index. The currently deployed oceanographic lidar system are capable of measuring profiles of water attenuation coefficient and particulate backscattering coefficient. Our approach goes one step further where by using an polarimetric lidar system we calculate the depth dependent oceanic turbulent parameters. In this paper we present lidar measurements of turbulent parameters in a laboratory generated turbulent flow and compare with previous results. We found the nearforward light depolarization to be dominated by turbulent processes with the depolarization rate as a function of turbulent flow parameters TKE and TKED, where TKED and TKE are the respective temperature variance and turbulent kinetic energy dissipation rates. The presence of particles in the flow modified value forward depolarization rate in such way that it continued to be particle concentration independent. Based on our observations, we posit that the underlying mechanism was a form of a collective light interaction between turbulent refractive index inhomogeneity and imbedded small-scale particle aggregates, culminating in observed depolarization rate much larger than expected from ‘pure’ turbulent flow - [3], [4], [5] or [6]. Our observations open up a fascinating possibility of using lidar, to sample with depth, the upper ocean turbulence. Current lidar systems are lightweight and use relatively low power, thus our observations, in principle permit, to carry out upper ocean turbulence measurements from UAV equipped with the polarimetric lidar system.

Particulate Matter Resuspension in the Mississippi Bight Assessed with Biophysical Modeling and *in-situ* Measurements

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Sediment exchange between the Mississippi Sound and Bight through the tidal passes is not well understood. The passes act as a transport pathway for the exchange of estuarine discharge and

* Student presenter

suspended particulate matter (SPM) that affects turbidity, nutrient supply and the aquatic ecosystem health. During the Consortium for oil spill exposure pathways in COastal River-Dominated Ecosystems's (CONCORDE's) spring 2016 field campaign, the *In-situ* Ichthyoplankton Imaging System (ISIIS) captured images of resuspended particulate matter and the Scanfish measured salinity, temperature and particle backscatter to characterize the physical and biological structure in the region. High amounts of SPM were observed by the ISIIS's camera, with concentrations at depth sufficient to completely occlude the *in-situ* images of planktonic organisms. A RU31 glider measured temperature, salinity, dissolved oxygen and optical backscatter on the continental shelf during the spring cruise in the proximity of the Mississippi River Delta, southwest of the ISIIS/Scanfish transects. Optical backscatter and salinity observed by the Scanfish and glider showed elevated SPM and increased salinity, suggesting a linkage to shoreward advection from the continental shelf of oceanic waters that are sufficiently energetic to drive sediment resuspension. A four-dimensional biogeochemical synthesis model for Mississippi Sound and Bight has been developed by CONCORDE, based on the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modeling System and a surficial sediment distribution map generated using *in-situ* multibeam sonar data. This study utilized CONCORDE's synthesis model to investigate the physical forcing mechanisms affecting the increased SPM concentration observed in the Mississippi Bight during spring 2016, and advection pathways between estuarine and shelf waters in the northern Gulf of Mexico. The results show that episodic, advection-driven resuspension is a critical aspect controlling suspended sediment distributions in Mississippi Bight, which has implications for observed spatiotemporal patterns of planktonic species.

Seasonality of Across-shelf Transport Pathway Patterns in Mississippi Bight

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This study investigates the seasonality and spatial variability of across shelf flow and transport in the Mississippi Bight region of the northern Gulf of Mexico using 4+ years of Navy Coastal Ocean Model (NCOM) results from 2013 to 2017. The Deepwater Horizon oil spill in 2010 showed the importance of enhancing our knowledge about the dynamics, connectivity and shelf interactions between the open waters of the Gulf and coastal waters of the western Mississippi Bight. Improving the understanding in the Mississippi Bight, where oil and gas operations are regularly conducted, is critical to enable implementation of an efficient and educated emergency response. This study focuses on identifying across-shelf advective transport pathways because toxic oil and dispersant systems may reach highly productive coastal ecosystems during future oil spill events. We initially computed the depth varying across-shelf transport perpendicular to three isobaths chosen to represent the outer edge of inner-shelf (20-m), mid-shelf (35-m) and inner edge of outer shelf (60-m) using the results of a 1-km resolution regional application of NCOM for the Gulf of Mexico. Hovmoeller diagrams of transport across these isobaths indicated that seasonally recurring onshore transport corridors exist. Analysis on current fields showed connectivity in between the corridors observed on different isobaths. We computed the empirical orthogonal functions (EOFs) of the current variability to explore for and reveal any recurring patterns in across-shelf flow at the surface layer, as well as at mid-depth levels and near the bottom. Results also indicate that some of the identified shelf break to nearshore transport pathways tend to follow bathymetry. A strong across-shore NE-SW transport pathway from the Mississippi Bird-foot delta to Mobile Bay's Main Pass was identified in different seasons along with

other patterns. The EOF analysis was repeated adding the wind forcing used by NCOM to understand the relationship between wind events and the identified across-shelf transport pathways.

Coastal Langmuir Circulations under Misaligned Currents, Wind, and Wave Forcing

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Langmuir circulations are a key contributor to mixing and vertical transport capacity in the upper mixed layer of the ocean. These circulations significantly contribute to physical and geochemical processes affecting oil dispersion, and oil aggregation with microbes and minerals suspended in the water column. Wind-driven shear and surface waves are required for sustenance of Langmuir circulations, whose non-linear interactions result in wind-direction aligned, counter-rotating vortical structures. In addition, the presence of strong mean current directions - whether associated with strong tidal currents, or with eddies shed from larger-scale circulations such as the Gulf of Mexico's ambient Loop Current - generate bottom boundary layer shear that can modulate Langmuir circulations in coastal zones. Tidal current directions exhibit seasonal oscillations, and can be misaligned with local wind directions that vary of much higher frequencies. Therefore, in this study, we investigate the influence of misaligned mean currents with wind and wave on the structural and dynamical properties of coastal Langmuir turbulence. We show that bottom boundary layer turbulence generated beneath misaligned, strong mean currents change the orientation of the of large-scale Langmuir cells. An additional observation of small-scale Langmuir structures reveals that packets of streaks at different horizontal planes align in different directions. This hints at the existence of a rotating small-scale Langmuir structures about the wall-normal axis forming a spiral, solely due to the interaction of misaligned wind-wave-mean current forcing; such a "secondary" Langmuir circulation would have unique importance in coastal zone oil dispersion mechanisms.

Rapid Spill Response: CARTHE Drifters Used During Active Sewage Leaks

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The Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE) is dedicated to predicting the fate of oil released into our environment and has developed new drifters to study how ocean currents transport oil and other pollutants. These drifters have been used in large-scale oceanographic experiments in the Gulf of Mexico, in citizen science projects in Biscayne Bay, and even released alongside sea turtles and mahi-mahi. In the summer of 2017, the new CARTHE drifters were called to action for the first time to respond to an emergency spill. Two large sewage leaks in South Florida required accurate data collection on the precise area affected by the spill. CARTHE supported the local environmental resources managers' response to the event by releasing drifters at the source and tracking the movement of the currents in order to confirm the predicted impacted areas, leading to more accurate water quality advisories for the public. This case study highlights the usefulness of the CARTHE drifter specifically, and more generally the many new tools developed by GoMRI scientists, on responding to not only oil spills but a variety of emergency response situations.

Observations of the Vertical Profile of Near Surface Currents in the Gulf of Mexico

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Marine plastics, spilled oil and biogenic materials are often concentrated on the air sea interface due to their physical and chemical properties. Theoretical and laboratory studies predict very strong velocity variation with depth over the upper few centimeters of the water column, a result of wind forcing and wave motions. However, observations of current shear in this layer of the real ocean have not been made- either remotely or using *in-situ* methods. This presents a critical data gap for planning response to oil spills. Here we present ocean near surface current measurements collected during the CARTE-SPLASH cruise in the Gulf of Mexico in April 2017. The measurements were obtained using a combination of *in-situ* observations using surface drifters and an AUV mounted ADCP and non-contact sampling from a research vessel using marine radar and polarimetric imaging. The radar and polarimetric imaging systems both use the observed 2-D wavenumber spectrum and the dispersion relationship to obtain the current vector profile from several meters to within 1-cm of the free surface. From this information we were able to identify the wave and wind-induced contributions to the current. These findings quantify the importance of the sampling depth to transport estimates. For example, the current magnitude averaged over the upper 1 cm of the ocean is shown to nearly four times the average over the upper 10 m, even for mild forcing. This shear will rapidly separate materials which vary in size or buoyancy, as a result, the consideration of these dynamics is essential to an improved understanding of the pathways along which marine plastics and oil are transported.

Can Artificial Intelligence Predict the Dispersion of Spilled Oil?

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Machine learning, commonly called artificial intelligence (AI), is a powerful pattern recognition tool for mining big data far more efficiently than a collaborating team of even the brightest human thinkers. By following the lead of large corporations such as Facebook, Google, and Apple that employ AI techniques to optimize product marketing and development based on extensive consumer usage data, the geosciences can tap into the potential of AI by integrating an enormous wealth of observational data toward a variety of applications. Here we explore the usage of neural networks for detecting statistical patterns across multiple platforms of atmospheric and oceanic observational data obtained during the Submesoscale Processes and Lagrangian Analysis on the Shelf (SPLASH) experiment conducted near the Louisiana bight in April-May 2017. Surface wind speed, atmospheric temperature, oceanic temperature and salinity, and surface and sub-surface current data from multiple remote sensing, ship, and *in-situ* platforms are compared to the dispersion of 5000+ floating bamboo plates monitored from drones and aircraft and 500+ 1-meter drogued GPS-tracked surface Lagrangian drifters deployed throughout the bight region. We suggest that, by extension of principle, similar AI tools can also predict the fate of spilled hydrocarbon as it disperses in the coastal ocean. Such an application builds upon the existing U.S. Integrated Ocean Observing System (IOOS) infrastructure and promises rapid advances toward the IOOS mission of generating data information products that guide informed decision making and mitigation efforts during both natural and man-made environmental disasters.

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Simulating the Dynamics and Water Properties of Mississippi Sound and Bight Using the CONCORDE Synthesis Model

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Mississippi (MS) Sound and Bight and Mobile Bay area constitute a river-dominated coastal system, in which the coastal circulation, multi-point-source river input, coastal sea breeze, tidal activities, and open ocean momentum all contribute to the complexity of local water properties. As part of the modeling effort of the Gulf of Mexico Research Initiative (GOMRI)-funded CONCORDE consortium, a high resolution (~400 m) ocean model is implemented for the MS Sound and Bight. The model is based on the Coupled Ocean Atmosphere Wave Sediment Transport Modeling System (COAWST), with initial and lateral boundary conditions drawn from 1km-resolution Gulf of Mexico Navy Coastal Ocean Model (GOM-NCOM). The model initiates on 01/01/2014 and runs for more than 3 years. A low-resolution surface forcing, drawn from the North America Regional Reanalysis (NARR), and a high-resolution forcing, called the CONCORDE Meteorological Analysis (CMA) that resolves the diurnal sea breeze and other mesoscale features, are used to drive the model to examine the sensitivity of the circulation to atmospheric forcing. The model responses to the NARR forcing and to the CMA forcing are compared in detail for the CONCORDE fall and spring field campaigns when contemporaneous *in-situ* data are available. Taylor diagrams that target the RMS errors, correlation coefficients and standard deviations between the model and observations suggest that the model has higher simulation skill when it is driven by CMA. Drifters and dye experiments near Mobile Bay demonstrate that material exchanges between Mobile Bay and the Sound, and between the Sound and Bight, are sensitive to the wind strength and direction. A model - data comparison targeting the Mobile Bay plume suggests that under both northerly and southerly wind conditions the model is capable of accurately simulating the variation of the plume in terms of velocity, plume extent, heat and salt budgets. The presentation will focus on critically assessing the contrasts in estuary-shelf exchange dynamics that are realized between the NARR and high-resolution CMA forcing.

RSP-003: How's the Weathering? Oil Chemistry, Dispersants, Toxicity

Cyclic of PAHs in Aboveground Marsh Vegetation: A New Paradigm for Response and Recovery for Oil Spills in Marshes

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Air and water cycling of polycyclic aromatic hydrocarbons (PAHs) were assessed in marshes using sampling of *Spartina* and *Avicennia* tissues and passive air and water semi-permeable membrane devices (SPMDs). Impacted marshes in Barataria Basin adjacent to Bay Jimmy and Bay Batiste were the

* Student presenter

focus of the sampling in 2016-17. Previous sampling at this location confirmed that vegetation in marsh environments can sequester PAHs by partitioning from the air phase through the waxy cuticle on the leaf surface and to periwinkle snails who spend a considerable portion of their life cycle on the leaf surface. Results from our current study demonstrate that alkylated naphthalenes and C1- and C2-phenanthrenes continue to cycle through aboveground biomass from originating as a flux to air from the marsh surface 6-7 years after the spill. These compounds transfer via the air from marshes with surface oiling to adjacent marshes with no surface oil through this mechanism. Under controlled laboratory conditions, the dynamic release of PAHs from leaf tissue can be observed. The cuticle is not the primary reservoir for these compounds but is the initial surface through which PAHs enter the plant. Evidence presented in this paper will include: SPMD data over an entire growing season in the canopy above the tidal and storm surge and on the marsh surface, sequential extractions of *Spartina* and *Avicennia* leaf tissue, controlled laboratory fugacity measurements and multiphoton confocal microscopy of leaf tissue. Taken together, this evidence changes the paradigm that visible crude oil should be the sole focus of response and restoration of oiled shorelines after a spill. A subset of crude oil compounds is continually moving through the canopy potentially affecting a wider range of organisms and processes than was previously understood.

Qualitative Characterization of SRM 2779 Gulf of Mexico Crude Oil for Polycyclic Aromatic Compounds via Normal-Phase Liquid Chromatography and Gas Chromatography/Mass Spectrometry

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The complexity of crude oil samples of higher boiling points and low biodegradability increases the concentrations of aromatic components such as polycyclic aromatic hydrocarbons (PAHs), polycyclic aromatic sulfur heterocycles (PASHs), and their methyl (Me-) derivatives. The identification of these compounds in environmental samples exposed to oil spills is of extreme importance due to their highly potential carcinogenic and mutagenic characteristics. Difficulty in the identification of these compounds arises from multiple structural isomers having similar gas chromatography (GC) retention times as well as identical mass fragmentation patterns. To help alleviate this issue, complete normal phase liquid chromatography (NPLC) retention behavior has been explored for these compounds. Retention indices were determined for 124 PAHs, 62 Me-PAHs, 67 PASHs, and 80 Me-PASHs on an aminopropyl (NH₂) stationary phase. NPLC retention behavior for PAHs and PASHs directly correlated to the total number of aromatic carbons in the parent structures. Within a group of isomers, non-planar PAHs and PASHs typically have earlier retention times. The position of the sulfur atom also showed correlation to the retention behavior of PASHs. Furthermore, Me-PAHs and Me-PASHs tend to elute slightly after their respective parent structures. This information was used to develop a NPLC fractionation procedure to aid in sample cleanup for complex environmental matrices which can later be analyzed by GC/MS. I will discuss the application of this complete NPLC fractionation - GC/MS process regarding the analysis of a coal tar Standard Reference Material (SRM) 1597a and SRM 2779 (Gulf of Mexico Crude Oil).

* Student presenter

Synthesis and Investigation of Amphiphilic Polypeptoid- Functionalized Halloysites Nanotubes (HNTs) as Stabilizer towards Oil Spill Remediation

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Halloysites nanotubes (HNTs), a class of naturally occurring aluminosilicate ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) clay nanotubes, have attracted great scientific interest due to their capability in stabilizing oil-in-water emulsions, which plays a vital role in treating marine oil spills. However, the pristine HNTs was not capable to reduce surface tension as stabilizers which often leads to the formation of oversize oil droplets and bacteria repellence, which deteriorate the oil remediation performance. To further control the wettability and interfacial activity of HNTs, we investigated the functionalization of HNTs with amphiphilic polypeptoids, a class of new biocompatible peptidomimetic polymers. The goal of this research is to investigate whether and how the polypeptoid-modified clay nanotubes (Halloysites) can enhance the oil remediation effort when used as stabilizers in the oil/ water emulsion. Homo and co-polypeptoid with varying compositions were successfully grafted to the HNTs exterior surface. Multiple characterizations were studied to confirm the successful polymer grafting. The interfacial tension measurement and contact angel study indicated that the wettability of HNTs were able to be adjusted via changing the chemistry composition of the polymers. The oil-in-water emulsion stability was further demonstrated to be significantly enhanced through the HNT functionalization with polypeptoids. In addition, biocompatibility study reveals that the polypeptoid functionalized halloysites (f-HNTs) may also stimulate the growth and proliferation of *A. borkumensis* at the oil-water interface, therefore facilitate the oil-degradation process.

Ontogony of Urea and Ammonia Transporters in Mahi-mahi (*Coryphaena hippurus*) Early Life Stages

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The timing and location of the 2010 Deepwater Horizon (DWH) incident within the Gulf of Mexico coincided with the spawning of many ecologically important fish species, such as mahi. Recent studies by our lab and others revealed upregulation of ammonia transporter genes and increased ammonia excretion in oil-exposed mahi embryos. The present study found that, similar to other teleosts, mahi avoid the toxic build-up of ammonia by being largely ureotelic during the embryonic stage and gradually switch to being ammonotelic at the time of hatch. Thus, any change in the timing of these processes could indicate significant physiological impacts with implications for survival. In this study, unexposed mahi embryos and larvae revealed mRNA expression changes for seven genes involved in nitrogenous waste excretion over the initial 96 h of life: Rhag, Rhbg, Rhcg1 and Rhcg2 (ammonia transporters), SLC14a2 (urea transporter), NHE2 and NHE3 (Na^+/H^+ exchanger) which are potentially involved in ammonia transport. The mRNA levels of the ammonia and urea transporters are highly consistent with ammonia and urea excretion rates in mahi embryos we observed. Additionally, *in-situ* hybridization examined tissue-specific expression of these genes. Each Rh protein has a unique expression pattern along the gills, skin and yolk sac. Contrary to what has been shown for other species, NHEs appear to play less of a role in ammonia transport. The results contribute to our understanding of ammonia excretion in pelagic fish and physiological consequences of oil exposures during early development. This research was made possible by a grant from The Gulf of Mexico

* Student presenter

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Toxicity of Oil to *Americamysis bahia* and Deep-water Column Micronekton with Comparisons to Model Predictions

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This research is part of a series of studies for the Deep-sea Risk Assessment and Species Sensitivity to WAF, CEWAF and Dispersant project (D-TOX), designed to advance the understanding of hydrocarbon toxicity in several ecologically important deep-sea zooplankton/micronekton. Previously, the target lipid model was used to calculate critical target lipid body burdens for *Americamysis bahia* and deep-sea micronekton following passively-dosed controlled exposures to a single hydrocarbon. These critical target lipid body burdens were used as inputs to the PETROTOX model in order to estimate the threshold concentrations of a Macondo surrogate oil for each organism. Model accuracy was then assessed in constant-exposure multi-concentration toxicity tests with Macondo surrogate oil (MC252) passively dosed via an emerging technique utilizing silicone tubing. Acute effects were evaluated both during exposure and at the end of the 48-h exposure period, and used to determine threshold concentrations for each organism. Estimates of toxic threshold concentrations from the PETROTOX model and those measured during the acute exposures were compared, and predicted and measured LC50s agreed within an order of magnitude. The data obtained from these toxicity experiments provides oil spill responders with definitive toxic thresholds for key mesopelagic organisms, and serves to advance the understanding of toxicological modeling to provide the best possible estimates of species sensitivity to oil pollution. This information can then be used in Net Environmental Benefit Analysis (NEBA) or Spill Impact Mitigation Assessment (SIMA) of predicted impacts and response options in deep-sea oil spill scenarios.

Assessment of Ultraviolet Light Enhanced Toxicity of Oil to Early Life Stages of Estuarine Species

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Photo-enhanced toxicity is an important consideration in oil spill response because the spatial and temporal extent of negative effects to aquatic organisms may be underestimated if based on standard laboratory bioassays with fluorescent lighting. Many early life stages, which are often translucent, congregate at the surface, or in the upper mixing layer of coastal waters. This makes them prone to significant ultraviolet (UV) light exposure, combined with physical interaction with thin sheens of oil at the surface. To evaluate the extent and mechanisms of UV-enhanced toxicity, this project examined both water-accommodated fractions of Louisiana Sweet Crude (LSC) oil and thin sheens to early life stages of fish and crustaceans (sheepshead minnow, *Cyprinodon variegatus*, and grass shrimp, *Palaemonetes pugio*). Potential pathways for interaction between UV light and the chemical constituents of oil were experimentally manipulated to differentiate photomodification of the chemical constituents of oil into more toxic forms from photoactivation of chemical constituents of the oil within the organism to increase toxicity. Effects of short-term exposures on mortality and subsequent fish and shrimp growth and development were assessed. Chemical profiles of LSC oil preparations were

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characterized. Results will be presented with an emphasis on the utility of these data in oil spill response and environmental assessment.

How Results from the Dispersion Research on Oil: Physics and Plankton Studies (DROPPS II) Can Be Leveraged to Improve Oil Spill Planning, Response and Outcome

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The DROPPS II program focuses on oil droplets from formation through transformation through physical, environmental, chemical and biological processes. Recently the program goes further to investigate human health issues as well. We present a vision for improvement in oil spill response. DROPPS II results are applicable for oil spill response, particularly the potential use of chemical dispersants. The results of this research are applicable to response operations and modeling. Droplet breakup can occur both in the subsurface, e.g. a well blowout scenario with or without subsurface dispersant injection (SSDI), or at the surface due to wave action with or without dispersant application. To understand droplet breakup, detailed observations using high speed cameras and modeling allow visualization of processes too small for us to easily see in nature. Analysis of small processes such as droplet internal vorticity, skirting and gas exchange need to be studied to understand droplet formation and breakup. Surface oil can also break into microdroplets that become aerosolized from the simple action of rain drops. Once droplets form in the ocean, dissolution, biodegradation, photooxidation and other processes modify the droplets, changing size and composition. During biodegradation, local dissolved oxygen is utilized. Droplets can be ingested by zooplankton and other species. Response options themselves can have effects on the local biota. Each of these factors are important for illuminating the tradeoffs among potential use of different response options. New technologies are being developed utilizing holography for *in-situ* monitoring of SSDI operations with automated systems for discerning and measuring oil droplets and gas bubbles and for examining imaging bacteria in 3D. Transitioning the scientific advances from experimental and modeling research and publications by 11 institutions into the different aspects of planning, response and restoration considerations is an important task in improving outcomes from future emergency events.

The Impact of the Solvent Base for a Dispersant on the Efficiency of Crude-Oil Dispersion

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Dispersants used in the mitigation of oil spills are mixtures of amphiphilic molecules in a solvent base. The recent large-scale use of dispersants has raised environmental concerns regarding the safety of these materials. Hence, we have reported a class of eco-friendly dispersants that utilize food-grade amphiphiles such as the phospholipid lecithin (L) (from soy) and the nonionic surfactant Tween-80 (T) to effectively disperse oil into seawater. The initial solvent used for the above LT dispersants was ethanol, which is relatively nontoxic but is volatile (low flash point), thus motivating our search for a different solvent. Typically, solvent choice has been based on factors like toxicity, volatility or the viscosity of the overall mixture. But with regard to the efficiency of oil dispersion, the solvent is considered to play a negligible role. Here, we firstly show that the solvent can have a *dramatic impact on dispersion efficiency*, i.e., on the extent of dispersion of a thin layer of oil in the water column for a

given amount of LT dispersant. For example, the dispersion efficiency (as measured by the conventional baffled flask test) can range from > 75% with one solvent to < 10% with another. Thus, the solvent has an independent role to play in oil dispersion over and above the amphiphiles. The properties of the crude oil being dispersed also has to be taken into consideration. For example, the LT dispersant with ethanol as the solvent is efficient at dispersing crude oils of low viscosity (10 cp), but not for crude oils of high viscosity (10,000 cp). For the latter, the same LT combination with a different solvent drastically improves the dispersion efficiency. We are interested in devising a systematic procedure to select the optimal solvent for a given oil. In this regard, we turned to Hansen Solubility Parameters (HSPs), which are parameters that quantify the chemical nature of each solvent. We assessed the quality of dispersion for a wide range of solvents across three different crude oils through a low-energy dispersion test. A plot of the Hansen parameters for each oil shows a systematic trend, with optimal solvents clustering around a particular region of the plot. Thus, our analysis enables us to identify solvents that combine high dispersion efficiency, good solubility of the LT amphiphiles, and also a low toxicity profile.

Characterizing Dispersant Effectiveness at Varying Salinities

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Dispersant formulations for marine use typically provide maximum dispersion at normal seawater salinity and most laboratory studies are conducted at low to average ocean salinity. Potential oil exploration and production activities in close proximity to hypersaline water bodies, such as brine channels in the Arctic or brine pools in the Gulf of Mexico, necessitates characterization of Dispersant Effectiveness (DE) at high salinities. In this study, the influence of salinity on DE was evaluated using the Baffled Flask Test (BFT) at a DOR of 1:25. The benchtop experiments were conducted with Alaskan North Slope (ANS) crude, an EPA standard reference medium crude, in the presence or absence of Corexit 9500 at 5 and 25°C and varying salinities (20 to 125 parts per thousand or ppt). In addition to DE as determined by BFT, the droplet size distribution (DSD) and fluorescence intensity was measured on a subsample of the dispersed oil from the baffled flask with the LISST-100X and WET Labs ECO Fluorometer respectively. Additionally, the interfacial tension (IFT) between the oil droplet and the artificial seawater at varying salinities was measured with a spinning drop tensiometer. Results indicated that maximum DE and fluorescence occurred at 35ppt while lower dispersion was observed at the other salinities. However, these differences were found to be statistically insignificant. The concentration of very small droplets (<10 µm) was twice as high at 35ppt than at the other salinities in the presence of dispersant at 25°C. The DSD of the treatment without dispersant did not vary significantly as a function of salinity. The addition of dispersant decreased the IFT by a factor of about 500 for a given salinity. Furthermore, the IFT decreased with increasing salinity in the presence of dispersant, while it increased in the absence of dispersant. These results provide a more comprehensive picture pertaining to the influence of salinity on dispersant usage at high salinities.

A Comprehensive View of an Effective Alternative Dispersant System using Food Grade Surfactants

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Mixtures of Lecithin (L), a phospholipid extracted from soybeans, and Tween 80 (T), a nonionic surfactant used in foods and cosmetics have shown significant potential as an environmentally safe alternative to Corexit 9500 A with laboratory tests indicating enhanced dispersability of oil. We show that these dispersant components dissolved in a benign solvent such as propylene glycol, spontaneously self-assemble to nanostructures such as bicelles and vesicles when contacted with water. Through small angle x-ray scattering (SAXS) and cryo transmission electron microscopy we show stacks of bicelles that gradually break into individual structures upon dilution thus characterizing the concentration trajectory of these systems. Upon contact with oil, the oil-water interfacial tension is reduced to 10^{-3} mN/m and baffle flask tests indicate stable oil dispersions. We have then exposed these systems to a model alkane-degrading bacterium *Alcanivorax borkumensis*. Growth of the organism and generation of biofilm at the oil-water interface further enhances emulsion droplet stability with biofilm bridging between oil droplets. Cryogenic scanning electron microscopy allows nanoscale visualization of biofilm formation and bacterial proliferation. After a week, we observed sedimentation of oil coated with bacteria and biofilm confirming the oil-sinking phenomenon. Gas chromatography analysis of the crude oil (Anadarko crude) reveals approximately. 80% reduction of the alkane content over the period of a week.

Photochemical Oxidation Reduces the Efficacy of Aerial Dispersants Applied in Response to Oil Spills

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Photochemical weathering is often considered too slow to impact the efficacy of chemical dispersants applied to floating oil in the aftermath of spills. However, using the Deepwater Horizon spill as a case study, we showed that photochemical oxidation was a dominant weathering process that oxidized over half of the floating oil on time-scales of days. These rapid changes to oil chemistry by sunlight suggest that photo-oxidation could conceivably impact the “window-of-opportunity” for chemical dispersant application during the emergency phase of a spill response. Here we show that on timescales of hours to days, sunlight substantially altered the chemical and physical properties of oil, which in turn decreased the efficacy of chemical dispersants used in response to the Deepwater Horizon spill. We further demonstrate that the impacts of photochemical weathering on the dispersant efficacy of Macondo Well oil greatly outweigh the impacts of evaporation, a weathering process regularly factored into oil spill response plans. Lastly, accounting for the decrease in dispersant efficacy due to photochemical oxidation, we revised downwards estimates for the amount of oil dispersed by aerial applications in the aftermath of the Deepwater Horizon spill. Collectively, our findings strongly suggest that photochemical weathering substantially impacts the “window-of-opportunity” to apply chemical dispersants in response to future oil spills in sunlit waters.

Using an Artificial Oil System to Assess Dissolution of PAHs from Droplets

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Oil is undoubtedly a complex mixture of different chemical components. Following an oil spill, micron-sized oil droplets may form naturally through the action of breaking waves. These droplets may persist in the water column and increase the surface:volume ratio of the oil and the rate of compounds partitioning into the water within their solubility limits. Polycyclic aromatic hydrocarbons (PAH) are viewed as the major determinant of oil toxicity and aquatic studies often report toxicity in terms of total PAH concentrations of the exposure media. Limited knowledge exists on the effect of individual compounds of oil droplets in the water in terms of its dissolution rates and toxicity. In this work, an artificial oil (AO) composed purely of alkanes (C7-C25) and an isoprenoid (pristane) at equimolar ratios was prepared with different amounts of individual PAHs commonly present in crude oil in order to test the dissolution of these compounds from droplets. Oil water dispersions (OWDs) consisting of 10µm droplets size were generated with the AO using an injection method capable of producing dispersed droplets with defined size distributions. Detection and quantification of the AO droplets was performed with a particle analyzer and an Epi-Fluorescence microscope. Chemical analysis for PAHs and saturated hydrocarbons was also conducted. The fluorescence of the AO droplets increased with increasing concentration of added PAHs so that microscopy could be used in both qualitative and quantitative way. Dissolution of Fluorene, Pyrene and Chrysene in the water column were measured by filtering samples collected at interval times. As expected, a linear relationship was observed between Log S and Log K_{ow}. To our knowledge, this is one of the first study to equilibrate individual PAHs in water solutions using droplets of an AO composed of pure alkanes as the delivery system. Comparisons with 10 PAHs present in the authentic Macondo MC-252 oil showed good overall consistency (affected only by evaporation or droplet formation) and allowed for an estimation of its average MW as 272 g/L. The AO model could be easily expanded to include other oil compositions specific gravities.

RSP-004: Biological Aspects and Recovery and Operational methods

A Bioremediation Field Trial for Buried Oil on a Coastal Headland Beach

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Hard structures used to close breaches on Fourchon Beach, LA were used to mitigate the transport of MC252 oil into adjacent marshes. These structures created conditions for oil burial across the beach profile where mechanical removal efforts left significant oil below the groundwater table. Groundwater at the site is hypersaline (>45 ppt) and anaerobic (DO below detection, less than 0.02 mg/L). Persistence of 3-ring polycyclic aromatic hydrocarbons (PAHs) (alkylated phenanthrenes, dibenzothiophenes) and 4-ring alkylated chrysenes has been observed in subsurface sediments 6-7 years after the spill. Subsurface *in-situ* chemical oxidation (ISCO) using an activated persulfate oxidant coupled with a slow release oxygen releasing compound (PersulfOx and ORC Plus) is being evaluated at the site as remediation alternative. Oxidants were mixed into a treatment plot, approximately 9.1 m × 9.1 m, approximately 3 m deep. We hypothesize that ISCO will oxidize crude oil compounds and oxygenation will stimulate biodegradation of PAHs. Weathering of 3-ring PAHs were monitored in

* Student presenter

sediments collected at approximately 1.0 m depth at 2 to 4 weeks intervals post initial PersulfOx addition from 02/2017 to 08/2017. Beach sands were analyzed by GC-MS and weathering ratios were constructed from 3 and 4-ring PAHs compound series (C1-, C2-, C3- and C4-, alkylated, phenanthrenes, and dibenzothiophenes) in the numerator and 4-ring C1-, C2 and C3-chrysene data, in the denominator. In sediments before PersulfOx addition, alkylated phenanthrenes and dibenzothiophenes levels evaluated through weathering ratios to alkylated chrysenes were close to the levels in freshly-spilled MC252 oil. 6-months after addition of PersulfOx, decreases in phenanthrenes and dibenzothiophenes weathering ratio ranged from 8 to 15% and the losses were statistically significant ($p > 0.05$). Follow-up additions of PersulfOx and ORC Plus are underway and results will be available for the conference.

Nutrient Amended Biodegradation of Hydrocarbon Contamination along Canada's Labrador Coast

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Newfoundland and Labrador's offshore region, an area larger than the Gulf of Mexico's outer continental shelf, is the focus of ongoing northern oil exploration via high-resolution seismic surveys along the Labrador coast. Future oil production and heavy shipping traffic into Hudson Bay increase this region's risk of an oil spill in the marine environment. Whether indigenous microbial communities in this marine corridor can effectively biodegrade spilled hydrocarbons, naturally or via nutrient amendment, remains poorly understood. To demonstrate the microbial response within this corridor (Labrador Shelf through to Hudson Bay), O_2 consumption and CO_2 production were monitored over time in the headspace of sediment microcosms amended with diesel or crude oil with different concentrations of limiting nutrients. Sequencing of 16S rRNA gene amplicon libraries using the Illumina MiSeq platform was used to determine baseline community composition within environmental samples, and to monitor community changes associated with biodegradation in the microcosm incubations. Labrador Shelf sediments amended with diesel (0.1% v/v) and incubated at 4°C experienced greater O_2 consumption and CO_2 production relative to unamended controls. Treatments with higher concentrations of nitrogen and phosphorous (4.7mM N, 1.5mM P) show elevated O_2 depletion and CO_2 production compared to those with ambient nutrient levels (i.e. seawater: 15μL N, 2μL P). Microcosms amended with a larger volume of diesel (1% v/v) and a high nutrient level experienced the fastest response, with complete removal of headspace O_2 ; demonstrating the ability of the sediment microbial community to respond to heavy contamination. These results indicate the potential for natural attenuation catalyzed by indigenous microbial communities in the event of a spill associated with shipping or oil production along the Labrador coast. Nutrient amendment as a strategy for enhanced bioremediation is likely to be effective in expediting near-shore clean up in the area.

Computational Modeling of Biofilm Chemotaxis Stimulated by the Dissolution of Oil Droplets Trapped in Sediments

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After an oil spill in the sea, part of the oil ends up in the form of droplets trapped between the grains of a sandy shoreline, or the sediments of the seafloor, and triggers the chemotactic response of indigenous oil-degrading microbes. Usually, the microbes reside in multicellular communities which are known as biofilms and are able to migrate towards the source of a chemoattractant even when the individual cells are neither chemotactic nor motile [1]. This intriguing phenomenon of *biofilm chemotaxis* is caused by anisotropic growth with higher cell proliferation rate along the concentration gradient of the chemoattractant. Fluid flow might enhance or suppress biofilm chemotaxis, depending on whether the directions of the two processes are concurrent or countercurrent. Although the occurrence of biofilms growing against the flow has been demonstrated experimentally [2], the pertinent theoretical analysis is yet missing. In this work, a computational study is presented for the *upstream biofilm migration* in sedimentary porous media during the dissolution of oil droplets trapped in the sediments at upstream locations. The analysis is based on an improved hybrid simulator that combines continuum-based descriptions of fluid flow and solute transport with particle-based descriptions of biofilm growth and detachment (Eulerian-Lagrangian approach) [3]. The impact of the flow and nutrient regimes on the rates of upstream and downstream biofilm migration is investigated for various sediment structures. Further, the enhancement of the droplet dissolution rate that is caused by the downstream biodegradation of dissolved oil is correlated to the hydrodynamic conditions, the pore structure and the microbial kinetics. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 741799.

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Detection and Monitoring of Oil by Snare

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Polypropylene synthetic sorbents, “snares,” are used to detect submerged oil during spills because they are low cost and can be readily deployed off vessels of opportunity (VOOs) or as monitoring sentinels. Multiple snares attached to rope or chains (i.e., arsenals) are towed through the water column or along the bottom on a predetermined grid. Once the “trawl” is complete, the snares are examined for oiling. When used for monitoring, chains with snares can be anchored in strategic locations and then observed over time. When snare is oiled, there is no quantitative understanding of how it relates to *in-situ* conditions. This research focused on three issues: (1) the impact of ambient salinity and temperature and oil type on the adsorption of oil to snare, (2) the retention of oil as a function of tow duration and velocity and ambient temperature, and (3) the movement and morphology of snare in the water column and along the bottom as a function of tow velocity. (1) The adsorption experiment was conducted with strands of snare in a full factorial (2x2x3) design, with ten samples at two salinities (0 and 35 ppt), three water temperatures (5, 20 and 27°C), and two oil types (No. 6 Fuel Oil, Alberta Bitumen). *Temperature was the driving factor for oil adsorption to strands of snare*. (2) The desorption experiment was conducted with strands of snare coated with No. 6 Fuel Oil following a full factorial (2x3) design using five samples at 6°C and 38°C and water velocities of 0, 1, 2 kt. *As temperature increased, less oil desorbed from the snare*. (3) The movement of snare was

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characterized (without oil) in a tow tank. Snare was dragged through the water column and along the bottom at velocities of 0 to 4 kt (0.5 kt increments). *Contact with the bottom is a function of chain weight and relative velocity of the snare.* Responders could apply these results during an emergency spill to optimize detection and monitoring of submerged oil by snare.

A Novel Material Solution to an Old Problem: Aerogel Fabrics for Oil Capture and Recovery

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Due to the recent achievements in material science, advanced composite materials such as aerogels could offer solutions for an improved oil spill response. Here, we explore the use of the mechanically-robust, flexible, hydrophobic aerogels, Cabot™ Thermal Wrap (TW) and Aspen Aerogels Spaceloft (SL). We demonstrated crude oil uptake of 8 ± 0.1 and 6.5 ± 0.3 g/g (Iraq and Bryan Mound Sweet oils, respectively) for SL, and 14 ± 0.1 and 12.2 ± 0.1 g/g for TW, respectively, nearly twice as high as similar polyurethane and polypropylene devices. Additionally, aerogel composites showed excellent reusability (at least 10 cycles) and high oil recoverability (40-60%) following mechanical pressing with modest force. Comparison of SL and state-of-the art polyurethane foam (PUF) over different use (single and multiple), and disposal (landfill, incinerator and waste-to-energy) scenarios showed that SL aerogels have an energy and material benefits relative to PUF, and the advantage is preserved regardless of how the material is deployed and disposed. Overall, these advanced materials provide several advantages: (1) rapid, efficient and selective oil removal (i.e., without water uptake), (2) the possibility of oil recovery through mechanical extraction, (3) an environmentally sustainable and economically feasible response option with less waste, less overall energy consumption, and lower cost.

Clay Nanotube-Bacteria Liquid Marbles for Oil Spill Remediation

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Halloysite clay nanotubes form Pickering emulsions with crude oil and enhance the growth of hydrocarbonoclastic bacteria on such emulsion surfaces (A. Panchal *et al*, *Coll. Surf.-Bio*, in press, 2017). In this approach, halloysite interface stabilizes oil droplets in water. In “symmetrical” approach we built halloysite interfaces to stabilize aqueous *A. Borkumensis* bacterial in clay coated microdroplets. Adding to the utility of halloysite tubes for oil spill remediation, we have employed liquid “marbles” of these clay nanotubes to encapsulate oil-eating bacteria, which then will be sprayed over oil spill spot. Hydrophilic pristine halloysites converted to hydrophobic (contact angle $>90^\circ$) with alkylsilanes treatment can form such liquid micromarbles. Oil-degrading bacteria encapsulated in the micromarbles proliferate on the inner capsule walls, producing biofilm which is strengthening the marbles. Being covered by a hydrophobic halloysite shell, these marbles remain stable on air and on the surface of water but collapse on contact with crude oil, thus synergistically emulsifying it and seeding with bacteria. Such bacteria-halloysite liquid marbles provide an elegant method to deliver clay nanotubes for oil spill bioremediation.

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Airborne Oil Spill Remote Sensing: POSEIDON a New Operational Approach

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Airborne remote sensing is becoming a foundation of the overall strategy to improve the ability to plan and position response resources in the optimal areas to respond to spills, it is also an effective and efficient support technique for natural resource damage assessment (NRDA) following the spill, and the preferred method for periodic surveillance of coastal areas against illegal or accidental discharge. The most important features that airborne remote sensing platforms should have are: multi-sensors system for complementarity and redundancy of information; capability to classify oil targets as Recoverable or Non-recoverable; capability to georeference the targets and track moving oil; real time information - for tactical and strategic use; data suitable to support the Common Operating Picture; ability to expand the operating window to low-light conditions. The airborne remote sensing platform POSEIDON was recently introduced into service to answer to the needs of the responders community. The aircraft integrates multiple remote sensors and mission system components into one network-based data acquisition, real-time processing and communication platform. The philosophy behind POSEIDON is to provide real time intelligence on the scene, which means understanding the environment, deciding on appropriate tactical-strategic actions and controlling the results. In this paper, we give an overview of currently existing oil spill remote sensing technology such as infrared/ultraviolet line scanners, microwave radiometers, laser fluorosensors and radar systems; and then we focus on the operational approach adopted during oil spill detection, that includes three basic steps: synoptic overview of the spill, near range analysis, data processing and data communication. The paper shows how this approach allows the responders to have a timely and clear picture of where the oil is, how much oil there is, where it is heading and where the hotspots are. Examples of images and data collected during the first year of operation of POSEIDON are presented and commented in detail.

Impact of *in-situ* Burning on Transformation and Solubilization of Spilled Oil and the Production of Dissolved Organic Matter

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Dissolved organic matter (DOM) exists in the marine environments as a highly functionalized and complex mixture of organic compounds derived from several sources and transformation reactions. DOM can provide valuable insights into the biogenic, petrogenic and pyrogenic ocean inputs and diagenetic alterations that may have occurred within those waters during transport. DOM in natural waters near oil seepage and spillage may, in part, represent a near terminal degradation product of petroleum. In addition to spillage, organics are introduced in the water column, from any *in-situ* burning (ISB) of the oil slick formed at the surface. During the Deepwater Horizon spill, about 15% of the spilled oil was burnt. To characterize the organics introduced into the water column following spillage, we conducted lab-scale experiments to isolate both the water-soluble oil fraction and combustion related pyrogenic fraction of oil. These fractions were analyzed to capture the input of the organics following the formation of an oil slick and its burning and these fractions were compared to the natural DOM composition, from waters in the northern and southern Gulf of Mexico. The water-soluble organics were characterized using ultra-high resolution mass spectrometry (FTICR-MS) and the results show that the oil burning process strongly increases the concentrations of oil related constituents entering the water column, due to transformation reactions producing oxidized organic

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species with higher water solubility. The toxicity impact of these organics on the ecosystem is currently unknown. While ISB offers some advantages over other methods of oil spill cleanup, such as less need of equipment and labor, the organics introduced into the water following the burning remain poorly understood. This attempt to characterize these ISB related organics entering the oceanic DOM pool will help better determine response strategies for future oil spills.

Changes in the Beach Microbial Community during Treatment of Buried Oil with *in-situ* Chemical Oxidation and Bioremediation

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The objective of this study is to evaluate the changes in the beach microbial community in response to *in-situ* chemical oxidation (ISCO) and aerobic bioremediation of buried MC252 oil on Fourchon beach, LA. Hard structures used to mitigate the transport of oil into adjacent marshes created conditions for oil burial across the beach profile. Mechanical removal was insufficient as a response option for buried oil. Groundwater at the site is hypersaline (>45 ppt) and anaerobic (DO non-detect and below 0.02 mg/L). Persistence of 3-ring polycyclic aromatic hydrocarbons (PAHs) (alkylated phenanthrenes, dibenzothiophenes) and 4-ring alkylated chrysenes were observed in subsurface sands 6-7 years after the spill. A plot, approximately 9.1 m × 9.1 m, 3 m in depth was mixed with an activated persulfate compound (PersulfOx). A second application of PersulfOx and an oxygen-release compound (ORC plus) is underway. Microbial community changes in subsurface beach sands collected at approximately 1.0 m depth was evaluated at 2-4 week intervals. 16S rRNA from genomic DNA extracted from beach sediments, was amplified with universal bacterial primers 515F and 806R overlapping in the V4 region, and sequenced using the Miseq Illumina platform. The Silva reference database was used for alignment of sequences and taxonomic identification. Initial aerobic biodegradation studies at the site demonstrated shifts in the composition of the diverse, halophilic, hydrocarbon-degrading microbial population. *Marinobacter* was the dominant phylotype in the pre-aeration sediments. However, addition of oxygen increased the abundance of *Halomonas*. When oxygen addition was stopped, the *Marinobacter* population rebounded and was observed as the most abundant phylotype in February 2017, prior to PersulfOx. Post PersulfOx addition, abundance of *Marinobacter* decreased with time but remained as the most dominant phylotype. *Alcanivorax* emerged as the second most abundant phylotype in 4 and 8 weeks sediments post PersulfOx addition. After 10 -12 weeks post PersulfOx addition, *Sulfurimonas* was observed as second most abundant phylotype in beach sands and *Alcanivorax* abundance decreased. Advanced bioinformatics analyses are in progress to better understand shifts in microbial community post PersulfOx addition and changes in PAHs weathering.

Vegetation Recovery in an Oil-impacted and Burned *Phragmites australis* Tidal Freshwater Marsh

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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 setting, and oiling conditions. In addition, possible *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, 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 exacerbate coastal erosion and wetland loss, a major concern in the region.

A Geographic Perspective for Protecting Sensitive Coastal Areas with Exclusion Booms during Oil Spill Events

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In the United States, there is a growing interest in the vulnerability of complex social, economic and environmental systems. Oil spills at sea remain a serious threat to coastal settlements and sensitive ecosystems. Although the impacts of spills are contingent upon a variety of environmental factors and the chemical composition of the oil itself, spill effects can be long lasting in the pelagic zone with broad impacts on sensitive bacterial, microbial, plant and animal communities. Efforts to contain, deflect, protect and mitigate the effects of oil are increasingly important, given the massive social, economic and environmental fallout connected to large spills. The purpose of this paper is to provide geographic perspective for protecting coastal areas with exclusion booms during oil spill events. Specifically, we introduce a generalized, extendable, spatial optimization model that simultaneously minimizes spill effects on vulnerable shorelines and the total costs associated with dispatching booms. The multi-objective model is solved with a weighting method to produce a Pareto optimal curve that reveals how the costs and protection operations change under different priorities. A simulated tanker spill near Mobile Bay (Alabama) in the United States is used as an illustrative example. The results of this paper help frame the complex interactions between offshore oil and gas operations and local social, economic, and environmental systems. In addition, rather than fostering a culture of reaction, the detailed simulations and optimization model are a good first step in allowing communities to proactively plan for extreme events and develop response strategies that minimize the impacts of spills.

Macondimonas diazotrophicus: A Novel Hydrocarbonoclastic Gammaproteobacterium as a Potential Biomarker for Ecosystem Recovery from Oil Spills

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Our previous analysis of the functional gene content of time series metagenomic data from beach sands affected by Macondo oil in Pensacola Municipal Beach, FL (Rodriguez-R et al., ISME 2015) revealed a high abundance of nitrogen fixing genes (namely *nifH*), which is a potentially important finding since oil biodegradation is often nitrogen-limited in these environments. Using population binning techniques, we have subsequently succeeded in reconstructing an almost complete genome that included the abundant *nifH* gene, together with other genes for hydrocarbon degradation, methanotrophy, biosurfactant production, nutrient scavenging and other related mechanisms required to adapt and thrive under the oil induced perturbations were recovered. The relative abundance of the genome bin rapidly increased from below detection in the clean/pre-spill samples to 29% of the entire community in oiled samples, returning to undetectable levels in the recovered sediments. SSU rRNA gene sequences of this genome were also widespread almost exclusively in oiled/hydrocarbon contaminated sediments across the globe including sediments impacted by the DWH oil spill. Therefore, this population potentially represents a keystone species of oil biodegradation in sediments and beach sands. Whole genome comparisons to available genomes revealed that our genome represents a member of a novel family within *Gammaproteobacteria*, for which we propose the name *Macondimonas diazotrophicus*. Targeted efforts to isolate this organism from oiled Pensacola beach sands were successful, yielding a rod-shaped bacterium that showed 99.8% genome-aggregate average nucleotide identity (ANI) to the previously identified population bin. The ecological distribution and metabolic versatility of *M. diazotrophicus* coupled to its abundance patterns during oil biodegradation make it a promising new biomarker for oil contamination and ecosystem recovery.

Science for Restoration, Management, and Policy

RMP-001: Regional and Local Restoration Programs and Strategies

Progress in Building a Monitoring and Adaptive Management Framework for Deepwater Horizon Natural Resource Damage Assessment Restoration

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The Oil Pollution Act (OPA) Natural Resource Damage Assessment (NRDA) regulations require monitoring of restoration projects to document effectiveness in meeting restoration objectives, and/or the need for corrective action. Given the unprecedented scale of the Deepwater Horizon oil spill and its associated restoration plan, the NRDA Trustees recognized a need for a robust, scientifically-based monitoring and adaptive management (MAM) framework to support restoration decision-making, corrective actions and measurement of restoration benefits across multiple scales. In July 2016, the NRDA Trustee Council formed the Cross-Trustee Implementation Group (Cross-TIG) MAM work group to promote consistency in monitoring across the seven TIGs and make recommendations on effective evaluation of restoration outcomes at project, resource, and programmatic scales. During its first year, the work group developed project-level monitoring guidance for version 1.0 of the Trustee Council Monitoring and Adaptive Management Procedures and Guidelines Manual (MAM Manual), including monitoring standards for a subset of Restoration Approaches. The work group also began to establish mechanisms to coordinate with other Gulf of Mexico programs on monitoring topics. Now in its second year, the Cross-TIG MAM work group is developing project-level monitoring standards for additional Restoration Approaches. It is also developing procedures for resource-level and programmatic evaluation and adaptive management to inform review of the NRDA restoration program. This includes developing processes for aggregating, analyzing, and synthesizing data and other information across TIGs and Restoration Types to evaluate progress towards meeting the ecosystem-level goals in the Programmatic Damage Assessment and Restoration Plan and Programmatic Environmental Impact Statement (PDARP/PEIS). A pilot study is currently underway to work through an example of the Restoration Type evaluation process.

Monitoring and Adaptive Management Manual to Support Integrated Ecosystem Restoration under the Deepwater Horizon Natural Resources Damage Assessment

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Given the unprecedented temporal, spatial, and funding scales associated with the Deepwater Horizon oil spill restoration effort, the Natural Resource Damage Assessment (NRDA) Trustees recognize the need for a robust monitoring and adaptive management (MAM) approach to support restoration

planning and implementation, One of the programmatic goals established in the Trustees' Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (PDARP/PEIS) is to "Provide for Monitoring, Adaptive Management, and Administrative Oversight to Support Restoration Implementation" to ensure that the portfolio of implemented restoration projects provides long-term benefits to the resources and services injured by the spill. A MAM approach to restoration will allow the Trustees to evaluate restoration effectiveness, address uncertainties related to project planning and implementation, and provide feedback to inform future restoration decisions. Building upon the monitoring frameworks and conceptual monitoring plans developed by the Trustees for Early Restoration, the Cross-Trustee Implementation Group (Cross-TIG) MAM Work Group recently developed the MAM Procedures and Guidelines Manual Version 1.0 (MAM Manual), on behalf of the Trustee Council. The MAM Manual provides recommended guidance on the: (1) development of project-level monitoring and adaptive management plans, (2) implementation of project MAM plans, (3) monitoring of restoration actions, (4) evaluation of restoration effectiveness, (5) feedback of information to future restoration planning and implementation, (6) data management, and (7) reporting on progress toward meeting restoration goals and objectives. The MAM Manual is intended to serve as a resource for the TIGs and future versions of the MAM Manual may include additional MAM topics beyond the project scale, such as approaches for resource-level and programmatic monitoring and evaluation.

Monitoring Guidelines for Evaluating Restoration Outcomes from the Deepwater Horizon Natural Resource Damage Assessment

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The Deepwater Horizon (DWH) Trustees selected a comprehensive, integrated ecosystem approach to restoration in the Gulf of Mexico, as presented in the Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (PDARP/PEIS). One of the programmatic goals in the PDARP/PEIS is "Provide for Monitoring, Adaptive Management and Administrative Oversight to Support Restoration Implementation" to ensure that the portfolio of restoration projects provides long-term benefits to the resources and services injured by the spill. On behalf of the Trustees, the Cross-Trustee Implementation Group (Cross-TIG) Monitoring and Adaptive Management (MAM) Work Group has developed a MAM Procedures and Guidelines Manual (MAM Manual) Version 1.0 to guide MAM efforts conducted by the Trustees. As part of this manual, monitoring recommendations are provided for a subset of Restoration Approaches for the following Restoration Types outlined in the PDARP/PEIS: Wetlands, Coastal and Nearshore Habitats; Water Quality; and Provide and Enhance Recreational Opportunities. Monitoring guidelines for other Restoration Types will be developed and presented in subsequent versions of the Manual. The monitoring guidelines include a suite of core monitoring parameters for each Restoration Approach. In addition to core monitoring parameters, the Manual provides objective-specific core monitoring parameters, definitions and associated guidelines for monitoring methods applicable to each core parameter, and recommendations of additional monitoring parameters to consider for adaptive management or validation of function and services. Finally, the Manual provides examples of project-

level restoration objectives, drivers of restoration outcomes, and potential uncertainties associated with each Restoration Approach. The establishment of monitoring guidelines facilitates the aggregation and analysis of monitoring results across projects.

RESTORE Council Monitoring and Assessment Program: Developing a Shared Monitoring and Adaptive Management Vision through Coordination and Collaboration

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The variety of mechanisms for funding ecosystem restoration in the Gulf of Mexico (e.g. RESTORE Council, Natural Resource Damage Assessment [NRDA], National Fish and Wildlife Foundation) poses unique challenges to establishing a coordinated and integrated monitoring, assessment and adaptive management response. Just as funding programs will not be able to achieve holistic Gulf restoration independent from one another, no one single monitoring and assessment effort can demonstrate ecosystem restoration success at the system-wide Gulf of Mexico scale. The RESTORE Council has funded the Council Monitoring and Assessment Program (CMAP), consisting of a program advisory team, a Council Monitoring and Assessment Working Group (CMAWG) that includes a representative from each Council Member, a Community of Practice facilitated by the Gulf of Mexico Alliance Priority Issue Teams, and a Monitoring Coordination Committee represented by other Gulf restoration organizations funding monitoring. The consistency in monitoring and adaptive management approaches across programs necessary to demonstrate holistic restoration requires synthesis across RESTORE CMAP and other existing programs and working groups (e.g., NRDA Cross-Trustee Implementation Group [TIG] Monitoring and Adaptive Management). The intent of CMAP is to coordinate the development of the foundational components for Gulf region-wide monitoring, including monitoring and adaptive management plan guidance and monitoring standards and protocols, that will facilitate a system-level view of response to restoration. We will describe RESTORE CMAP working groups' activities and plans to integrate, build off of and/or provide input to the other related programs and activities. We will also discuss the challenges and opportunities we have encountered in developing a shared monitoring and adaptive management vision among Gulf States, Federal and local partners, academia, non-governmental organizations, and industry.

Deepwater Horizon Cross-Program Coordination: Connecting the Dots to Evaluate Holistic Gulf Restoration

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Since the settlements and penalties from Deepwater Horizon (DWH) have been determined, Gulf restoration and monitoring of the implemented restoration is moving forward under several separate programs and processes that are in different stages of development and execution. Some have been operating for several years and some are just getting underway. The intent of this panel is to have a cohesive discussion among the DWH entities that are planning, conducting and monitoring restoration activities. The panel discussion follows a suite of presentations from the Cross-Trustee Implementation

Group Monitoring and Adaptive Management (Cross-TIG MAM) Work Group and RESTORE Council's Monitoring and Assessment Work Group (CMAWG) that will describe activities, standards and protocols, data management, adaptive management strategy, and products. Presentations include:

- Progress in building a monitoring and adaptive management framework for Deepwater Horizon Natural Resource Damage Assessment restoration
- Monitoring and Adaptive Management Manual to Support Integrated Ecosystem Restoration under the Deepwater Horizon Natural Resources Damage Assessment
- Monitoring Guidelines for Evaluating Restoration Outcomes from the Deepwater Horizon Natural Resource Damage Assessment
- RESTORE Council Monitoring & Assessment Program: Developing a Shared Monitoring and Adaptive Management Vision through Coordination and Collaboration.

The focus of the panel is to identify common goals among groups so that monitoring and evaluation of restoration outcomes within and across programs occurs in the most efficient manner, reduces redundancy and maximizes collective output. The CMAWG has a higher-level coordination mandate and would benefit by understanding where its objectives and outcomes fit with other programs. Focusing on higher-level coordination, all groups would benefit from understanding the details of, and attempting to unify processes such as, standards and protocols, shared data access, monitoring approaches, and outcomes. Desired performance metrics would be strong coordination across all monitoring groups and increased collaboration, where appropriate, to ensure that the outcomes of restoration efforts can be effectively measured to provide maximal impact for future restoration planning.

Integrating Adaptive Management into NEPA

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Major federal legislation that governs the impacts of natural resource use, primarily the National Environmental Policy Act (NEPA), are inherently 'front-loaded' statutes that place restrictions on potentially environmentally harmful actions with a deterministic and static view of future conditions. NEPA, for example, requires extensive documentation and public disclosure of any significant environmental impacts resulting from actions undertaken or financed by federal agencies. To maintain its environmental protections, the statute is inherently inflexible; in increasingly variable conditions, however, more flexibility is required for it to remain effective. Adaptive management is one potential tool to address heightened levels of uncertainty and stochasticity in natural resource management and a variety of stressors and triggers at a larger landscape level. Adaptive management emphasizes 'learning while doing' to manage natural resources in the face of uncertainty and risk often through experimentation, active learning, and stakeholder engagement. Various forms of AM have been widely embraced by the natural resources community and environmental lawyers. Here, we will provide a single, nuanced definition of AM that reflects much of the scientific literature. For the purpose of this discussion, we use the definition of adaptive management (AM) as defined by Craig and Ruhl (2014): "Adaptive management is a structured decision making method, the core of which is a multistep, iterative process for adjusting management measures to changing circumstances or new information about the effectiveness of prior measurements or the system being managed." The utilization of AM will be critical in order for future management plans to be successful in such conditions. Large projects that influence the natural environment at a landscape scale in complex ways in particular, such as sediment diversions, can benefit from the use of adaptive management strategies as a way to adjust

actions based on the conditions being experienced at any given point in time. This flexibility, however, must still be able to work within the relatively rigid constraints of environmental policy and legislation such as NEPA.

GulfCorps Project - A New Model of Conservation Corps Work

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The NOAA project team introduces a new project type to the restoration community; this project focuses on people and communities affected by the 2010 Deepwater Horizon spill. The principal objective of the Gulf of Mexico Coastal Conservation Corps (“GulfCorps”) Program is to develop a Gulf-wide conservation corps that will contribute to meaningful Gulf of Mexico ecosystem restoration benefiting coastal habitat and water quality in each of the Gulf coast states, while economically benefiting coastal communities through education, training, and employment opportunities. This project was funded in the summer of 2017 through an interagency agreement with the RESTORE Council and NOAA. NOAA is partnering with The Nature Conservancy, the Corps Network, and the Student Conservation Association to build a diverse and responsive group of local labor expertise in coastal habitats. The success of this program will be in partnership and coalition building, particularly in helping to establish job-based skills training that can assist participants’ employ-ability in environmental-based jobs. The GulfCorps project team emphasizes partnership-leveraging, synergy, and networking opportunities with other existing conservation groups across the Gulf coast as we recruit, train, and employ workers to implement habitat restoration projects and develop skills in support of long-term Gulf coast restoration. Join us to learn more about this innovative and exciting new project and how you can be a part.

Development of a Next-Generation Decision Support Tool for Coastal Ecosystem Restoration: Adaptation of Coastal Urban and Natural Ecosystems (ACUNE)

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We present a recently NOAA-NCCOS funded project which aims to assess the vulnerability and enhance the resilience of Southwest Florida coastal urban and natural ecosystems. This coastal region contains the largest area of tidally influenced public lands in the Gulf of Mexico and the fastest growing urban landscape in Florida. Both the human and natural components of the regional ecosystem, are under increasing risk due to the threats of a growing human population, sea-level rise (SLR), and tropical cyclones (TCs) which are becoming more intense, and increasing salt water inundation. Mangrove forests, salt marshes, and beaches, which provide flood protection and fishery habitat, are highly vulnerable to these stressors. Local governments (Collier County, Naples, Marco Island, and Everglades City) and natural resource managers (Rookery Bay NERR, Ten Thousand Islands National Wildlife Refuge, South Florida Water Management, and Big Cypress Basin) have partnered with the team to define the questions that motivated the project and the features of the decision support tool. Two

major products will be developed by this project. First, using a suite of coupled state-of-the-art climate and coastal models, we will create inundation maps, salinity maps, habitat maps, beach and barrier islands vulnerability maps, and economic impact maps for both current and future climates and for various sea level rise scenarios. Second, these maps will be integrated into a web-based interactive decision-support tool *Adaptation of Coastal Urban and Natural Ecosystems (ACUNE)* that enables users to identify areas of high vulnerability and use this information for strategic coastal resiliency planning. ACUNE will allow the end users to make decisions in coastal planning, zoning, land acquisition, and mangrove/marsh restoration that are based on models that are far more robust than those currently available. The approach and decision support tool can be extended to other GOM regions.

Moving Beyond Restoration in the Gulf of Mexico: Using Gulf Science to Implement Conservation in a Highly Altered, Large Marine Ecosystem

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The Gulf of Mexico (Gulf) was historically among the more poorly studied of the major US waters. Following the Deepwater Horizon (DWH) disaster, support from the Gulf of Mexico Research Initiative (GoMRI) fostered development of unprecedented studies of the biological, ecological, physical, geological, and chemical conditions of the Gulf. In addition, the magnitude of the impacts of the DWH spill on the well-being of Gulf communities promoted novel insights into the effects of a spill on human health, economics, and ecosystem services. The collective results of that research have informed discussions and strategies to restore Gulf ecosystem integrity and living resources, as well as human stakeholder needs there. However, restoration is a reactive enterprise designed to undo damage. In fact, restoration is one component of the larger, more comprehensive, integrative, and proactive approach of conservation. This presentation synthesizes conservation recommendations of GoMRI-supported scientists in the Gulf, as well as of peer-reviewed conservation studies elsewhere, to promote improved conservation outcomes for the Gulf and other marine and coastal environments. The challenge to conserve large marine ecosystems and the species, habitats, and human enterprises that rely on those ecosystems can seem insurmountable. However, case studies demonstrate that success can be reached through meaningful input from the natural and social sciences, communication and leadership, collectively agreed-upon rules of governance, and adherence to a conservation ethic based on stakeholder acceptance of the precautionary principle and an appropriately-placed burden of proof. In the US and globally, well-implemented conservation planning would help to reduce the impact and subsequent costs of responding to repeated environmental disasters. We recommend a rational and long overdue balanced strategy to sustain ecosystems, living resources, and a range of human cultures and enterprises.

RMP-002: Restoring and Managing Ecosystems for Resiliency: From Coastal Communities to the Deep Ocean

Is the Cart ahead of the Horse? Benthic Habitat Mapping and Characterization in the Eastern Gulf of Mexico

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Appropriate and effective management and restoration strategies of benthic organisms require data on the extent, composition, and condition of the biological community to understand past, present, and future environmental states. This is provided by habitat mapping and community characterization. A very small percentage of the benthos has been mapped and characterized in the Eastern GOM. The lack of this information impedes many aspects of the science and management of bottom fish and invertebrates including population estimates, estimating ecological services, ecological modeling, impact avoidance from planned activities, responding to and quantifying anthropogenic impacts, and optimizing study designs based on ecologically relevant strata. Recent mapping has yielded 294 km² of hardbottom within two areas totaling 1,263 km² between four and 16 m depth off Clearwater and Sarasota, Florida. A total of 4,079 of nine stony coral species and 1,918 soft corals were measured. Populations were dominated by four species: *Siderastrea radians* (4.9 m⁻²), *Oculina robusta* (3.3 m⁻²), *Solenastrea hyades* (2.5 m⁻²), and *Cladocora arbuscula* (0.7 m⁻²). Most corals were less than 10 cm in length (73%), width (85%), and height (80%). Bleaching prevalence was high but mostly specific to *O. robusta* (52%) and *S. hyades* (17%). Pooled soft coral density across all sites was 5.4 m⁻². Geographic patterns were evident between counties where higher densities of corals and gorgonians occurred further south. The amount of hardbottom also varied spatially with more in the north and less in the south. A large area of the Eastern GOM shallow-water benthos is available for mapping and characterization using similar methods. Reef fish distribution models are presently available to prioritize mapping areas. Benthic mapping and characterization should be a top priority to provide the vital missing components to the aforementioned aspects of the reef science and management.

You Can't Conserve or Restore What You Don't Know: Benthic Habitat Characterization on Gulf of Mexico Continental Shelves

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The Deepwater Horizon incident has highlighted significant gaps in knowledge of the spatial extent of benthic habitats on Gulf of Mexico (GoM) continental shelves. Natural and human-constructed habitats on the shelves are critical for the sustained productivity, diversity and resilience of GoM ecosystems including fisheries and the multitude of protected species. Some sensitive benthic ecosystems on the shelf have been mapped, but well over 90% of waters between state jurisdictions and the 200-m contour have not been systematically imaged with high-resolution bathymetry or characterized in terms of geological and ecological habitat types. The value of benthic mapping to enhancing ecosystem protection and recovery is illustrated using results from a current, intensive characterization program

funded by the National Fish and Wildlife Foundation (NFWF), through its Gulf Environmental Benefit Fund (GEBF). The program seeks to characterize an additional 2,900 km² of high-value habitats for economically important reef fishes and sea turtles in the NE GoM, more than doubling the amount of habitat so mapped to date. Bathymetry is being extended using 4-m resolution multibeam mapping. Habitats are being characterized with a unique towed video system - the Camera-Based Assessment and Survey System, or C-BASS. Results will have immediate utility for management institutions including those involved in regulating GoM fisheries and protected species. Scaling up a mapping program for the wider GoM would significantly affect the ability of management agencies to protect, conserve and restore high-value habitats essential to long-term sustainability of GoM living marine resources, in the face of existential threats to them, including future oil spills.

Cold-water Corals as Indicators of Anthropogenic Impact in the Deep Sea: Lessons Learned from the Deepwater Horizon Oil Spill

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After the Deepwater Horizon oil spill in 2010, 3 impacted coral communities were discovered. When the first community was discovered 3 months after the well was capped, corals were covered in a brown flocculent material (floc) that contained traces of oil, directly linking the observed damages to the spill. 11 months later, the other affected communities were discovered and, although corals were no longer covered in floc, the characteristic patchy impact distribution on the colonies, only observed at the first site discovered, indicated that these corals had also been impacted by the spill. We developed a method to quantify the impact and assess the recovery of deep-sea corals in the Gulf of Mexico using high-definition photographs. *Paramuricea* spp. colonies, well suited for visual monitoring due to their morphology, were imaged and digitized every year between 2011 and 2017. Overall, recovery was extremely slow. Improvements in condition between every consecutive years was negatively correlated with the initial level of impact. Furthermore, branch loss was still significantly higher at 2 impacted sites over the last year than at the reference sites. Using this method, we were also able to measure *in-situ* growth rates and found that growth was negatively affected by the level of impact. Because their skeleton is attached, almost entirely covered with living tissue, making potential damage easily detectable, and natural mortality is an extremely rare event, deep-sea corals are reliable indicators of anthropogenic impact in the deep sea, in particular when stressors are not visible in the environment (e.g. floc on corals). The method we developed allows the detection of small changes in the health of coral colonies that would not be visible with monitoring based on transects. Therefore, we suggest the establishment of photo-based coral-monitoring sites as part of protected areas to detect and limit future anthropogenic impact to these vulnerable deep sea ecosystems.

Restoration Planning for Mesophotic and Deep Benthic Communities by the Deepwater Horizon Open Ocean Trustee Implementation Group

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This presentation will describe a suite of activities that comprise an incremental and iterative approach to understanding and restoring mesophotic and deep benthic communities (MDBC). These activities are intended to implement the restoration strategy called for in the DWH Programmatic Damage

* Student presenter

Assessment and Restoration Plan and Programmatic Environmental Impact Statement (PDARP/PEIS). As described in the PDARP/PEIS, restoration for these resources is complicated by a limited understanding of key biological functions and limited experience with restoration at the depths at which they occur. Therefore, a phased restoration approach for these resources would allow for data collection to address critical uncertainties and inform adaptive decision-making. The suite of activities together creates an adaptive management feedback loop by advancing restoration planning, implementing initial restoration actions, monitoring restoration actions, evaluating restoration effectiveness, feeding back information to restoration planning and implementation, refining restoration implementation, and reporting on restoration progress toward meeting restoration goals and objectives. The emphasis on monitoring and adaptive management in the PDARP/PEIS also reflects the need for additional information about these communities to inform or augment ongoing efforts to protect and manage them.

Deepwater Horizon Early Restoration Phase IV, Sea Turtle Restoration Project Status Update

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The Deepwater Horizon Trustees and BP approved a \$45M, 10-year sea turtle early restoration project to begin to restore Gulf of Mexico sea turtle populations affected by the Deepwater Horizon oil spill. NOAA, DOI, and the state of Texas are responsible for implementation. The project has four components that address threats to sea turtles on nesting beaches and in the marine environment: Kemp's Ridley Nest Detection and Enhancement, Texas Enhanced Fisheries Bycatch Enforcement, Gulf of Mexico Shrimp Trawl Bycatch Reduction, and Enhancement of the Sea Turtle Stranding and Salvage Network and Development of an Emergency Response Program. We are now two years into the project and the project teams are pleased to share some of our successes and challenges from the past two years, as well as projected milestones for the next 8 years. Join us as we discuss project management, resource management, and working across a large region.

An Overview of the Deepwater Horizon Trustees' Strategic Frameworks for Restoration of Sea Turtles, Marine Mammals, Oysters and Birds

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The Deepwater Horizon Natural Resource Damage Assessment Trustees developed a set of strategic frameworks to assist with restoration planning for this case. The frameworks guide prioritization, sequencing, and selection of projects in future Trustee Implementation Group (TIG) restoration plans. Teams of Trustee scientists and resource experts developed these frameworks for oysters, birds, marine mammals, and sea turtles. The strategic frameworks include project concepts for consideration, but specific projects will be selected by the TIGs during the restoration planning process. These frameworks are intended to promote information sharing and coordination across the TIGs and across the restoration types, as well as guide planning, implementing, and monitoring restoration activities.

North Breton Island Early Restoration Project

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North Breton Island is being restored under a contract to the U.S. Fish & Wildlife Service (USFWS) as part of the Deepwater Horizon Oil Spill Natural Resource Damage Assessment and Restoration (NRDAR) process. Currently, the project scope includes permitting, investigation, and construction design and planning. This project is within the Breton National Wildlife Refuge (BNWR) and is owned and operated by the USFWS National Wildlife Refuge System. The design will restore beach, dune, and back-barrier marsh habitats within the island platform's footprint to support breeding birds, including brown pelicans, terns, skimmers, and gulls. Under the USFWS's oversight, the project team is collecting, compiling, analyzing, and managing topographic, bathymetric, sub-bottom, and magnetometer data of the island and the target borrow area and associated conveyance corridors, access channels, and project fill areas. The team is also providing geotechnical, environmental, and cultural resource investigations in the target borrow area and within the project fill area and developing strategies to resolve potential conflicts with land rights, oyster leases, and oil and gas infrastructure. North Breton Island construction design includes; approximately 76.2 acres (16,000 linear feet) of beach, 138.7 acres of dune, 137.3 acres of back barrier marsh habitat, a total island width of 1,100 feet, bounded by sloped foreshore and back barrier marsh platforms (optimum slope to be determined), an elevated dune platform of 8 to 10 ft. above sea level (optimum elevation to be determined through engineering and design) by 400 ft. wide at the base and 100 ft. wide at the top, a gulf-side beach 3 feet above sea level by 200 ft. wide, a landward back barrier marsh platform approximately 3 ft. above sea level and 500 ft. wide, and a targeted borrow area of approximately 677 acres. Construction is planned to begin in late 2018.

Soil Binding Ability of *Spartina alterniflora*, Smooth Cord Grass, Established on Dredged Soils in Louisiana Coastal Area

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Several researches indicate that vegetation protect the coast from erosion by providing soil reinforcement, wave buffering, sediment trapping and overall hydrologic regime control. However, the complex nature of coastal erosion process makes it hard to quantify the erosion resistance provided by vegetation. This research is focused on the study of soil binding ability provided by smooth cord grass, *Spartina alterniflora*, flourishing in dredged soil of Sabine Refuge Marsh Creation Project. Field vane shear test was conducted to obtain the in-situ un-drained shear strength of soil vegetated by *Spartina alterniflora*. Direct shear tests on the rooted soil samples collected from the site were performed to investigate the overall effects of roots on the shear strength of the soil. Laboratory tensile strength tests of the roots of plant was done. Two different root reinforcement models were used to study the correlation between the root-induced cohesion, C_r , and the root tensile strength. The first model, Wu et al. model, assumes that the tensile strength of all the roots crossing the shear plane is fully mobilized and all the roots break at the same time. The second model, Fiber Bundle Model, assumes that since roots have different strength values, they break at different points as a load is applied to the soil. Results from the vane shear test and the direct shear test reflected that the roots of *Spartina alterniflora* significantly increases the shear strength of soil. The increased shear strength for a location

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varied depending upon the root area ratio (RAR), depth of the soil sample and tensile strength of roots. Analysis using both the root reinforcement models shows overestimation of root induced cohesion and a new co-relation was proposed.

Effect of Restoration on Recovery of Coastal Salt Marshes Impacted by the Deepwater Horizon Oil Spill

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We have conducted a 3-year field restoration/remediation study in northern Barataria Bay, Louisiana. We established 20 field plots along marsh shorelines that were heavily oiled by the Deepwater Horizon oil spill and in which no vegetation recovery had occurred. We investigated two important approaches to promote marsh recovery in a factorial design: (1) by planting *Spartina alterniflora* or without planting and (2) fertilization with or without controlled release N-P-K fertilizer. The planting significantly increased live aboveground biomass of *S. alterniflora*, total plant aboveground biomass, live plant belowground biomass in surface soil and total live belowground biomass in the soil from the surface to 36 cm depth. Natural recruitment of *Distichlis spicata* and *S. alterniflora* occurred during the study period. Fertilization significantly increased total live plant aboveground biomass, which was primarily due to the increase in live aboveground biomass of *Spartina*. Interestingly, effect of fertilization was species-specific. Fertilization significantly increased live aboveground biomass of *S. alterniflora*; however, it did not significantly affect *D. spicata*. In addition, fertilization significantly increased the total live belowground biomass compared to the no-fertilization treatments. Moreover, the planting and fertilization significantly increased the surface soil shear strength. Therefore, the planting and fertilization potentially accelerated marsh recovery and enhanced marsh soil stability.

Physiological Resilience to Salinity and Hypoxia in Subadult Gulf Brown Shrimp (*Farfantepenaeus aztecus*)

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Shrimp support one of the largest commercial fisheries in Louisiana and across the northern Gulf of Mexico, with Louisiana's inshore and offshore fisheries catching 28.0 million pounds of brown shrimp (*Farfantepenaeus aztecus*) alone in 2015. Brown shrimp have an annual life cycle and rely on nearshore wetlands as nursery habitats for growth and survival during their juvenile and subadult life stages. Environmental stressors in these areas, such as increased freshwater input and hypoxia, have been shown to influence subsequent annual fishery yield. Characterizing the environmental susceptibility of brown shrimp during these life stages is essential for predicting future habitat viability and appropriate management strategies. Previous studies have shown that brown shrimp can tolerate a wide range of salinities with no decrease in survival. However, the effects of hyper- and hyposalinity on underlying physiological performance are unknown. Here, we acclimate subadult brown shrimp to salinities of 10, 15 and 20 ppt for 72 hours and examine the effect on their critical oxygen partial pressure (Pcrit), defined as the environmental oxygen concentration needed to support individual routine metabolic rate. Our results show that brown shrimp express a low Pcrit (0.8 mg/L) and therefore an inherent capacity for hypoxia tolerance. Further, changes in salinity had no effect on Pcrit in this species. These

findings are in contrast to previous studies conducted in fishes and support brown shrimp's ability to occur and function across a wide range of salinities. Our study suggests that large fluctuations in salinity (for example, through the creation of diversions) will not negatively impact subadult brown shrimp inhabiting nearshore wetlands or overall production of the brown shrimp industry.

Why Were Saltmarsh Species Assemblages So Resilient to the Deepwater Horizon Oil Spill?

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The 2010 Deepwater Horizon oil spill released approximately 210 million gallons of oil into the Gulf of Mexico, impacting all ecosystems in the region. There was a clear signal of oil exposure in individuals across many taxa, lab experiments have shown oil to be a stressor that leads to physiological responses in vital rates, and there were changes observed in lower trophic level communities. Together this indicates a strong potential for population declines of commercially and recreationally valuable fishes and aquatic invertebrates. However, there has been little evidence of population declines for those species, and in some cases, brief increases were even observed. Several hypotheses have been proposed to explain this apparent paradox. These include a fishing moratorium that occurred the summer after the spill, changes in predation pressure, the existence of alternative trophic pathways, and strong density-dependence. To study these possible mechanisms for population resilience, we built a small food web model around blue crabs (*Callinectes sapidus*), a key saltmarsh species due to both its commercial value and high level of connectedness within the marsh community; blue crab is either a consumer or prey resource of most saltmarsh species at various points in its life history. We used this model to test the necessary strength of each hypothesized mechanism to maintain population abundance, despite oil-induced changes in vital rates. We conducted these analyses under high and low sensitivities of vital rates to oil. Food web resilience to oil spills is not unique to the Deepwater Horizon, and this work tests possible mechanisms for such resilience so that we can better anticipate how ecological communities may respond to future spills or other pulsed environmental disturbances globally.

Oxygen Oscillation Effects on Microbial Community Activity and Nitrogen Metabolism in Oil Contaminated Beachsands

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Following the 2010 Deepwater Horizon blowout, large sections of the intertidal zones along the Gulf of Mexico became contaminated as oil slicks rode in on high tides. This oil was subsequently trapped in sediments as tides receded. Oxygen levels in intertidal zone sediments fluctuate in accordance to tide but their effects on microbial activity and oil-degradation rates remain essentially unknown. Advancing these issues will be important for better predicting and modeling microbial oil biodegradation in beach sands. The primary objectives of this study were to determine the effect of oxygen oscillations on buried oil hydrocarbon degradation in the sediment and nitrogen (N) cycling, an important function of

* Student presenter

a healthy ecosystem that controls the fate of an often limiting nutrient (N) for oil biodegradation. For this, advective-flow chambers that mimic well *in-situ* pressure gradients in saturated beach sediments were inoculated with weathered Macondo oil; un-inoculated chambers served as controls. Microbial oxygen consumption, coupled to oil biodegradation proceeded until anoxic conditions prevailed. The chambers were then re-aerated to full oxygen saturation levels in order to simulate an oxic-anoxic cycle. The effects of the cycle on hydrocarbon degradation kinetics, nitrogen fixation and bacterial community shifts were quantified using mass spectrometry analysis for quantification of hydrocarbon depletion coupled with metagenomics and metatranscriptomics. Our preliminary results revealed increasing rates of oil hydrocarbon biodegradation after repeated oxic-anoxic cycles and a key role of nitrogen fixation in this process.

RMP-003: Fisheries Science and Management Tools for Recovery and Restoration following Deepwater Horizon

Fish Stock Resiliency to Environmental PAH

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Fish muscle PAH content of continental shelf and deepwater of the SW GoM collected with two different gears was analyzed and related to gonad and liver histopathological analysis. Red Snapper and Yellowedge Grouper caught with demersal longline gear, from Yucatán to South Veracruz, showed a PAH muscle concentration that varied between 17-151 and 10-157 µg/kg with means of 59.2 and 53.1 µg/kg, respectively. Highest PAH muscle concentrations were found in three areas related to oil extraction, seeps and the influence of the Loop current (South of Veracruz, Oil Platform Exclusion zone and off Yucatán). Deepwater fishes collected with a trawl net, showed a PAH muscle content between 150-1516 µg/kg with a mean of 490 µg/kg. Highest muscle concentrations were associated to high sediment PAH values. Muscle PAH values were significantly higher in deepwater fishes than Red Snapper and Yellowedge Grouper. Fish gonad were found healthy in 90 % of Red Snapper and Yellowedge Groupers, whereas in deepwater fish 80% were with no lesions. Conversely, fishes showed a high incidence of liver damage in continental (80%) and deepwater area (90%). Hepatic damage degree shows an apparent relationship with PAH muscle concentration, but gonad lesions do not. PAH environment concentrations seems mostly to affect liver condition, but not gonad state. Previous data obtained in the oil platform area in the SW GOM showed that fish hepatic damage frequency can be influenced by chronic and episodic exposure to PAH. Apparently, exposure to episodic events of high PAH levels may increase the impact on fish liver condition. The effect on reproductive potential and fish stock resiliency to PAH content in the GoM is discussed.

Restoration Strategies Following Open Ocean Oil Spills: Potential for Stock Enhancement of Apex Pelagic Fish Species

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In the wake of the Deepwater Horizon (DWH) oil spill a number of restoration strategies have been proposed and implemented. Many of these restoration programs have focused on coastal resiliency, recovery of nearshore natural resources, and assistance to coastal communities impacted by the spill. However, relatively few strategies have been implemented to directly address the documented loss of apex pelagic fish species aside from fishing area closures in the months during and after the spill and limited fishing mortality reduction measures. The potential benefits of stock enhancement programs for coastal species are well known, and many such programs have been implemented following marine oil spills. Reasons for the lack of any such programs for apex pelagic fish species, such as mahi-mahi (*Coryphaena hippurus*) and tuna (*Thunnus* spp.), are complex and will be discussed. Research funding following the DWH incident has allowed for unprecedented research on the GoM ecosystem, including on a number of high-value pelagic fish species in the region. Findings from such research have not only increased our understanding of crude oil impacts to a variety of life stages of high-value apex pelagic fish species, but have also opened the door to potential methods for successful stock enhancement of such species. Through advancements in aquaculture technologies, ecophysiological research, bioenergetics, and tracking technologies it is now possible to execute and quantify stock enhancement of these species. The potential benefits of such programs are numerous, not only for restoration of pelagic ecosystems impacted by open ocean oil spills, but also for recovery and resiliency of coastal communities that are reliant upon the ecological services provided by healthy and abundant fish stocks in the region. This research was made possible by a grant from The Gulf of Mexico Research Initiative. Grant No: SA-1520; Name: Relationship of Effects of Cardiac Outcomes in fish for Validation of Ecological Risk (RECOVER).

Developing a Holopelagic *Sargassum* Habitat Index for Fisheries Management in the Northern Gulf of Mexico

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Holopelagic *Sargassum* (*natan/fluitans*) is widely considered to be an important nursery habitat for the early life stages of many fish species in the northern Gulf of Mexico (nGOM), including several federally managed species, such as Greater Amberjack (*Seriola dumerili*), Mahi Mahi (*Coryphaena hippurus*), and Gray Triggerfish (*Balistes capriscus*). *Sargassum* has been designated an Essential Fish Habitat in the South Atlantic, but currently does not have this status in the nGOM, and a quantitative assessment of its nursery role function is lacking. Larval abundance data for managed fish species associated with *Sargassum* may prove to be a valuable index of stock size, however, the relationship with *Sargassum* may confound estimates of larval (and juvenile) abundances in the nGOM due to its ephemeral nature caused by storms, currents, and other oceanographic factors. The Southeast Area Monitoring and Assessment Program (SEAMAP) surveys have recorded the abundance and distribution of *Sargassum* collected in ichthyoplankton sampling gear since the early 2000s. Here, we use the *Sargassum* data collected during SEAMAP ichthyoplankton surveys to create a habitat index for population assessments of several fisheries species in the nGOM. A yearly and seasonal *Sargassum* index was created from abundance data gathered in neuston tows from 2006 - 2017 using a delta-lognormal model. The index

was compared to the recruitment index created for Gray Triggerfish in GOM stock assessments to determine the relationship between yearly/seasonal amounts of *Sargassum* habitat and stock size of Gray Triggerfish. The habitat index can provide information that will be useful in 'tuning' stock assessments of Gray Triggerfish and other managed species that utilize *Sargassum* during a portion of their life history.

Juvenile Assemblages of Families Lutjanidae and Serranidae in the Gulf of Mexico, with Respect to the Loop Current and other Hydrographic Features

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The Gulf of Mexico (GoM) is a dynamic environment with a variety of oceanographic processes taking place. These features include; the Loop Current, cyclonic and anticyclonic eddies, and the Mississippi River Plume. These features were directly responsible for the extent to which the Deepwater Horizon Oil Spill (DWH) spread throughout the Gulf and are important drivers of the biological processes within the GoM. The relationship these features have on the long-term community assemblages of Families Lutjanidae and Serranidae has been of great interest from both biological and economic standpoints. These families represent some of the most economically important fisheries in the GoM. Identifying the role these features play in the transportation of larval and juvenile nearshore species to offshore environments is vital to resource managers. Using historical data collected shortly after the DWH Oil Spill via the NOAA Natural Resource Damage Assessment (NRDA) in 2011, the faunal composition and abundance of these families were analyzed. In conjunction with these data, cruises conducted by the Deep Pelagic Nekton Dynamics of the Gulf of Mexico (DEEPEND) Consortium from 2015-2017, were analyzed to identify any changes in faunal composition in an attempt to characterize what oceanographic processes affect these assemblages. In comparing these two studies, we have identified seasonal differences in the faunal composition and abundance of these two families within the pelagic environment. Ontogenetic changes were also observed in the genus *Pristipomoides* of family Lutjanidae, where high numbers of larger individuals who were found far from suitable habitats. This suggests an increased ability to remain in the pelagic ecosystem and stall the settling process until a suitable habitat can be found.

Predicting and Quantifying Spatial Distribution of Fish Populations in the Gulf of Mexico Based on Habitat Characteristics

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Understanding the spatial relationship of fish populations to the habitats they occupy is an important prerequisite for designing management measures. Coral reef associated habitats can be broadly defined to include not only areas that contain live coral cover, but also associated habitat types such as seagrass beds and sand flats. These varying habitats associated with coral reefs, and the diversity of rugose structure (i.e. three-dimensional structure of reef building corals) they provide, is thought to provide a range of habitat options for reef associated fish species. The benthic environment of the Gulf of Mexico consists of ancient drowned reef carbonate platform, with crevices and solution holes, together with sand, mud and gravel. A thorough understanding of how fish populations are spatially distributed in the Gulf of Mexico is an important baseline to establish. Knowledge of the habitat niches

^{*} Student presenter

that fish occupy can be used to understand the effects of a natural disaster (such as an oil spill) on living marine resources, and can help managers properly maintain the sustainability of fish populations. This study combines fishery-independent video survey observations of reef fish gathered by NOAA Fisheries, together with habitat information to quantify how the two correlate. Habitat data is obtained from the dbSEABED dataset, a combination of numerous individual datasets, managed by the University of Colorado at Boulder. Generalized linear modeling and boosted regression trees are used to quantify this relationship. Model estimates are then used to develop predictive maps of fish spatial abundance across the entire Gulf within the U.S. exclusive economic zone (EEZ). In addition, this work will establish the linkages between reef fish in the Gulf of Mexico and that habitats in which they reside.

Statistical Methods for Spatial Analysis of Reef Fish Abundance in the Gulf of Mexico

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Understanding the spatial distribution of abundance is fundamental to assessing and managing ecological populations. Compared to species living on land, which can be observed more easily, quantifying the spatial distribution of fish is difficult due to low detection rates when sampling in the ocean. Video surveys of fish abundance are conducted annually over reef habitats in the Gulf of Mexico. However, the detection of species is sometimes sparse resulting in zero inflated data. This renders the data difficult to use for inferring the spatial distribution of fish abundance. As a result, we developed statistical methodology and a simulation model to address this problem. We simulated the video survey process over different hypotheses of species density, in order to infer the level of fish density that would need to be present in each sampling region to replicate the abundance counts observed in the video survey data. The maximum likelihood estimator was calculated using Monte Carlo simulation and the resulting maximum likelihood density in each sample region was statistically smoothed using random smoothing windows. Uncertainty was characterized using credibility theory and variance to balance sampling with modeling error. Grid cell abundance estimates below an *a priori* selected credibility tolerance level and above an *a priori* selected variance acceptance level, were rejected. This resulted in a series of clipped polygons, with high quality (high credibility, low variance) estimates of spatial abundance (labeled data), locally in areas where video sampling took place. Grid cell estimates in each final clipped polygon, were combined with habitat variables (independent predictors), in order to compute their quantitative relationship using models like multi-Linear regression or machine learning. This quantitative relationship was used to predict the spatial distribution of abundance in the Gulf of Mexico for species of management interest.

Simulating Fish Migration Trails in the Gulf of Mexico Using a Biased Random Path in Continuous Space

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Migration constitutes an essential part of the life history and ontogeny of reef fish. In the Gulf of Mexico, the movement of fish from shallow inshore nursery to deeper offshore areas reflects a change in habitat in response to animal growth. This sets up a general spatial pattern of smaller sized, younger individuals inshore, and older individuals offshore. Understanding the movement of reef fish in the Gulf

* Student presenter

of Mexico is important because the spatial distribution of fish in different size and age groups is spatially correlated with the location of recreational and commercial fishing activity. In this work we present an agent-based model that represents fish migration patterns using a dynamic continuous distribution of angles. The resulting algorithm produces migration paths which can follow any parametrically defined curve as a guide. The algorithm operates in continuous space and addresses downfalls associated with modeling animal movement as a random walk in discrete space. The algorithm is also generalizable to different fish species across a range of life history characteristics (i.e. from demersal reef fish to highly migratory tuna and billfish species). This is because the model is easily tuned using parameters that control the coarseness in fish path during migration, fish movement speed, and the variability with which fish wander from their *a priori* specified parametrically defined curve. Input parameters are estimated using tagging datasets. Simulated output is validated using pattern-oriented modeling against tagged fish observations that were not also used for model parametrization. Findings suggest that the algorithm generates plausible fish movement pathways and delivers fish to fishing grounds at the appropriate size, age, time, and location. The algorithm is one component of a larger agent-based model that addresses the effects of the Gulf oil spill on reef fish, the fishing fleet, and how the two interact.

Fishery Closure Areas following the Deepwater Horizon Oil Spill - Revisited

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Following the Deepwater Horizon (DWH) oil spill, vast areas in the Gulf of Mexico were closed for fishing to ensure sea food safety. The decision upon which areas to close encompass a careful tradeoff between public safety, and the welfare of the fisherman communities who suffer economic losses. The size and location of closures was dynamically determined by the National Oceanic and Atmospheric Association (NOAA) according to the estimated oil slick locations using to areal imaging, and 2D hydrodynamic modeling. However, studies have revealed that (1) the oil released from 1522 m has a dynamical 3D structure in the water column, and (2) the coverage area of the detected surface oil slick dramatically decreased (~50%) following Hurricane Alex, (June 28-30, 2010). In addition, some GoM fisheries target demersal species inhabiting the slope of the continental shelf. In the current work, we combine spatio-temporal analysis of the BP Gulf Science Data together with hydrodynamic hindcast modeling of the oil transport from the DWH blowout to assess the degree to which the areal imaging and the fishery closure areas captured the actual 3D dispersion of oil in the field. Our analysis indicates that, in contrast to the areal imaging, oil mass did not decrease following Hurricane Alex. Indeed, samples with high oil concentration were found in the subsurface and outside the closure areas. We suggest that the delicate tradeoff between fisherman welfare and public safety requires a more accurate assessment of oil transport, taking into account subsea oil, which can be mixed by wind and wave action and is invisible to areal imaging.

Deepwater Horizon Oceanic Fish Restoration Project: Updates and Lessons Learned after Completing the Pilot Year

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The Deepwater Horizon oil spill injured vast quantities of oceanic fish representing a broad range of taxa. Many species of injured fish have little or no affinity to coastal habitats, making habitat restoration for such species impossible. Instead, one early restoration project has focused on reducing bycatch in the Gulf of Mexico pelagic longline fishery. By partnering with longliners to stop using pelagic longline gear during the bluefin tuna spawning season and instead use two alternative gear types, greenstick and buoy gear, the Trustees have estimated that hundreds of thousands of kilograms of fish, e.g., bluefin and yellowfin tuna, swordfish, lancetfish, could be restored for. After the pilot year of implementation, the project team has developed a process to incorporate and account for feedback and lessons learned. Our presentation will discuss the monitoring and feedback used to develop implementation alternatives, explore the success and realizations learned during the first year, and explain the challenges that the team faced. Having systems in place to monitor and adaptively manage novel restoration types/projects may be critical for ensuring restoration success in offshore environments.

Quantifying and Comparing Fisher Decision-making Strategies Before and After the Deepwater Horizon Oil Spill

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The Gulf of Mexico (GOM) large marine ecosystem is characterized by fishery resources which spatially and temporally overlap in different ways with several important non-fishing uses including oil and gas production, shipping, tourism, habitat for endangered species, and economic support for coastal communities. During the Deepwater Horizon Oil Spill, the overlap of oil and gas ecosystem services with fishing activity, led to unintended consequences to the fishery. Vessels that target reef fish endured large scale spatial closures of oil contaminated waters to protect human health, public mistrust in GOM seafood quality, and in some cases, repurposing of their vessel to assist with clean-up efforts. Understanding the spatial distribution of fishing activity is important for assessment and management because data provided by fishing vessels are used in assessments to infer fish population abundance. When, where, and how a commercial vessel fishes determines the temporal and spatial placement of the data they are mandated to report. This study quantifies how the effects of the Deepwater Horizon Oil Spill may have affected daily fishing vessel decisions about participation, site choice, and trip termination. Commercial fishing vessel logbook data were used, in conjunction with state variable data such as weather, fuel price, fish price, etc. to develop a panel dataset. Discrete choice models were fit to participation, site choice, and trip termination decisions for years before, during, and after the oil spill. The study looked at how fishers may have altered their behavior, and whether behavioral responses from the oil spill became permanent new behaviors. Results are discussed in the context of oil spill response efforts, and implications for fishery assessment, regulation and sustainability.

The Impacts of the 2010 Deepwater Horizon Oil Spill on the Gulf Fisheries and Tourism Industries

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What were the impacts of the 2010 Deepwater Horizon (DH) oil spill on the Gulf fisheries and tourism industries? In this paper, we conduct an ex-post analysis of how the fishing industry responded to the spill in both the short and medium run, using detailed data on landings and fishing effort for select species in Louisiana. We also draw on publicly available data to examine how the impacts to fisheries were transmitted up the supply chain, to the seafood processing industry, and to assess the impacts on tourism-related industries in the Gulf. A key contribution of our work is that we apply causal inference methods from the econometrics literature in order to disentangle the impacts of the spill from the longer-term trends in the fisheries, seafood processing and tourism industries in the Gulf, and discuss the dynamics of the shock and recovery path. In addition, our estimates shed light on the extent to which impacts to the fishing industry were due to changes in biology versus changes in fisher behavior.

Are More Explorative Fishing Vessels Less Vulnerable to Disturbance?

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Decision-making agents ranging from financial investors to foraging birds are faced with a trade-off between exploration of the system and exploitation of current knowledge. While exploration generates new knowledge, it can fail to deliver the tangible benefits that could have been gained by instead exploiting current knowledge. However, exploitation also comes at a cost, as eschewing new knowledge can result in lost opportunities and diminished resilience to shocks if habitually exploited system space becomes unavailable. Although experimental trials indicate that people tend to occupy consistent niches within the exploit-explore trade off (EETO), few human field studies have investigated the real-world consequences, if any, of being more or less explorative. Here we ask whether exploration actually confers its putative advantages, using human mobility datasets comprising >540,000 GPS locations and corresponding catch revenues of 112 anonymised Gulf of Mexico commercial fishing vessels during a period interrupted by a major disturbance event. We quantify the entropy of each vessel's mobility pattern as a measure of explorativeness and find that more explorative vessels incurred higher costs prior to the disturbance but gained no performance advantage. During the disturbance, however, we find that more explorative vessels performed significantly better and were more likely to remain in the fishery. Our results provide strong empirical support for some (but not all) of the conjectural costs and benefits of exploration in a large-scale natural setting, with participants performing a task that is strikingly similar to the foraging context within which the human EETO-mediating apparatus would have evolved. As mobility datasets burgeon and natural disturbances increase in frequency, we anticipate that our work may stimulate research on which agent-level attributes, such as vulnerability to disturbance or tolerance of risk, may be inferred from mobility patterns.

Social and Ecological Resilience

SER-001: Fostering Individual, Social, and Community Resources to Build Resilience to Oil Spills and Other Disasters in the Gulf

Understanding Social Capital's Effects on Health: Opportunities for Resilience Activation in the Gulf Coast Region

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Research on community resilience consistently points to social capital as an adaptive capacity that can activate resilience during disasters. However, social capital is an amorphous term, variously conceptualized across literatures. In this study, we examine the effects of three major social capital indicators used in different veins of literature—trust, participation in local organizations, and social network support—on the mental and physical health of Gulf Coast residents six years after the Deepwater Horizon oil spill (DHOS). Drawing on data from the Survey of Trauma, Resilience, and Opportunity among Neighborhoods in the Gulf (STRONG), preliminary analyses suggest that, after controlling for exposure to the DHOS and sociodemographic factors, social capital indicators are generally associated with positive mental and physical health outcomes among Gulf Coast residents, though not all social capital indicators have a significant effect on health outcomes. These findings contribute to the existing literature on the ameliorative effects of social capital after disasters while complicating the often undifferentiated usage of the term social capital. Disaster researchers and practitioners should be cognizant of these different capacities when communicating with organizations involved in long-term disaster recovery.

Building Disaster Resilience with Community Health Workers

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Community Health Workers (CHWs) can play a pivotal role in building community resilience in anticipation of the next disastrous oil spill. As trusted members of their communities who “speak the language” of the people served, they enjoy high levels of legitimacy and credibility. This gives CHWs significant advantages in promoting disaster preparedness, publicizing needed resources, and serving as intermediaries between emergency managers and community members. However, it is through their ongoing daily activities that CHWs may have the greatest potential to build resilience by enhancing the overall health of their communities. These activities include conducting educational outreach, expanding access to healthcare and social services, and supplementing health professionals in clinical settings, all of which can contribute significantly to community health. To what extent do CHWs actually participate in these activities? As part of the Consortium for Resilient Gulf Communities and the Gulf Region Health Outreach Program, the University of South Alabama’s Coastal Resource and Resiliency Center (USA-CRRC) has collected the data needed to answer this question. USA-CRRC currently has seven CHWs placed in health clinics and community-based organizations in three

* Student presenter

communities affected by the Deepwater Horizon Oil Spill. Between May 1, 2016, and June 30, 2017, these CHWs completed 2,749 client interaction forms recording 6,266 services provided to community members. These services range from conducting health fairs to collecting vital signs to signing up patients for Obamacare. An accounting and review of these data confirm that CHWs are making major contributions to improving community health, especially among vulnerable and under-served populations, thereby enhancing disaster resilience in their communities. These findings confirm a priori expectations regarding the utility of CHWs and point to the need for intervention research to demonstrate this utility more broadly.

Time after Time: A Case Study in Longitudinal Disaster Survey Research Protocol in South Louisiana

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South Louisiana is home to diverse communities and a vibrant blend of culture, livelihoods, and identity. Over the past two decades, this region has experienced numerous natural and technological disasters-- hurricanes, catastrophic flooding, and the Deepwater Horizon oil spill (DHOS). Rebuilding and rebounding after these events is a process that unfolds at the individual, family, community, and state level over many years. Studying social processes and effects alongside these efforts often involves a longitudinal approach by evaluating a cohort over time. This paper provides a methodological case study of the second wave of data collection as part of the Resilient Children, Youth, and Communities (RCYC) project to explore efficacy in field technique, technology, and protocol. RCYC is a longitudinal study of over 480 households with children living in highly impacted areas of Louisiana at the time of the DHOS. Over a nine-month period from October 2016 through July 2017, interviewers conducted face-to-face surveys achieving a 74% retention rate with a 94% cooperation rate between the end of this wave the initial recruitment in 2014. Respondent engagement becomes increasingly difficult as distance increases—in time, place, and psychology—from the disaster onset and as result special considerations should be made during outreach and re-interview. Field staff were equipped with tablets to allow both on-line and off-line access to respondent databases, the survey instrument, and field team communications. Data collections systems were created to help reduce systematic error while also providing for quality control and assurance. We will discuss crucial elements in personnel management including hiring interviewers on a rolling basis and ongoing training to support flexibility and accountability as well as ideal field staff characteristics. With regard to respondent re-engagement and tracking, we will discuss how multiple methods of outreach were leveraged throughout the various stages of field effort. In addition to common strategies for retaining respondents in longitudinal survey work, we will discuss more nuanced methodologies to improve respondent retention and tracking/tracing based on findings from this field effort.

Community Resilience, Experience, and Perception as Factors Associated with Disaster Preparedness Among Coastal Mississippi Residents

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Disaster preparedness is a complex condition influenced by many factors, including resilience, social capital, past experience, and perceptions of risk. This study was conducted in 2017 by an

interdisciplinary research team from Geography, Social Work, and Public Health at the University of Southern Mississippi. The team administered a survey to a spatially-stratified, random sample of Mississippi residents living south of Interstate 10 in close proximity to the Gulf of Mexico (N=328). The survey included the Communities Advancing Resilience Toolkit (CART) instrument, as well as Likert-scale questions devised by the team that focused on past experiences with disasters, perceptions of risk, and reliance on social support networks, as well as actual (e.g. knowledge of evacuation plans, possession of emergency kits) and perceived levels of preparedness of respondents. Multivariate regression revealed that the five CART domains and past experience with hazards predicted reliance upon social networks and actual preparedness of survey respondents. Likewise, actual preparedness, reliance on social networks, and past experience with hazards predicted perceived preparedness. These results corroborate previous findings of the team and published research about the importance of past experience in disaster preparedness. The results are also of value to emergency management policy makers and practitioners in that they highlight factors that might help to better identify preparedness and mitigative behavior among coastal populations in the Greater Gulf of Mexico.

Experience with Past Disaster: Influences on Impact from and Preparation for Future Disasters

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As the Gulf Coast is disproportionately impacted by disasters and these disasters are expected to increase in both frequency and intensity, it is important to understand the individual-level impacts of multiple disasters over time. In this research we assess the influence of a previous disaster on preparation for a future disaster, on one's degree of negative impact from a subsequent disaster, and on feeling prepared for a future disaster. To this effect, we conducted a random digit dialing phone survey (n=712) of residents living in counties impacted by one of three case disasters: the Deepwater Horizon Oil Spill, the Mississippi River Flooding in the Delta Community, and the Tuscaloosa Tornado. We asked respondents about their preparedness for and impact from one of these three disasters, but also asked about their previous experience with tornadoes, hurricanes, earthquakes, fire, flooding, chemical spills, or other disasters. Using OLS regression models for each of the three disasters and controlling for age, income, race, education, and gender, we find that in regards to the relationship between prior experience with a disaster and feeling prepared for the disaster of interest, prior experience is only statistically significant for those who had been through a tornado and were also affected by the Tuscaloosa Tornado ($r=.88$, $p<.05$). To assess the relationship between prior experience with a disaster and one's reported level of negative impact from the case disaster, we again used OLS regression models for each of the three disasters and controlled for demographics, but did not find any significant effects. In similar models assessing the relationship between prior experience with a disaster and how prepared one feels for future disasters, we again did not find any of the prior disasters to be statistically significant. Finally, in exploring the relationship between feeling prepared from the case disaster, negative impact from the case disaster, and feeling prepared for a future disaster, we regressed these three variables on each other using each as the dependent variable of a model. We found that people who felt prepared for the case disaster also feel prepared for a future disaster, but that negative effect from the case disaster was not a factor in this relationship.

The Role of Perception in Anthropogenic and Natural Disaster Preparedness

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Social capital, especially localized support, contributes to individual and community resilience. Perceived preparedness for future disasters may also be an important factor influencing an individual's—and more broadly a community's—resilience. Improving the perception and practice of preparedness should therefore be viewed as a mitigation strategy. Mitigation to future disasters typically centers on improving protective infrastructure and ensuring safety plans are updated. While this type of mitigation is necessary and should be of growing concern, human and social factors need to be considered to more holistically understand building disaster resilience. An in-person, mixed methods survey was administered to approximately 300 individuals that reside in Port Sulphur, Galliano, and Bayou La Batre; all three areas were impacted by the 2010 Deepwater Horizon Oil Spill. Over 90% of the survey participants stated that they had never prepared for a large oil spill disaster, while over 95% of survey participants had previously prepared for a natural disaster. One of the quantifiable metrics of the survey was rating an individual's perception of preparedness to a future catastrophic event. Out of the interviewees, more than half believed their safety preparations would be very effective to protect members of their households. However, less than 25% believed their preparations would be very effective in limiting negative financial impact from a future disaster. Furthermore, results highlighted differing perceptions of preparedness to technological and natural disasters. This research provides a useful case study that can be utilized to further understand the link between individual perceptions and disaster preparedness. The work contrasts perceptions to anthropogenic versus natural disasters, which is necessary as many communities, such as those on the Gulf Coast, increasingly experience multiple kinds of disasters over relatively short periods of time.

Gender Differences in Resilience, Social Support, and Preparedness in Post-Disaster Settings

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Over the last five decades disasters have affected 6.9 trillion people and caused damages totaling US \$2.6 trillion. Natural and anthropogenic disasters affect and disrupt millions of people, indifferent to age, race, socioeconomic status. However, scant research has focused on how gender impacts resilience in post-disaster settings. Females may be especially vulnerable following disasters, in large part due to family responsibilities and economic constraints, and susceptibility to domestic violence. Adding an explicit analysis of gender offers an important contribution to the body of literature looking at the impact of disasters. A face-to-face mixed-methods survey was administered to a total of 300 Gulf Coast residents in three communities in coastal Louisiana and Alabama to assess their resilience following the Deep-Water Horizon oil spill. Respondents were asked questions about their social networks, the economic and social impact of the disaster, their individual resilience, and their perceived preparedness for future disasters. Independent sample t-tests were conducted to analyze significant differences between male and female respondents. The sample was 57% female. Women reported higher overall individual resiliency scores compared to men. Compared to men, women reported being more worried about the continued impact of the spill, but reported larger and stronger social networks. Both men and women reported experiencing a similar amount of disasters, though men were more likely to report losing a job because of the oil spill. Women and men did not differ in

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future disaster preparedness or belief in the likelihood of another disaster. Though there is an increasing body of research investigating resilience, differences in resilience based on gender have been less explored. This research begins to address this gap and identifies differences in strengths and vulnerabilities, in addition to discussing implications for policy and social programs.

The Role of Place in Predicting Individual Resilience: Lessons from the Deepwater Horizon Oil Spill

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The 2010 Deepwater Horizon Oil Spill (DWH) was one of the largest hydrocarbon disasters in US history. The 4.9 million barrels of oil that poured into the Gulf of Mexico impacted the natural environment, as well as the lives of individuals and communities residing along the coastal region. While these communities share a common experience through their connection to the Gulf of Mexico, they vary demographically and socioeconomically. This paper explores place-based predictors of individual resilience among people exposed to disaster, presenting findings from a recently completed disaster preparedness and resilience study from three Gulf Coast communities impacted by the DWH Oil Spill. An in-person mixed methods survey was administered to a total of 300 residents from the Gulf Coast communities of Port Sulphur, LA, Galliano, LA, and Bayou La Batre, AL to determine their resilience to future hydrocarbon events. The dependent variable of individual resilience was measured using the ten-item Connor Davidson Resilience Scale. Multivariate regression was used to determine place-based predictors of individual resilience, including geographic location, location of social networks, previous experiences with natural and hydrocarbon disasters in the area, perceived likelihood of future disasters in the area, perceived consequences that the DWH Oil Spill had on one's community, willingness to relocate, as well as demographic and socioeconomic factors. According to the model, place-based factors contributed significantly to the variance in individual resilience. This study offers several important insights to inform policy, practice, and research in the area of disaster resilience. Specifically, the findings suggest more nuanced and targeted interventions in the areas of disaster response and preparedness may be needed to address the unique experiences and contexts of communities like the Gulf Coast that have disproportionately been affected by natural and hydrocarbon disasters.

The Deepwater Horizon Oil Spill - Predictors of Individual Resilience

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The Deepwater Horizon Oil Spill is regarded as the worst hydrocarbon disaster in the history of the United States. The impact from hydrocarbon disasters results in uncertainty for residents of affected communities regarding the immediate and long-term future, a situation exacerbated by social vulnerability and lack of equity. The DWH disaster provides an opportunity to gain scientific understanding of individual resilience within the context of hydrocarbon disaster events. The purpose is to present findings from a study on predictors of individual resilience in three natural resource dependent Gulf Coast communities (Port Sulphur & Galliano, LA and Bayou La Batre, AL) impacted by the DWH Oil Spill. An in-person mixed methods survey was administered to a total of 300 Gulf Coast residents. The outcome variable, individual resilience, was operationalized using the ten-item Connor

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Davidson Resilience Scale. A hierarchical multiple regression analysis indicated that loss factors explained 7% of the variance in individual resilience. Furthermore, protective factors explained an additional 12% of the variance in individual resilience above and beyond the variance explained by loss factors. The results identify several significant losses and protective predictors of resilience among residents. This study provides recommendations for future research, policy and practice and contributing new knowledge on hydrocarbon disaster resilience. With the increase in disasters and associated psychosocial impacts, the need to identify and support resilience attributes is crucial to enhancing equity and well-being for all those impacted by hydrocarbon disasters.

Measuring Social Media Use as a Source of Resilience During and After the Deepwater Horizon Oil Spill

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During the Deepwater Horizon Oil Spill in 2010, social media platforms provided a medium for current, local, detailed, and continuous flows of information on disaster conditions and community needs. After clean-up efforts concluded, communities located in southern Louisiana continued to use online platforms such as Twitter to engage in virtual discussions regarding long term health issues, while also interacting with other government and nonprofit stakeholders within the local health system. This presentation will address findings from a social media data analysis conducted by the National Center for Disaster Preparedness, Columbia University, and Louisiana State University on the ways in which online communication among the general public was carried out with policymakers, first responders and public health organizations and how the nature of this communication changed over the years in relation to the disaster. The investigators have examined more than 500,000 Twitter records, and will describe how the actions of highly-retweeted Twitter users have helped to impact public policy, and advocate for the emerging needs of socially vulnerable communities. Findings will also be linked to a parallel research effort for which investigators have been conducting face-to-face surveys with southern Louisiana household members to gather quantitative information about children's direct and indirect oil spill exposure; lasting physical, mental, and social health impacts; the household's economic constraints and access to healthcare; and the community's perceived recovery or deterioration. Given the tremendous presence of social media in modern life, and its great potential both to activate resilience and generate misinformation in disaster contexts, researchers and policymakers need to continually develop new mechanisms for monitoring, analyzing, and acting upon online communication.

Social Resources, Community Religiosity, and Depression among Gulf Coast Residents

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A widely established literature has demonstrated the importance of social resources in promoting resiliency among disaster-affected populations. More recent research, though, has shown that the contexts within which the provision of social support occurs may moderate its ability to promote resilience. Using data from a probabilistic survey of residents on the Gulf coast, we extend this vein of inquiry through multilevel analysis of community religiosity's moderation of the relationship between

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self-reported close social ties and depression. Our findings indicate that close social ties and depression are inversely correlated, but that the magnitude of this relationship varies relative to level of community religiosity. Further analysis suggests that religious theologies, such as those specific to Catholic and Mainline Protestant congregations, that promote bridging pro-social activities may be a key motivator of this effect. These results indicate that community contexts, including the social environment of religion, may exert influence on residents' mental health, and that local stakeholders should remain cognizant of community religious characteristics and their potential influences when planning disaster responses.

Financial Capability among Residents in the Gulf Coast after the Deepwater Horizon Oil Spill

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Economic disruptions are common after disasters, and ensuring the availability of emergency funds is a critical aspect of disaster preparedness. This study examines the financial capabilities of Gulf Coast residents from the Survey on Trauma, Resilience, and Opportunity among Neighborhoods in the Gulf (STRONG), a probability-based sample of 2,520 adult respondents weighted to generalize to the region. Less than half of the sample (48%) reported that they had set aside emergency funds that would cover their expenses for 3 months in case of sickness, job loss, economic downturn, or other emergencies. Thirty percent reported that they could probably not or certainly not come up with \$2,000 if an expected need arose in the next month; those who could come up with the money primarily would rely on savings (57%), would borrow from family or friends (14%), or would work more (14%). In addition to those with annual incomes of less than \$10,000, those 35-64, women, and racial/ethnic minorities were less likely to report having emergency funds than their counterparts. Finally, 48% of the sample reported that it was somewhat or very difficult to cover their expenses or pay their bills in a typical month, and as their self-reported difficulty increased, so too did their persistent worry about the ongoing impacts of the Deepwater Horizon oil spill. These results suggest that more than half of residents along the Gulf Coast, a region prone to hurricanes and oil spills, are economically vulnerable to large scale disasters. Regional policies and programs are needed to increase financial capabilities, especially in the face of unforeseen emergencies. This could also include training to bolster financial resilience (e.g., encouraging savings prior to a disaster, avoiding scams in the wake of disaster) and focusing attention to sub-populations that may be a greatest risk (e.g., racial and ethnic minorities).

SER-002: Measuring, Understanding, and Responding to Human Health Factors in the Wake of an Oil Spill

Strengthening Community Preparedness through the Long-term Perspectives of Louisiana First Responders Involved in the 2010 Deepwater Horizon Oil Spill

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Introduction: The 2010 Deepwater Horizon oil spill is considered the largest accidental marine oil spill in United States history. The spill had severe environmental impacts on the United States Gulf coastline as well as far-reaching effects on the health and safety of first responders. Louisiana firefighters participated in the rescue and clean-up activities along the coastline. Despite the magnitude of the oil spill, there is limited information documenting the long-term health and safety experience and perspectives of this workforce. **Methods:** Six focus group sessions (8-10 first responders in each session) were conducted in May 2017. Louisiana firefighters were consented and initially invited to complete a self-administered questionnaire, followed by a 60-minute semi-structured focus group session assessing perceptions of safety and health conditions related to the oil spill event. Focus group audio files were transcribed verbatim and analysed using a general inductive approach to identify emergent themes. **Result:** Study participants (n=50) were mostly male (98.0%), non-Hispanic (95.3%), white (98.0%) with mean age 40.6 years (standard deviation [SD]=9.8) and mean job tenure of 15.3 years (SD=8.2). During the oil spill, 56.3% of participants came into direct contact with oil, 36.7% visited a doctor after the spill, and 18.8% reported feeling musculoskeletal pain. Major themes that emerged included concerns regarding personnel decontamination procedures, heat-related illnesses, ocular disorders, fear of cross-contamination, and the unknown long-term health impact of chemical exposures from the oil spill. Firefighters expressed interest in additional safety training, specific knowledge as it pertains to dispatched response jobsite, and environmental monitoring necessary to protect their health. **Discussion:** Exposure to large-scale environmental disasters such as the 2010 oil spill have long-term effects on the physical health of first responders. Unregulated workweek hours, high job demand, uncertainty of jobsite exposure and low job control may contribute to poor health outcomes in this workforce. Strategies to engage first responders early in the response phase and monitor long-term health are needed.

Federally Designated Primary Healthcare Need as a Dimension of Resilience Following the Deepwater Horizon Oil Spill

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The BP Deepwater Horizon Oil Spill stands out as an industrial accident of unprecedented scale and ongoing impact. This study seeks to understand primary care healthcare need as a factor in understanding individual and family resilience. The primary care setting acts as a common “gateway” to mental health interventions, with many visits including a behavioral health concern. The Health Resource and Services Administration (HRSA), an agency of the US Department of Health and Human Services, defines a Medically Underserved Area (MUA) as a “geographic area with a lack of access to

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primary care services.” With consideration to vulnerability and resilience, we ask: Do children and families living in MUAs experience health needs and access differently in the years following the spill than those who do not? We use data collected as part of the Resilient Children Youth and Communities study—a face-to-face, longitudinal panel survey following over 480 parents with children living in affected Louisiana parishes at the time of the spill. This information will be analyzed alongside current HRSA data on MUA need and access. An exploration of the relationship between access to and availability of primary care health services and physical/mental health variables will contribute to a fuller understanding of need and its role in resilience in the face of industrial disaster.

Lessons Learned from the Louisiana Mental and Behavioral Capacity Project as a Post Disaster Service Model

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The Louisiana Mental and Behavioral Health Capacity Project (MBHCP-LA) led by the Louisiana State University Health Sciences Center Department of Psychiatry is designed to provide integrated mental and behavioral health care to largely rural communities covering vast geographic distances in Louisiana. As part of the Gulf Region Health Outreach Program (GRHOP), the project is working to meeting diverse needs and carrying out collaborative cross-site consultation and training programs. This presentation will describe the evolution and implementation of the multidisciplinary program. Over the past 5 years the MBHCP-LA has provided therapeutic and supportive services in health care clinics and community settings across Southeastern Louisiana. The combined approach allows the program to serve communities in remote areas of Louisiana where many residents have limited, if any, access to behavioral health services. In addition, these communities have repeatedly been exposed to disasters, such as Hurricane Katrina and the Gulf Oil Spill. Services have included direct patient care and education, including telemedicine; training and workforce development; community outreach; and school based services. An overview of success with services listed above will be presented and evaluation data from over 10,000 contacts will demonstrate program impact. Utilizing community participatory and culturally sensitive approaches, results from the program support the value of increased access to care and the importance of sustainability.

Applied Research with Integrated Behavioral Health Care: Sustainability of Disaster Response

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Integration of mental health services into primary care clinics is becoming the standard of care, and provides an opportunity to increase access to behavioral health care for underserved populations. The Louisiana Mental and Behavioral Health Capacity Project (MBHCP-LA), through the Deepwater Horizon Medical Benefits Class Action Settlement: Gulf Region Health Outreach Program, has collaborated with rural health care clinics to integrate behavioral health services with the goal of increasing capacity on a sustainable basis. The purpose of this presentation is to describe measurement of behavioral health service integration and reimbursement through use of best practice billing procedures. The current research was conducted as part of the MBHCP-LA evaluation protocol which began in 2012. Clinic data was analyzed from 1,472 clients using over 8,917 progress notes to improve the connection of patient

needs, services provided, and billing practices. Findings revealed areas where future integrative efforts should be directed. Results were used to develop a matrix of best practice billing procedures to further the Triple Aim of improving healthcare and reducing costs. Integration of behavioral health services has allowed for access to treatment in rural underserved areas following the Deepwater Horizon Oil Spill. Current findings support the goal of increased integration by connecting primary care practitioners with mental and behavioral health specialist. In addition, findings also provide a model for integrated health care that is related to both client and clinic needs. Sustainability is enhanced through electronic health records and population health outcome readiness.

Long-term Depression Rates among Adults Impacted by Hurricane Katrina and the Deepwater Horizon Oil Spill on the Mississippi Gulf Coast

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Background: Research has linked disaster experiences to depression and found that post-disaster depression rates can remain stable over time. The current study builds on this research by examining depression rates among Mississippi Gulf Coast residents across three survey administrations from 2010 - 2017. **Methods:** An interdisciplinary team of social work, geography, and public health researchers used spatially stratified sampling procedures to identify random households in the southernmost areas of the three Mississippi coastal counties. The sample consisted of adults who resided in close proximity to the Gulf of Mexico and experienced both Hurricane Katrina and the Deepwater Horizon oil spill. Although over 1,000 surveys were collected, this study included only those that moved from their homes either temporarily or permanently due to damage from Hurricane Katrina (N = 523). Survey administrations took place in 2010 (n = 190), 2015 (n = 194), and 2017 (n = 139). The survey included the Center for Epidemiologic Studies Depression scale as well as other demographic- and disaster-related questions. The predictor variables included race, gender, education, health insurance, living situation, and oil spill impacts. **Findings:** No significant differences were found among depression rates across the survey administrations, as they remained relatively stable at 30%, 27%, and 27%. The depression rate for the overall sample (N = 523) was 28.1%. Lower education attainment, lower household income, lack of health insurance, and minority race were significantly associated with depression across all three administrations. Worry about the impact of the oil spill on health was one of strongest factors associated with depression in 2010, but no longer a significant factor in subsequent administrations. However, life disruption due to the oil spill was a significant factor associated with depression in 2017. **Implications:** Depression rates remain high on the Mississippi Gulf Coast, especially among the most vulnerable who have felt the cumulative impact of the two aforementioned disasters. Long-term disaster recovery interventions should emphasize evidence-based behavioral health services that target vulnerable populations in disaster prone communities in the Deep South.

Identifying Trajectories of Change to Integrated Healthcare for Patients with PTSD Symptoms Post Environmental Disaster

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Addressing life stressors is an important function for integrated care, especially for health care clinics located in disaster prone environments. This study evaluated trajectories of change for patients with post-disaster PTSD who were seen in integrated care. In addition to presenting the results, this paper will provide the methods of sub-group analyses. Patients (N = 340) receiving services at five rural health clinics self-reported PTSD symptoms as part of an ongoing evaluation to study the effectiveness of integrated health. ANOVA was used to assess differences overtime and trajectories were identified with cluster analyses. Disaster and trauma related factors associated with these trajectories were assessed using logistic regression. Significant overall decreases in PTSD symptoms were found; individual trajectories were identified and include stable low, steep declines, stable high symptoms, and increasing symptoms. Stress related to disasters and the number of other traumas clients reported correctly classified trajectory membership. Trajectories indicate that patients have differing treatment needs and cluster analysis as an evaluation technique may be useful in identifying what treatment works and for whom. The present study addresses a major concern for healthcare providers serving disaster prone communities and emphasizes the importance of identifying pre-incident and disaster related risk vulnerabilities that contribute to mental health outcomes.

Environmental Disasters and Life Stressors Contributing to Increased Mental Health Symptoms, Decreased Resilience and Substance Use

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Environmental disasters tend to compound existing life stressors, where individuals often revert to negative coping mechanisms. Notable research has demonstrated increases in posttraumatic stress and serious mental illness along the Gulf Coast related to both Hurricane Katrina and the Deepwater Horizon Gulf Oil Spill. However little is known about how substance use influences negative mental health symptoms and impacts resilience; the purpose of this presentation is to better understand this connection. Over 300 residents living along the Louisiana Gulf Coast were sampled following the spill. Purposive sampling techniques were used to increase participation from coastal parishes and sample parameters included exposure to Hurricane Katrina, the Gulf Oil Spill and survey completion. The majority of participants, were 41 years of age and older (56%), married/cohabitating (63%); female (65%); and identified as white (67%). The survey was comprised of the following sections measuring: Hurricane Katrina losses; oil spill disruption and concerns; posttraumatic stress and serious mental illness; resilience; pre- and post-spill substance use; and indicators of alcohol use problems. Preliminary findings suggest significant positive associations among posttraumatic stress, serious mental illness, additional stressors, quality of life, substance use pre- and post-spill, alcohol use, oil spill disruption, and oil spill concerns. Positive associations were also revealed among Hurricane Katrina exposure with posttraumatic stress, serious mental illness, and additional stressors. Decreases in resilience are negatively associated with increases in mental health symptoms, life stressors, and oil spill disruptions. Further multivariate techniques will be used to understand these bivariate associations. Implications for disaster recovery initiatives, including stress reduction and resilience building efforts will be discussed.

Trauma History, Oil Spill Exposure and Their Associations with Mental Health Symptoms among Residents in the Gulf of Mexico

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Previous research on the Deepwater Horizon Oil Spill (DHOS) and other oil spills suggests that this disaster poses risks to community members' mental health. Individuals with a history of exposure to extremely stressful events may be particularly prone to negative mental health sequelae of oil spills. In this study, we examined the associations between DHOS exposure, trauma history, and mental health. We expected that greater DHOS exposure and trauma history would be significantly associated with mental health problems, and that prior trauma would moderate the relationship between oil spill exposure and mental health problems. We tested these hypotheses in a sample of 2,490 randomly selected adults in coastal areas along the Gulf of Mexico. Participants were asked about their level of exposure to the oil spill (e.g., employment in affected industries, participation in clean-up activities, economic and property damage), trauma history (e.g., physical or sexual assault, accident, natural disaster), and mental health (depression, anxiety/worry, health-related anxiety, and alcohol use). Individuals who had experienced more traumatic events had significantly higher risk for depression, anxiety, health-related anxiety, and alcohol use, after controlling for demographic factors. Those with higher levels of DHOS exposure were also at greater risk for anxiety and health-related anxiety, but not depression or alcohol use, relative to those with less exposure. Contrary to our prediction, there was no evidence that trauma history moderated the effect of DHOS exposure on mental health. Findings suggest that the DHOS may have elevated anxiety symptoms specifically and that while residents with trauma histories were at risk for numerous mental health concerns, trauma history did not appear to exacerbate risk for mental health problems among Gulf residents exposed to the DHOS.

Distribution of Oil Spill Chemicals in Nearshore Beach Environments

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As part of the Beach Exposure And Child HEalth Study (BEACHES), the distribution of oil spill chemicals (OSCs) at recreational beach areas will be evaluated in areas used by children for beach play activities. Considerable efforts have been made to measure the distribution of OSCs in the environment. For example, for sand, cross shore distribution of OSCs is more heterogeneous than longshore distributions with distinct zones of oil accumulation. Vertical layering is also characteristic of oil impacted beaches and the depth of oil burial has been shown to be a function of beach geomorphology and wave characteristics. We have started to capitalize on this work by synthesizing this data to develop a sequence of algorithms that describe the distribution of OSCs in air, water, and beach sand as a function of physical factors and child play location on the beach. For air, physical factors that influence the variability of the OSCs are the wind intensity and direction plus uptake from dust near the beach surface as influenced by child play activities. For water, wind/wave conditions and depth of water will play an important role in the heterogeneity in the OSC distribution between floating oil and oil dissolved in the water column, whereas child bathing and wading periods would influence their

exposure to OSCs in water. For beach sediments, physical factors that influence the distribution of OSCs include beach geomorphology, sand/sediment characteristics, and wave conditions, plus child sand play activities such as digging would influence OSC exposure through sand ingestion and dermal contact. During this presentation we will describe work in consolidating available information on the spatial and temporal distributions of OSC concentration in the nearshore environment and how this data relates to output from recognized and validated fate and transport models. We will also describe how we can combine OSC distribution data to estimate exposures given a child's physical location and play activity within the beach environment.

Long Term Health Effects on Children and Adolescents in Areas Heavily Impacted by the Deepwater Horizon Oil Spill

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Understanding the long-term health outcomes of children and their families following the Deepwater Horizon Oil Spill is critical in determining the directions for much-needed health system enhancements and for targeted pediatric mental and physical health services. This presentation will focus on the direct and indirect exposure pathways and the trends in the long term physical and mental health outcomes of children and youth in the wake of the oil spill. In 2014, the investigators conducted household surveys in highly impacted areas in Louisiana. Census blocks were selected based upon a standardized oil impact score composed of BP compensation claims data and NOAA oil monitoring data. Households with children were randomly selected for interviews from these blocks. In 2017 the team returned to the 652 respondents who had agreed to be followed up and completed more than 480 interviews. Wave 1 data showed that nearly half of the respondents in the study reported that their children experienced mental and/or physical health effects following the oil spill. Preliminary results suggest that children who were exposed economically, physically and/or by smell to the oil spill, continue to have significantly greater odds of experiencing physical and mental health effects than those who were not exposed. We will analyze the data from waves 1 and 2, and investigate the trajectories of health symptoms among the oil-spill exposed children. Findings and observations will be described and discussed at the presentation.

Videotaping and Video-Translation Techniques to Improve Children Risk Assessment to Oil-Spill Chemical

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Children are potentially a susceptible and vulnerable group to adverse health outcomes from exposures to oil spill chemicals (OSC) residuals on beaches. First, children transition through critical developmental periods when toxic exposures can impact developing organs and systems. Additionally, a child's mouth and nose are generally closer to the ground than an adult's, resulting in greater inhalation of pollutants that accumulate in sediments. Children are also at higher risk because of their play habits which involve intimate contact (digging, burying, rolling), and potentially ingestion of beach sands. Beach-related activities that expose children to OSC can be quantified more accurately and

completely through state of the art videotaping and video-translation methodologies to improve estimates of aggregate (inhalation, ingestion and dermal) exposures. These methodologies for collection of children's activities will be presented, along with a discussion of the added benefit they provide in supplementing existing databases of children activities patterns in terms of more applicable micro and meso-activities. Existing children activities can be extracted from, for example, the EPA *Children's Exposure Factors Handbook* which offers well-accepted consolidated exposure-dose factors and algorithms (e.g., breathing rates, adherence factors). In addition, other studies such as the EPA's NEER (National Epidemiological and Environmental Assessment of Recreational Water) provide data from surveys of 29,100 beach visitors across multiple States for macro-activities. However, the value-added use of these video-translated micro and meso-activities in tailored risk assessment models will also be presented. Specifically, these powerful micro and meso-activity datasets allow for sequences and contacts to be extracted and recombined to computationally simulate "person-activities" and additional sets of summary statistics for population modeling. They also allow for the unique opportunity of collecting spatial and temporal data of beach activities and behaviors, and based on beach profiles. By more robustly estimating risks to our most compromised population, i.e., children, response and resilience in our communities can be improved.

Human Health Risk Assessment for Children Playing at Beaches Following an Oil Spill

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The overall objective of the Beach Exposure And Child HEalth Study (BEACHES) is to quantify exposures among children playing on beaches following an oil spill to create micro- and macro-activity databases. These data will inform risk assessments that will characterize the exposures in the context of beach physical factors that impact child beach play and the distribution of oil spill contaminants (OSCs), such as polycyclic aromatic hydrocarbons, metals, dispersants, and alkanes. The National Research Council (NRC) risk assessment framework will be modified to integrate information on child play activities and OSC distributions in the environment. Other components of BEACHES, as well as the peer-reviewed literature, will provide such information to estimate exposure. Scenarios will be developed that represent child activity patterns along shorelines, and will consider ingestion (non-dietary), dermal, and inhalation transmission of OSC levels. In addition, exposures that account for child-specific activities and differences in child play at beaches with different physical characteristics will be considered, as well as non-specific beach factors such as transdermal uptake, absorption across gut barrier, and dose-response from toxicity data. Further, computed risks will be aggregated to estimate cumulative risk. Both cancer and non-cancer health risks will be estimated. Uncertainty and variability will be addressed through the use of Monte Carlo approaches that will incorporate observed or assumed distributions. A sensitivity analysis will also be conducted to evaluate the different distributional assumptions for each model input, and provide information on data gaps where further research would provide the greatest benefit.

Mini-Sessions

MS-001: Gulf-wide Research

Trace Metal Concentration and Fluxes in Sediment from the Southern Gulf of Mexico and Its Relationship with the Ixtoc Oil Spill

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Twelve sediment cores, collected during the C-IMAGE II 2015 and 2016 offshore and coastal sampling expeditions in the Southern Gulf of Mexico, were analyzed to identify trace element enrichment and fluxes, potentially associated to the Ixtoc-1 blowout, which occurred in the Bay of Campeche from June 1979 through March 1980. Sediment cores were ²¹⁰Pb dated, trace elements (Co, Cr, Cu, Ni, Pb, V and Zn) were analyzed by X-ray fluorescence spectrometry (XRF), and the degree of trace metal contamination was evaluated by using an aluminum normalized enrichment factor. Several geochemical indexes were used [terrestrial input (K/(Fe+Mg)), weathering (Al/(Al+Fe+Mn)), redox conditions (Mo/Al, U/Th) and crude oil contamination ratio (Ni/V)] to evaluate the spatial and temporal variations of the metal fluxes within the study sites. Results showed that sediment elemental composition is quite homogenous among cores; whereas the elemental ratios indicate the presence of multiple and simultaneous processes (e.g. natural seep, Ixtoc petroleum sources and volcanic processes), which are difficult to delimit. Trace metal concentrations are naturally high in the region, at least during the past 100 years, and the crude oil contamination ratio indicated that Ixtoc event traces are comparable to conditions prevailing in the region since the beginning of past century, most likely due to active natural oil seeps. Our study is a significant contribution to the knowledge of pre-industrial contamination levels in the region, useful to establish national and international benchmarks. Radiometrically dated sediment cores are fundamental to reconstruct historical trends of contaminants in this and other regions where long-term environmental studies are scarce, and should be included in any marine monitoring program.

Can Oil Spills Cause Toxic Algal Blooms in the Gulf of Mexico?

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The diatom genus *Pseudo-nitzschia* is a common component of phytoplankton communities in the Gulf of Mexico, and is potentially toxic as some species produce the potent neurotoxin domoic acid. The impact of oil and chemical dispersants on *Pseudo-nitzschia* spp. and domoic acid production have not yet been studied; preliminary findings from a mesocosm experiment suggest this genus may be particularly resilient. We conducted a toxicological study using *P. delicatissima*, a known domoic acid producer from the Gulf of Mexico, using laboratory cultures isolated off Louisiana. Treatments were designed to reproduce conditions following the Deepwater Horizon spill. Oil exposure was facilitated

using the water accommodated fraction (WAF) of Macondo surrogate oil, while two dispersed oil treatments were used; a chemically enhanced WAF (CEWAF) and a dilute (1:10) CEWAF (DCEWAF). WAF and DCEWAF exposed cultures had slower growth rates relative to controls, but showed no detectable changes in photosynthesis (Fv/Fm or electron transfer rates). CEWAF exposed cultures were severely impacted, and rates of photosynthesis neared zero by 72h. Domoic acid production was measured at the end of the experiment to characterize changes in toxicity between treatments. Additional samples were taken to analyze pigment content, frustule structure and transcriptomic response. These results demonstrate that oil spills have the potential to increase the risk of toxic blooms occurring in the Gulf of Mexico given the right conditions, which puts both human health and local economies at risk. This study further underlines the complex nature of predicting how a marine system might respond to an incident like the Deepwater Horizon spill.

All These Hosts Are Yours: Microbial Assemblage in Benthic Meiofauna of the Gulf of Mexico

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Most multicellular animals establish a “host” relationship with a community of microbes (a microbiome). This microbiome is composed of both core and accessory microbiota. Core microbiota remain temporally and spatially stable across the majority of a given taxonomic level. They may be transmitted between host generations or environmentally acquired, remain stable across may even co-evolve with the host. By contrast, the accessory, or adaptive, microbial community components change in response to local and more short-term variation, such as ecological fluctuations, environmental perturbations, or variations in the host condition. Both core and accessory components of the microbiome may provide the host with fundamental functions and adaptive advantages that are not available within the host’s genome itself. This study investigates the bacterial associates of benthic meiofauna, which are microscopic eukaryotes that live in marine sediments. Meiofaunal organisms are known to impact microbial communities and affect nutrient cycling within their benthic habitats. To investigate the patterns of meiofaunal microbial community assemblage, we have conducted 16S rRNA surveys of microbiomes from thousands of individual meiofauna belonging to several species from ten phyla. Specimens were collected from the Gulf of Mexico and from other close sub-tropical and tropical locations that have not been affected by oil contamination. We expect to discover assemblage patterns of meiofaunal microbiota that (i) show a correlation with the phylogeny of the host (core microbiota), or (ii) are correlated to environmental parameters (accessory microbiota). Analysis follows a “systems ecology” approach, with the aim to provide a broader view of natural ecosystems and environmental disturbance by understanding complex interactions within biological systems. Results from this study will assist in understanding how meiofauna communities in the Gulf of Mexico are impacted by their own microbiomes, and open investigation into the role such interactions play in benthic ecosystems.

Physical Constraints on Biological Connectivity in the Gulf of Mexico

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Using more than twenty years (1994-2017) of surface drifting buoy trajectories, a Lagrangian dynamical geography of the Gulf of Mexico's surface ocean has been recently constructed. The geography has weakly dynamically interacting provinces that constrain the physical connectivity between distant locations in the Gulf. Here we investigate the implications of these results for biological connectivity by examining the correspondence between the provinces and: 1) the abundance, uniqueness, and richness of fish communities; and 2) the network modularity of the system predicted from biophysical probabilistic modeling using the Connectivity Modeling System.

MS-002: Microbial Communities at Depth

Microbial Crude Oil Degradation Under the Influence of Dispersant and Elevated Pressure

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A substantial amount of the hydrocarbons spilled into the Gulf of Mexico after the Deepwater Horizon oil spill in 2010 were presumably consumed by microorganisms. The composition of a persistent plume between 900-1300 m depth was characterized by high concentrations of polycyclic aromatic hydrocarbons (PAHs), medium length alkanes, and natural gases. Oxygen anomalies were detected which are believed to result from oxidative processes caused by the indigenous microbial community.[1] Most lab-based research to investigate microbial hydrocarbon degradation under deep sea conditions neglected the effect of elevated pressure on microbial performance.[2] We incubated the model strain *Rhodococcus* PC20, which was isolated from sediment in the vicinity of the spill site, at ambient and elevated pressure (150 bar) with dispersed and non-dispersed crude oil. Our studies found a pressure tolerance of this strain concerning growth. However, the overall oxygen consumption is hindered at elevated pressure and thus indicate an altered activity during high pressure incubations. During incubations with dispersant we observed a toxic effect of Corexit EC9500A towards the model strain's growth and a complete inactivity in crude oil degradation.

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In-situ Pressure Acts as a Selective Force on the Structure and Function of Deepsea Microbial Communities that Mediate Petroleum Hydrocarbon Degradation

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The Deepwater Horizon (DWH) disaster represents the largest accidental marine oil spill in human history. One of the unique characteristics of the DWH spill is the depth at which it occurred, approximately one mile below the sea surface. In the deepsea, overlying water (~1,500m) leads to high hydrostatic pressure, equivalent to 150 times that of atmospheric pressure. Our understanding of the impacts of hydrostatic pressure on the structure and function of microbial communities remains in its infancy. The goal of this study is to investigate how *in situ* microbial communities respond to oil contamination at pressures observed in the deepsea in comparison to atmospheric pressure. Shallow and deepsea sediments were collected in the northern and southern Gulf of Mexico. Seawater and/or sediments were incubated in specially designed high-pressure incubation chambers, with or without oil addition, at atmospheric or elevated (10 MPa) pressure, equivalent to the pressure expected at 1000 m water depth. Results indicate that samples from the deepsea show a distinct response to pressure in comparison to shallow origin samples. While shallow origin samples showed little impact of elevated pressure on oxygen consumption as a proxy for hydrocarbon degradation, the activity measured in deep-origin samples was elevated by up to 2-4 times at the *in-situ* pressure of 10 MPa. Microbial community analysis of deepsea water incubations showed that treatments at atmosphere pressure were dominated by OTUs that share nearly 100% sequence identity to *Oleispira antarctica* RB-8, a psychrophilic microorganism isolated from surface water in Antarctica. In contrast, the high-pressure oil treatment in seawater was dominated by OTUs which show high sequence identity (~ 100%) to Oceanospirillaceae sequences retrieved by Hazen et al. from deep plumes generated after the DWH discharge. This study is among the first to use *ex situ* incubations to determine the impacts of high pressure on the structure and function of indigenous microbial communities, which should aid in refining model predictions of oil fate to take into account pressure effects.

Effect of Elevated Pressure on Bacterial Communities

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The Deepwater Horizon incident in 2010 released an unprecedented amount of petroleum hydrocarbons from the wellhead at 1500-meter depth, at which hydrostatic pressure is 15 MPa. Indigenous petroleum-degrading bacteria were enriched by the deep-sea oil plume and were responsible for biodegradation of the released hydrocarbons [1]. Hydrostatic pressure has been shown to affect bacterial community abundance and diversity [2], and hydrocarbon degradation activity [3, 4]. However, the influence of hydrostatic pressure on bacterial community and activity, especially in the presence of hydrocarbons, is not fully understood. The aim of this study is to investigate the impact of hydrostatic pressure and hydrocarbons on microbial communities. Deep-sea sediment samples collected from the northern Gulf of Mexico were incubated in high-pressure reactors at atmospheric pressure and at high pressure with and without the addition of methane and oil. Microbial community compositions were analyzed by next-generation sequencing of 16s ribosomal RNA gene amplicons. The outcome provides insight into the influence of hydrostatic pressure on hydrocarbons biodegradation in marine environment [5].

* Student presenter

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MS-003: Oil Degradation in Coastal Sediments

Compositional Changes in Deepwater Horizon Oil Impacting Coastal Marshes

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Oil spills caused by tanker accidents or pipeline ruptures spill oil onto the sea or coastline surfaces, where the oil's composition is changed by weathering. The DWH oil was released into the deep sea, and mostly small droplets of oil rose to the sea surface, thus causing the surface expression of the spill. Some of this surface oil was then driven by winds and currents and eventually impacted sandy beaches and wetland marshes along the northern Gulf coast. The composition of all oil that reached the shoreline was substantially changes from its initial composition at the discharge point by weathering factors dominated by dissolution during ascent. After surfacing, the oil residues composition was further changed by evaporation, some more dissolution, biodegradation and photo oxidation. This oily residue washed ashore on beaches and marshes. The isotopic patterns of most PAH compounds showed PAH weathering, even in residues with little evidence of normal alkane biodegradation, suggesting significant photo oxidation. We have followed the chemical composition of oil residues collected just offshore before landfall in June 2010, and then after landfall onto coastal Louisiana marshes for seven years. These stranded oily residues were subjected to mostly aerobic weathering with some of the oil sequestered below the surface in borrows undergoing anaerobic weathering. Presumably, photo degradation was only a minor component of onshore weathering. Weathering and dispersion by weather events dramatically reduced the quantity of oily residues in coastal marshes during the first three years, and the composition was also significantly altered from that which came ashore. The PAH composition changes from being dominated by the lower molecular weight 2 & 3 ringed parent and alkyl aromatics to being dominated by the 4 & 5 ringed compounds. Extensive weathering seemed to leave oily residues predominantly composed of the chrysene family, and since 2014, the PAH composition was dominated by PAH compounds with a signature of pyrogenic sources. The petroleum biomarker compounds also underwent biodegradation changing showing significant compositional changes to the sterane biomarkers with lesser degradation of the terpanes. Sequestered oily residues underwent only minor weathering compositional changes.

Water and Air Flows Affecting Degradation of Buried Crude Oil

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After the Deepwater Horizon accident, oil was deposited in submerged and exposed coastal sands. The degradation rate of buried oil is highly dependent on the concentration of oxygen available to the aerobic decomposition process. We report results from laboratory experiments that investigated the effects of tides and water currents on the transport of oxygen to the buried oil. Tide simulator experiments revealed that gas transport through unsaturated sediment can maintain aerobic conditions around embedded oil. Investigations in a recirculating flume system demonstrated that tidal current changes produce oscillating oxygen conditions around buried oil thereby accelerating its decomposition. We contrast oil degradation rates reported from studies investigating oil buried in sandy and muddy sediments. The results emphasize the role of sediment permeability for the aerobic decomposition of buried oil.

Three-Year Time Series Monitoring Deepwater Horizon Oil Degradation in Pensacola Beach Sand

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Following the 2010 Macondo blowout, a significant amount of released oil was transported from surface water to the shoreline of Pensacola Beach. Some of the weathered oil became imbedded in Pensacola Beach sand and it was unknown how this oil would be degraded. To address this question, a time series study was initiated that investigated the fate of oil buried at different depth in dry beach sand. The primary objectives of the study were (i) to determine the loss over time and depth of total hydrocarbons (ii) to investigate the degradation rates of hydrocarbons in the buried oil. Oil-sand aggregates were collected from Pensacola Beach. Afterwards, known amounts of the homogenized material was encased in stainless steel mesh balls and buried over three years at different depths in the beach where the material was removed. Initial and final weights of the oil-sand samples were taken to assess the loss of material. Straight chain alkanes and PAHs of interest were analyzed to evaluate details of the degradation process.

Characterization of Weathered Petroleum in the Coastal Samples from the Southern Gulf of Mexico using FTICR-MS

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Ixtoc-I platform blowout in 1979 released 3 million barrels of oil to the Campeche Bay in the southern Gulf of Mexico (sGoM), which affected extended areas of coastline, as documented by a post-spill survey by Texas A&M University-Corpus Christi in 1979/80. Thirty years later, the oil spilled during the Deepwater Horizon incident had similar coastal impacts, and it still can be found in mangrove swamps in the form of heavily weathered tar mats and rock residues. Analyses of such samples using advanced

analytical techniques, for example Fourier-transform ion cyclotron resonance mass spectrometry (FTICR-MS), discovered a unique class of polar, oxidized, non GC-amenable compounds, products of oil photooxidation and biodegradation (Aeppli *et al.*, 2012, Radovic *et al.*, 2014, Ruddy *et al.*, 2014). Environmental behavior, effects and ultimate fate of these compounds are still contentious. In such context, the investigation of decadal scale, biotic and abiotic transformation processes and weathering products of the Ixtoc-I oil, in the coastal samples is of utmost importance, in order to establish a predictive model for the fate of coastal DWH residues. In this study, we analyzed coastal samples collected in 2016 at various locations in the sGoM, during a sampling campaign by C-IMAGE II researchers. Whole oil extracts were directly infused via electrospray and atmospheric pressure ionization sources to the ultrahigh resolution FTICR-MS, for an untargeted screening and characterization of non-hydrocarbon, heavy molecular weight oil residues and weathering products. The obtained broad range spectra were then compared to the FTICR-MS fingerprint of reference Ixtoc-I oil, for source apportionment. In addition, we compared the composition of sGoM oil residues, with the results of the FTICR-MS analyses of Macondo well oil coastal samples collected in the aftermath of Deepwater Horizon, to assess the potential for long-term oil preservation in coastal environments.

MS-004: The Last Mile before Landfall: Measuring Coastal Transport

Fine-scale Features on the Sea Surface Observed in the Vicinity of an Oil Seep in the Gulf of Mexico during SPLASH

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The focus of this work is to estimate the role of fine-scale features in the near-surface layer of the ocean, including fresh-water lenses and sharp frontal interfaces, in oil spill propagation in the Gulf of Mexico. As a part of the Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE/GoMRI) Submesoscale Processes and Lagrangian Analysis on the Shelf (SPLASH) experiment, we conducted fine-scale measurements near an oil seep located 12 miles off the coast of Louisiana. This part of the Gulf of Mexico is characterized by strong outflow from the Mississippi River. Measurements included vertical and horizontal T-S structure in the near-surface layer of the ocean in the vicinity of the oil seep, vertical shear (calculated from collocated drifters with drogues at 0.25 m, 2.5 m, and 5 m depths), and directional spectra of surface waves. We have also obtained SAR satellite imagery from TerraSAR-X, RADARSAT-2, and Sentinel-1B to monitor oil slicks in the vicinity of the oil seep. We observed some correlation between the position of oil slicks and sharp frontal interfaces. The observations, however, reveal the transient nature of some of the frontal interfaces that were appearing and disappearing within a few hours. The in-situ measurements revealed that under low wind speed conditions, freshwater outflow from the Mississippi River propagated in relatively thin near-surface layers - which was confirmed by modeling fresh-water lens dynamics with computational fluid dynamics tools. The sharp frontal interfaces formed by these thin fresh-water layers significantly depended on wind-wave and tidal mixing. This may explain the transient nature of the frontal interfaces as observed from in-situ measurements and SAR imagery.

Drifter Analysis of Surface Transport of Oil onto the Shore in the Louisiana Bight

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The Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE) executed another large, multi-platform, field campaign in the Northern Gulf of Mexico in the Spring of 2017. The Submesoscale Processes and Lagrangian Analysis on the Shelf (SPLASH) experiment was designed to study processes that control the cross-shelf transport of surface concentrated material such as hydrocarbons. The field campaign included several vessels, multiple aircraft, moorings, and the deployment of hundreds of surface drifters. The results of this experiment include new insights in the way that the river plume dynamics of the Mississippi outflow interact with the surface oil transport onto the shore. Analysis of surface drifter trajectories reveals several direct pathways from offshore to shore, depending on the dynamical regime of the fresh water plume under influence of local wind forcing. Insight in these pathways opens up new opportunities for response in case of an oil spill in the area.

Airborne Survey of Sea Fronts as a Guidance for *in-situ* Response Activities during the SPLASH Experiment

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Response and cleanup activities at sea generally focus on areas of strong surface convergence where oil tends to aggregate. There are several evidences of oil alignment with fronts, being characterized by sharp surface temperature gradients and strong convergence at the sea surface. In particular we focus on a frontal structure observed in the Louisiana Bight, in the framework of the SPLASH (Submesoscale Processes and Lagrangian Analysis on the Shelf) experiment. The targeted area is rich in fronts partly induced by the interaction between the Mississippi River output and the Gulf of Mexico waters, and the shelf is largely exploited by oil and gas production. SPLASH involved several aerial surveys and here we focus on three subsequent aerial surveys of the sea front in the Louisiana Bight ranging from 4 to 7 hours each in May 1st - 2nd 2017. The aircraft was equipped with different cameras (in the visible and infrared spectra) and with an inertial navigation system (INS) providing accurate Sea Surface Temperature (SST) over adjacent 2.5km-wide tracks. Final composite SST maps cover an area of about 50km x 50km with 5m resolution. The airborne SST maps were used in near-real time to guide the front localization by the vessel dedicated to in situ monitoring of the front. Several drifters were released to follow the surface evolution of the front, while across-front vessel transects measured the physical properties at depth. At the end of the survey most of the drifters washed ashore following the advection of the front toward the coast. The employment of both airborne and vessel surveys in SPLASH supports the complementarity of remote and in situ platforms to locate and monitor fronts and convergence lines where passive tracers tend to converge. Considering drifters as a proxy for oil, we will show that the proposed approach is very effective in order to track the advection of pollutant patches and to guide response activities.

Quantifying the Influence of Wind and Waves on the Upper Transport in the Gulf of Mexico

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Thus far, the upper meters of the surface currents in the Gulf of Mexico have been vastly understudied and much of the variability of these currents on the order of 1 day to a few weeks is yet to be documented. Through the use of a large data set containing trajectories from over 1000 surface drifters from the LAgrangian Submesoscale Experiment, LASER, that took place in January-February of 2016, this study's main focus is to analyze the upper 60cm of submesoscale surface currents and compare velocity magnitudes and directions to that of 10m wind and stokes drift output data from the UWIN-CM model, which has been validated with observational wind and wave data over the duration of the experiment. Observations of the velocity profile in the first 60cm of the ocean are made possible through the use of both drogued and undrogued surface drifters during LASER. Drogued drifters span from the surface down to 60cm, where the undrogued drifters only span the top 5cm of the ocean. In order to compare the drifter velocities to the model data, velocity fields for both drogued and undrogued drifters are created using the LAgrangian Variational Analysis (LAVA). The standard deviation of drifter velocity directions is used to analyze the varying influence between the mesoscale/submesoscale flow and the forcing of the wind/waves on the upper surface currents. In order to measure the direct influence of the wind and waves, this study focuses on high wind events during the experiment, where the drifter velocity directions are uniform and the underlying submesoscale/mesoscale influence is negligible. The comparison of these data sets will lead to a better understanding of upper surface dynamics, specifically the transfer and effects of wind and wave energy in the upper water column, which are vital processes in any upper ocean transport problem.

MS-005: Oil and Gas Plumes

Rotating Plumes and Spinning Tops

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Motivated by potential effects of the Earth's rotation on the dynamics of the Deepwater Horizon oil plume, we conducted laboratory experiments on saltwater and bubble axisymmetric point plumes in a homogeneous rotating environment. The effect of rotation is conventionally characterized by a Rossby number, based on the source buoyancy flux, the rotation rate of the system and the total water depth and which ranged from 0.02 to 1.3 in our experiments. In the range of parameters studied, we report a striking new physical instability in the plume dynamics near the source. After approximately one rotation period, the plume axis tilts away laterally from the centerline and the plume starts to precess in the anticyclonic direction. We find that the mean precession frequency of the plume scales linearly with the rotation rate of the environment. Surprisingly, the precession frequency is found to be independent of the diameter of the plume nozzle, the source buoyancy flux, the water depth and the geometry of the domain and, hence, of the Rossby number. We present our experimental results and

develop simple theoretical toy models to explain the observed plume behaviour. We also discuss the consequences of the plume precession on the spread of contaminants in the ocean.

Methane Plumes in the Deep Northern Gulf of Mexico

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Time-series measurements from free vehicle mini-landers (ML's) of methane and bottom currents in the friction layer at multiple hydrocarbon-rich lease blocks in the northern Gulf of Mexico reveal methane concentrations ranging from background values of <5 nM to over 4000 nM in plumes associated with natural hydrocarbon seeps. The dissolved methane is injected through rapid dissolution of rising gas bubbles streams. At 1000m depth and 5°C, methane saturation values in seawater would approach 175 mM, suggesting that much higher concentrations can occur naturally from gas seepage. Continuous laser measurements of methane concentrations within 10 m of the seafloor combined with current speeds and directions obtained from acoustic Doppler profilers revealed temporal variability controlled by change in water transport over nearby hydrocarbon seeps and in seep gas bubble release rates. Observed current speeds at Green Canyon (GC) locations ranged from < 2 to over 30 cm/s within the friction layer from 2 to 30 m above the seafloor. Triangulation and downstream deployments of ML's around multiple gas and oil seeps provide capabilities for long term monitoring and rapid responses to both natural and accidental hydrocarbon releases.

Predicting Dissolved Concentrations in the Water Column for Natural Seep Plumes in the Gulf of Mexico

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Natural seeps, the flow of hydrocarbons from the seafloor to ocean water column, are an important part of the global methane budget, and it remains unknown what the vertical distribution of methane is in the water column surrounding a natural seep flare. As methane dissolves out of bubbles, methane-enriched water is transported horizontally by the currents. How much methane enters the atmosphere and the fate of dissolved methane in the ocean both depend on the rate of gas dissolution. The purpose of this study is to provide information about the spatial scale of the velocity field and the concentration distribution of dissolved hydrocarbons in the near-field of seeps as observed by cruises in the Gulf of Mexico by the Gulf Integrated Spill Research (GISR) Consortium and predicted by a numerical model. In this study, we predict the dissolved hydrocarbon concentration around the natural seep in the Gulf of Mexico compared with the field experiment data. The GISR Consortium collected the field measurements around natural seeps to characterize the bubble flares and their fate in the water column. They observed the rise of bubbles using acoustic and optical sensors, and they measured the dissolved methane concentration distribution around the seeps using in-situ measurements. For the numerical simulations, bubbles are randomly generated based on the measured bubble size distribution and the gas composition. The random walk method is applied to the model with the measured diffusion coefficient of bubbles from the field, and the resulting model is validated by comparing between the bubble spreading map and the M3 sonar image. The model calculates the concentration of the dissolved phase by the analytical solutions to the advection-

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diffusion equation. The result shows that the main axis of the dissolved concentration distribution can be different from the long axis of the bubbles spreading in the plume. Bubbles spread out due to the integration of the currents from their release to the measurement location. However, the dissolved phase distribution at the certain water depth depends on the local current direction at that depth only. This explains why the maximum measured concentration is sometimes located at the edge of bubble distribution, which is different from what was expected during the cruise and what guided the sampling plan.

The Effect of Oil Droplet Size on the Surface Signature of Oil Plumes Under Free-Convection

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For oil plumes in the ocean surface mixed layer (OSML), measurement of quantities of interest such as the total amount of oil or oil droplet size distribution is generally challenging within the necessary time-frame for action. Thus, methods to infer such quantities from easily-obtainable observations can facilitate real time understanding of oil spills. In this work we explore the relationship between the characteristics of the surface oil plume and droplet size in a case of free-convection. Because buoyancy levels depend on the size of oil droplets, it may be possible to infer droplet sizes from the patterns at the surface, which are easily observed from aerial images. Furthermore, from the inferred droplet sizes it is also possible to relate the amount of oil at the surface to the amount contained in the entire vertical extent of the mixed layer. With these issues in mind, we use a Large Eddy Simulation to investigate the behaviors of oil droplets of different sizes in the OSML under a convective regime. We focus on the patterns that arise in the oil distribution due to the different levels of buoyancy associated with different droplet sizes. Moreover, we compute surface concentration statistics and link surface patterns to the invariants of the surface velocity gradient tensor, showing strong dependence of the droplet concentration behavior on droplet size. We found that for small droplets the surface horizontal divergence is a good predictor of oil concentration, with the oil aligning along convergence lines. For large droplets, however, the topology of the flow in the convergence zones has to be considered.

MS-006: Let's Give Them Something to Talk About – The Importance of Communication and Public Engagement in Gulf Research

Citizen Science in Oil Spill Research: An Evaluation of Trust and Value in CONCORDE

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There has traditionally been a top-down communication process in which scientists inform the public and trust and literacy of this communication was assumed or even disregarded. Yet the broad consensus is that it is important for citizens to be scientifically literate, which includes basic understandings of scientific concepts and constructs and of scientific processes and inquiry. The

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Consortium for Oil Spill Exposure Pathways in Coastal River-Dominated Ecosystems (CONCORDE), a three-year \$11 million GoMRI grant-funded project led by The University of Southern Mississippi, works to incorporate citizen science into the data collection and analysis as a way of promoting both scientific literacy and trust in science. Broadly speaking, citizen science is designed and implemented to bring the public and professional researchers closer together, but it can take on many different forms and levels of involvement. CONCORDE's citizen science component fosters partnerships between academic researchers and Gulf Coast fisherman. The fishermen, most of whom are Vietnamese-American, attend trainings to learn about the project and are active participants in the collection of data. In this research, we evaluated the social impact of this component of the project. Specifically, in the second and third year of the project we conducted 58 interviews with researchers, both academics and citizen scientists, to understand 1) what each group views as the value of the citizen science component of CONCORDE and 2) how the component impacts public trust in science. We find that the two groups—academic researchers and citizen scientists—view the value of the project and the contribution of the citizen scientists differently. Interestingly, we found evidence of different trust issues than were expected. The data indicate that both groups recognize the value in the citizen science component of CONCORDE, in the ability of the component to increase public trust in the study as one of its specific aims, and the foundation that the partnership is laying for future collaboration.

Effectiveness of a Web-based Virtual Lab Application to Disseminate and Communicate GoMRI Science

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The RECOVER Consortium developed and released a web-based interactive teaching app geared for students grades 8-12 and beyond on aerobic swim performance in fish. The app allows students and teachers to perform virtual experiments akin to those conducted by RECOVER scientists in the lab to determine the effects of oil on fish swim performance and metabolic rate. The simulation module is paired with lesson plans to assist teachers and includes an assessment of the knowledge gained by students after having completed the module. The post-lab assessment gathers detailed demographic data allowing for evaluation of impact of this outreach effort. The effectiveness of this approach and teaching module will be examined and based off student performance and participation in the Fall 2017 semester. Insights gained through student assessments and teacher feedback will highlight successful areas as well as those in need of improvement. The continued partnership with teachers and educators will steer development and practicality of these virtual learning experiences. This research was made possible by a grant from The Gulf of Mexico Research Initiative. Grant No: SA-1520; Name: Relationship of Effects of Cardiac Outcomes in fish for Validation of Ecological Risk (RECOVER). Data are publicly available through the Gulf of Mexico Research Initiative Information & Data Cooperative (GRIIDC) at <https://data.gulfresearchinitiative.org>.

Evaluating Interdisciplinary Program Performance and Impact

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An extensive array of research, outreach, and education activities was initiated following the Deepwater Horizon Oil Spill (DHOS), including multiple interdisciplinary programs. What can we learn from these programs about the challenges and opportunities afforded by such comprehensive efforts to assess and address disaster impacts? In this paper, we describe a multi-method evaluation approach that was initiated when the Consortium for Resilient Gulf Communities was first established to examine the human dimensions of DHOS. We aimed to obtain a diverse, complete, and in-depth assessment of the Consortium's performance and impacts. We will report on our change model, from which metrics were derived to capture internal team perceptions, the nature of diverse and integrated activities, and traceable impacts. We will describe the results of quantitative and qualitative analyses that illustrate how an evidence-based approach can be used to pinpoint a program's strengths and opportunities for improvement. Such evidence is necessary to generate generalizable knowledge about how to advance science aimed at developing useable, context-sensitive information. We will discuss lessons learned about best practices in program evaluation that will assist other large, interdisciplinary efforts to determine what approaches are and are not effective and why.

MS-007: Response Planning and Management in the International Arena

Field Trials Using Conventional and Unconventional Drifters to Support the Canadian Operational Oil Spill Modelling in the Northeast Atlantic

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Four field trials were conducted during the summer of 2016 in Notre Dame Bay off Change Islands in Newfoundland, Canada to simulate trajectories of bunker spills from the sunken vessel Manolis L. Ten modified Orion oil spill buoys, six MetOcean iSPHERE buoys, two flat top and two standard CANATEC oil spill tracker buoys, two cases of oranges and several cedar shingles were used in the study. Three trials were run for about 6 hours each on August 20, 21, and 26. The fourth trial was run for three days from August 29 to September 01 during which time a severe storm passed through the area. The objectives were to obtain surface currents to validate an ocean model, to validate an operational oil spill model, to assess the ability of the different drifters to follow oil spills, and to test the survival of the modified Orion buoys during high wind speed conditions. Orion buoys were shown from previous studies to be good drifters to follow oil spills. They were used as a surrogate of oil spills in this study. The experiment showed significant differences in the trajectories of the drifters. The iSPHERE buoys drifted much faster than all the other buoys. Their dispersion was different during the first three trials. All the other drifters remain relatively closer to the Orion buoys. During the fourth trial two Orion buoys were released. They survived through strong gale force winds of speeds from 50 to 86 km/h. The storm lasted for

more than 10 hours and the buoys kept sending signals at the pre-set time interval of 5 minutes. Application of the data collected to real oil spill events and validation of oil spill modelling will be discussed.

Exposure Assessment of Rayong Oil Spill Cleanup Workers

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Background: In July of 2013, a pipeline connecting an offshore oil platform to a tanker caused crude oil to spill into the Sea of Rayong off the coast of Thailand. The estimated amount of oil spilled was between 50 and 190 cubic meters or 336-1,200 barrels. The resulting oil slick washed ashore one day later on the island of Samet. On-land cleanup lasted about a month and was performed by a combination of territorial defense volunteers, citizen volunteers, Thai military personnel and company employees. We conducted a study to quantify internal dose of polycyclic aromatic hydrocarbons (PAHs) and benzene in these workers and to examine factors related to their dose. **Methods:** Frozen stored urine samples (n=1343) collected from the workers throughout the one-month cleanup were used to measure the concentration of 1-hydroxypyrene-glucuronide (1-OHPG), cotinine and creatinine. Data from questionnaires and urinary trans,trans-muconic acid (t,t-MA) measured as part of a cleanup worker health surveillance plan, were linked with the laboratory data. **Results:** The internal dose of PAHs as measured by urinary 1-OHPG was highest in individuals who worked during the first 3 days of cleanup work (median: 0.97 pmol/ml) and was 66.7% lower (median: 0.32 pmol/ml) among individuals who worked in the final week of the study (days 21-28). This was consistent with our hypothesis that the exposure levels of PAHs would be the highest in the first week of cleanup and decline thereafter. After adjusting for cotinine and creatinine by regression analysis, the decline in urinary 1-OHPG concentration with days of cleanup remained significant (P-trend <0.001). Job descriptions with the highest level of urinary 1-OHPG after adjustment were oil dispersant applicators and contaminated sand/trash handlers. A decreasing trend by days of cleanup was also observed for detectable urinary t,t-MA percentage (P-trend <0.001). **Conclusion:** Rayong oil spill cleanup workers exhibited evidence of elevated levels of PAH and benzene exposure during the early weeks of cleanup, compared to near background levels 4 weeks after cleanup began. Long-term health monitoring of oil spill cleanup workers should be implemented.

How Should China Improve Offshore Oil Spill Governance? -- In the Light of Deepwater Horizon

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The Gulf of Mexico Oil Spill of 2010 was an ecological disaster. It has resulted in the largest mobilization of resources to address an environmental emergency in the history of the United States. The remarkable performances of US government agencies, community groups, and the public in response to the event have had a profound influence on the international community in dealing with marine oil

pollution incidents. According to the prediction of the U.S. Energy Information Administration, China's energy consumption will exceed the U.S around 2030, it is expected that China will increase domestic oil and gas production to ensure energy security. The offshore oil and gas industry has been growing rapidly in China, and in the meantime, the risk of offshore oil spills is also increasing. The Chinese government has made considerable efforts to deal with the problem, especially after the Penglai 19-3 oil spill in Bohai. It is now a crucial time for China to formulate an offshore oil spill governance regime to cope with the growing risks. Offshore oil spill governance involves the application of externality theory and governance theory to manage oil spill accidents. The governance regime is an integrated, interdisciplinary system which requires significant scientific support. The governance framework must be carefully designed to address effectively legal, economic, managerial, and ecological issues associated with a major pollution incident. The framework must facilitate key players (environmental management agencies, responsible parties, the general public, courts, and scientific organizations) to interact in a way to reduce negative externalities. This paper presents an analysis of the Deepwater Horizon oil spill governance regime, including legal framework, response system, and restoration efforts. Especially, we analyze the role of scientific decision-making in detail. In addition, we examine China's oil spill governance regime with a focus on changes after the Penlai19-3 oil spill. Finally, we make recommendations on how China should learn from the Deepwater Horizon experience and improve the nation's governance regime.

MT Dawn Oil Spill Trajectory Simulation along the Chennai Coast, India

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The major public issue on spill accident occurred in Chennai coast, Tamil Nadu, India due to collision between the LPG vessel M.T Maple and oil tanker M.T Dawn on 28 January 2017 can have long term impacts on marine environment due to huge quantity of oil spill. Assessment of an oil spill trajectory for the emergency response still remains a challenging task in terms of accuracy in track prediction. In the present work, an attempt has been made to predict the spilled oil along the Chennai coast using General National Ocean and Atmospheric Administration Operational Modeling Environment. The Mike 21 two-dimensional hydrodynamic model is used to simulate the surface currents. The results of model such as tidal level, along shore and cross shore currents agree well with the surface current data provided by Indian National Centre for Ocean Information Services. We found that the contribution of current is more than, winds on the spill trajectory. The spill trajectory shows that, the oil patches moved toward south westward direction. In addition to the trajectory, the model also quantified the most significant weathering processes of spreading, evaporation and beached oil which in turn highlights long term oil pollution impacts on the marine ecosystem along the Chennai coast. The regular monitoring of the level of hydrocarbons in water, sediment and biota are necessary for effective planning and oil spill risk assessment.