
Abstracts of Oral Presentations

## Session 001: Oil Spill Response and Mitigation Agents

Evaluation of Chemical Countermeasures as Potential Response Options
**P. Doelling**
NOAA, Houston, TX

When responding to an oil spill, it is important to consider all "tools in the toolbox," including alternative response technologies. Chemical countermeasures such as dispersants, surface washing agents, and bioremediation products which are listed in Subpart J are evaluated on an incident specific basis. In certain situations, they may require approval by the Regional Response Team (RRT). The discussion presented will describe factors generally considered in such evaluations, and include case study examples.

Emissions from Crude Oil- and Crude Oil-Dispersant Contaminated Seawaters due to Breaking Waves
**N. Afshar-Mohajer**, C. Li, A. M. Rule, J. Katz, K. Koehler
Johns Hopkins University, Baltimore, MD

Crude oil spill incidents generate a variety of occupational, ecological and environmental issues. Application of chemical dispersants to oil contaminated water drastically reduces the oil-seawater interfacial tension, thereby decreasing the size of droplets, and enhancing their dispersion. However, little is known about how the use of dispersants impact the generation of aerosolized droplets as well as the concentration and composition of emitted gases during breakup of oil slicks by waves on the ocean surface. The purpose of this study, was to measure the size distribution of aerosols in the 10 nm to 20 µm diameter range, the total particle-bound polycyclic aromatic hydrocarbons (pPAH) and the total volatile organic compounds (TVOC) above breaking waves impacting oil slicks. Chemical speciation of VOCs was conducted to identify toxic constituents. Air samples were collected as plunging breaking waves of varying strength were generated periodically for extended periods in a wave tank (6 × 0.3 × 0.6 m) containing seawater. Waves impinged on clean water as well as 0.5 mm thick slicks containing crude oil and crude-oil pre-mixed with Corexit 9500A dispersant. The number concentration of aerosolized droplets smaller than 20 nm was 30 and 102 times larger when dispersant was used compared to clean water, for droplet diameter of 12.6 nm at kinetic wave energies of 0.007 and 0.01 $m^2/s^3$, respectively. Concentration of pPAH was 152 $ng/m^3$ with dispersant and 269 $ng/m^3$ without. In contrast to the nano-droplets, the average concentration of TVOC and individual VOCs measured with the crude oil-dispersant mixture was about 3 times lower than that of crude oil without dispersant. Further investigation is needed to determine mechanisms preventing VOC evaporation when dispersants are involved. Health concerns and risks associated with inhalation of oil and dispersant nano-droplets along with their atmospheric transport should also be investigated.

Analysis of the Community Structure of Planktonic Protozoa Following Exposure to Physically and Chemically Dispersed Crude Oil
**S. Cosgrove**, M. Moison, T. Severin, E. J. Buskey
University of Texas Marine Science Institute, Port Aransas, TX

Planktonic protozoa are an essential part of the marine food web serving as consumers of phytoplankton species and as prey of larger zooplankton. Little is known regarding the effect of crude



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oil spills and the use of dispersant on this important group. As plankton diversity can be greatly reduced in areas of oil spill, our aim was to determine the effect of Louisiana light sweet crude oil and dispersant Corexit 9500A on the community structure of protozoan groups during 7 day mesocosm experiments. Using crude oil concentrations of 5ppm and 10ppm with a dispersant to oil ratio of 1:20, we examined the survival, mortality and potential recovery rates of protozoan species within conditions which best reflect the natural environment. Alterations in community diversity and species richness were observed most in the 10ppm dispersed oil treatment, including the greatest decrease in cell density for all dinoflagellate and tintinnid ciliate species. This lead to dominance by the ciliate groups' oligiotrichea and spirotrichaea, with *Strombidium* sp. representing 24% and *Euplotes* sp. 47% of the total observed protozoan population by day 7. Less alteration in community diversity was observed in the 5ppm dispersed oil treatment, and the recovery of *Strombidium* sp. and *Mesodinium* sp. was observed by day 5 after initial suppression. Of the 9 dinoflagellates genera quantified over the sampling period, *Ceratium* sp. and *Prorocentrum* sp. demonstrated the most tolerance to the 5ppm treatment, with increased cell densities of 2000 cells $L^{-1}$ and 500 cells $L^{-1}$ respectively, following 5 days of exposure. These results show certain protozoan groups exhibit a higher level of tolerance and potential for recovery following exposure to chemically dispersed crude oil, while the groups oligiotrichea and spirotrichaea have the ability to dominate a protozoan community exposed to crude oil concentrations of 10ppm and potentially influence the planktonic food chain.

Effects of Salinity on the Toxicity of Oil Dispersants in Eastern Mud Snails

**B. Evans***[1], P. Key[2], K. Chung[2], M. DeLorenzo[2], M. Fulton[2]

[1]Eckerd College, St. Petersburg, FL, [2]National Oceanic and Atmospheric Administration, National Ocean Service, Center for Coastal Environmental Health and Biomolecular Research, Charleston, SC

Chemical dispersants can be an effective method for combating oil spill disasters. However, their use in mitigation should be carefully considered due to their potential toxic effects in the marine environment. While dispersant toxicity may be established under standard conditions, it is uncertain what role abiotic factors might have on their toxicity. This study looked at the effect of salinity on oil dispersant toxicity in the Eastern mud snail, *Ilyanassa obsoleta*, a common estuarine species. Using two dispersants authorized for oil spill response, Corexit 9500 and Finasol OSR 52, mean acute lethal toxicity (LC50) values and sublethal effects were examined at 10, 20, and 30 ppt salinity in adult and larval snails. Two biomarkers (lipid peroxidation and acetylcholinesterase) were used to measure sublethal effects. The 96-hour static renewal LC50 values indicated significant differences in toxicity between dispersants and salinities. Larval snails were significantly more sensitive than adult snails to both dispersants, and both life stages were significantly more sensitive to Finasol than to Corexit. Larval snails were more sensitive to dispersants at lower salinity, while adult snails were more sensitive at higher salinities. Dispersants increased lipid peroxidation activity and decreased acetylcholinesterase activity in adults. These results demonstrate that dispersant toxicity varies among compounds and organism life stages, and that physicochemical properties of the environment, such as salinity, affect the potential dispersant toxicity to estuarine species.



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Efficacy and Ecotoxicological Effects of Shoreline Cleaners in Salt Marsh Ecosystems
**M. DeLorenzo**, P. Key, E. Wirth, P. Pennington, K. Chung, E. Pisarski, B. Shaddrix, M. Fulton
NOAA, National Centers for Coastal Ocean Science, Charleston, SC

Oil spills that occur in estuaries, bays, or enclosed harbors have the potential to contaminate docks, bulkheads, ship hulls, and sensitive estuarine habitat. Depending on the situation and location, shoreline cleaners may be applied to oiled surfaces within inshore areas. Decisions as to where and when individual products will be utilized depend on understanding the efficacy, environmental fate, and environmental effects of these compounds. This study evaluated the efficacy and possible ecotoxicity of three shoreline cleaner products (Accell Clean, PES-51, and Cytosol) using a salt marsh mesocosm test system and laboratory exposures. Ceramic tiles were used to represent oiled seawall. The mesocosms were dosed with oil, followed by shoreline cleaner application to the oiled tiles. Samples were collected at multiple time-points during the 30-day experiment. The Oil+Accell treatment significantly reduced fish, mud snail, and clam survival compared to the control. Both the Oil+Accell and Oil+Cytosol treatments significantly reduced amphipod and polychaete survival. Sublethal effects were observed on clam and marsh grass growth, and dissolved oxygen content was reduced in the shoreline cleaner treatments. While the Oil+Accell treatment had the greatest animal mortality, it had the highest bacterial (heterotrophic and *Vibrio*) densities. Bacterial densities returned to pre-dose levels after 30d. The Oil+Accell treatment had significantly higher measured hydrocarbons (TEH and Total PAH50) in the water column 24h post-cleaner application than the oil alone treatment, the Oil+PES treatment and the control. The results of this study will help inform management decisions regarding the use of shoreline cleaners in oil-spill response, particularly with regard to estuarine species.

Efficient Dispersion of Crude Oil by Blends of Food-Grade Surfactants: Toward Greener Oil Spill Treatments
D. Riehm[1], J. Athas[2], J. Neilsen[3], G. Bothun[3], V. John[4], S. Raghavan[2], **A. McCormick**[1]
[1]University of Minnesota, Minneapolis, MN, [2]University of Maryland, College Park, MD, [3]University of Rhode Island, Kingston, RI, [4]Tulane University, New Orleans, LA

Recent work has suggested that marine oil dispersants containing blends of the nontoxic surfactants lecithin (L) and Tween 80 (T) may be effective alternatives to traditional dispersant formulations containing blends of Tween 80, Span 80, and DOSS (dioctyl sodium sulfosuccinate). The dispersion effectiveness of lecithin-Tween 80 (L-T) blends in an ethanol solvent was measured for South Louisiana crude oil using baffled flask effectiveness testing, as a function of L:T ratio, surfactant:solvent ratio, solvent composition, and wt% dispersant in oil. The most effective L-T dispersants performed comparably to Tween 80-Span 80-DOSS dispersants, dispersing 75-90% of the test slick at 1.25-5 wt% dispersant in crude oil. Increasing surfactant:solvent ratio increased dispersant effectiveness even when dispersant dosage was proportionally reduced to keep total wt% surfactant in the oil constant. Replacing some of the ethanol solvent with octane or octanol also increased dispersant effectiveness, suggesting that ethanol's hydrophilicity lowered dispersant-oil miscibility, and that more hydrophobic solvents would increase dispersant effectiveness.

Two other important findings were that (1) lecithin-rich L-T dispersants were significantly more effective than Tween 80-rich L-T dispersants with lower or comparable interfacial tension, and (2) all L-T dispersants produced much higher interfacial tension than Tween 80/Span 80/DOSS dispersants. This suggests that interfacial phenomena other than interfacial tension, such as the formation of an



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interfacial gel or oil-droplets' resistance to coalescence, may also influence L-T dispersants' effectiveness.

Comparative Toxicity of Chemical Dispersants and Weathered Oil in Saltmarsh Mesocosm Systems
**P. Key**[1], M. DeLorenzo[1], E. Wirth[1], P. Pennington[1], K. Chung[2], C. Cooksey[1], E. Pisarski[2], B. Shaddrix[2], M. Fulton[1]
[1]NOAA/NOS/NCCOS, Charleston, SC, [2]JHT, Inc., Charleston, SC

While chemical dispersants are useful in mitigating oil spills, the potential risks to sensitive coastal ecosystems should be carefully considered. To improve the decision making process, more information is needed on the effects of oil dispersants on coastal ecosystems. This study compared the toxicity of two oil dispersants (Corexit® EC9500A and Finasol® OSR52) individually and in mixture with weathered Louisiana Sweet Crude oil in saltmarsh mesocosms in a chronic (45 day) exposure. The mesocosms contained sediments, marsh grass, pelagic and benthic fauna that represented different habitats, feeding types and trophic levels. These systems also incorporated tidal flux. There were 16 mesocosms consisting of four replicates each of control, oil only, oil dispersed with Corexit, and oil dispersed with Finasol. Survival was reduced in the benthic organisms (clams, amphipods, and polychaetes) in both dispersed oil treatments. Survival was also reduced in clams in the oil-only treatment. Marsh grass stem density, shoot density, and stem regrowth showed a significant treatment effect and a significant time effect. Both dispersed oil treatments caused hypoxia, altered microbial community structure, and reduced survival of grass shrimp and snails. The Total Extractable Hydrocarbons (TEH) and PAHs that were measured were generally similar among the oil-only and dispersed oil treatments. Both TEH and PAH concentrations declined rapidly over time. These findings demonstrate the need to consider complex dispersant-oil interactions when making oil-spill response decisions.

Natural Clay Nanotubes for Emulsification and Bioremediation of Spilled Crude Oil
**Y. Lvov**[1], A. Panchal[1], R. Minullina[1], D. Zhang[2], D. Blake[3], M. Omarova[3], V. John[3]
[1]Institute for Micromanufacturing, Louisiana Tech University, Ruston, LA, [2]Department of Chemistry, Louisiana State University, Baton Rouge, LA, [3]Department of Chemical Engineering and Department of Biochemistry and Molecular Biology, Tulane University, New Orleans, LA

Halloysite clay nanotubes are an indigenous material naturally mined in large quantities. These biocompatible clay nanotubes can replace organic amphiphiles for stabilization of oil-in-water emulsions in sea conditions. We extended our earlier works on of petroleum Pickering emulsification using pristine and hydrophobized halloysite nanotubes at ca. 0.5 wt. %. Optimization of the nanotube sizes in the length range of 0.5 to 1.5 micrometer allowed establishment of standard clay tube supply of 50 nm diameter and of ca. 1 micrometer length. The hydrophobization was carried out with octadecyltrimethoxysilane (ODTMS) allowing for crude oil emulsions with 10-20 micrometers droplet diameters. The resulting emulsion droplets have a rough surface coated with 1-2 layers of laterally located clay tubes, as evident from cryo-SEM imaging.

Attachment and proliferation of alkane degrading *Alcanivorax borkumensis* on halloysite emulsions was drastically increased in comparison to emulsions formed with Corexit-like surfactant. The number of bacteria at the halloysite-covered oil-water droplet interface increased approximately 30 times over three days, promising better oil decomposition. Halloysites possess a lumen with diameter of 10-20 nm which was used as reservoir for nitrogen and phosphorus based nutrients to accelerate the growth of



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attached bacteria around the oil. We have established the protocol to conduct alkane analysis of Macondo basin crude oil using Gas-Chromatography coupled with Mass-Spectroscopy (GC-MS) and are monitoring crude oil decomposition with *A. borkumensis* trying to optimize the bioremediation.

Dispersion Effectiveness of Buoyant Gel Dispersants in Oil Spill Treatment

**V. T. John**[1], O. Owoseni[1], M. Omarova[1], Y. Zhang[1], A. Bose[2], S. Raghavan[3]
[1]Tulane University, New Orleans, LA, [2]University of Rhode Island, Kingston, RI, [3]University of Maryland, College Park, MD

The dispersion of crude oil spills into tiny droplets that mix vertically and horizontally in the water column is often employed in the treatment of oil spills. Existing dispersant systems are liquid solutions of surfactant such as dioctyl sulfosuccinate sodium salt (DOSS) and polyoxyethylene (20) sorbitan monooleate (Tween 80) in hydrocarbon solvents. Such dispersants are easily washed away by ocean current especially when applied to heavy or weathered oils and suffer from spray drift during aerial application. Developing environmentally benign dispersant systems and efficiently targeting the dispersant to spill oils has huge economic and environmental significance. We have developed a surfactant gel system consisting of the environmentally benign phospholipid, l-α-phosphatidylcholine (PC); anionic surfactant, DOSS; and nonionic surfactant, Tween 80 as a buoyant gel dispersant for the treatment of petroleum hydrocarbon spills. In this presentation, we elucidate the underlying mechanisms driving the emulsion stabilization characteristics and effectiveness of the gel dispersant. The dispersion effectiveness of the gel is characterized using the standard baffled flask test for varying oil phase viscosity and environmental temperature conditions. Small Angle Neutron Scattering (SANS) analysis and modelling provides quantitative structural features of the gel dispersant as a function of temperature conditions. We demonstrate that under varying temperature conditions, the gel retains its structural integrity and positively buoyant characteristics on water, breaks down on contact with oil and release surfactant components that stabilize the crude oil in saline water macroemulsions.

Oil Spill Fate and Exposure Modeling of a Deep Sea Blowout - Effects of Including Subsea Dispersant Injection Treatment

**D. French-McCay**[1], J. J. Rowe[1], J. Joeckel[2]
[1]RPS ASA, South Kingstown, RI, [2]SEA Consulting Group, Cape Charles, VA

Controversy remains over the potential mitigating effects of dispersant use as opposed to mechanical cleanup and in situ burning. Modeling the efficacy and effects of alternative spill response countermeasures is a powerful approach to inform decision-makers, as it can quantify the likely water volume adversely affected by naturally- or chemically-dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil, with which they can evaluate tradeoffs of dispersant use. In order for the decision makers and stakeholders to accept such modeling results, the modeling needs to be synthesized, clearly presented, clarified as to uncertainties of the results, and backed up with documentation as to the model's algorithms, assumptions, inputs, and reliability. Subsea dispersant injection (SSDI) has been put forward as the preferred countermeasure for deep water blowouts with the assertions that it increases effectiveness of dispersant treatment over that achievable at the water surface; reduces the volume of oil that surfaces and exposes surface and nearshore resources; reduces exposure to volatile organic compounds (VOCs) for workers in the area above the release; reduces exposure of wildlife to surfaced oil and VOCs; and enhances biodegradation because of increased surface area and dissolution from small oil droplets. Potential tradeoffs to be considered include



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increased water column and benthic exposure to dispersed oil and dissolved components at depth. Blowout and oil spill trajectory model simulations of non-treated versus SSDI-treated oil blowouts in the Gulf of Mexico quantifying these exposures are compared with respect to oil fate, amount and area of surfaced oil, and exposure concentrations greater than thresholds for potential effects, demonstrating the potential tradeoffs but overall reduction in exposure for resources as a whole when SSDI is included in the response.

State-of-Science of Dispersants and Dispersed Oil in U.S. Arctic Waters

**N. E. Kinner**[1], G. Shigenaka[2], D. Helton[2]

[1]Coastal Response Research Center, Durham, NH, [2]NOAA Office of Response and Restoration, Seattle, WA

Use of dispersants was very limited in the U.S. prior to the Deepwater Horizon (DWH) oil spill in 2010. For that spill, the volume of dispersants applied as well as the subsea injection as a countermeasure, was unprecedented. It has been suggested that dispersants could be a response option to a large oil spill in the Arctic, particularly because of the remoteness and harsh environmental conditions. One of the outcomes of a 2014 Arctic oil spill drill for senior U.S. agency leadership identified the need for a definitive evaluation of the state-of-science of dispersants and dispersed oil (DDO), particularly as it applies to Arctic waters. The Coastal Response Research Center (CRRC) convened five panels of governmental, academic, NGO, and private sector experts to determine the state of DDO science, specifically knowns and uncertainties. The panels focused on the following five topics: Efficacy and Effectiveness; Physical Transport and Chemical Behavior; Degradation and Fate; Public Health and Food Security; and Eco-Toxicity and Sublethal Impacts. Activities conducted by the CRRC included: collating and constructing a database of the existing scientific literature, and facilitating the discussions of each panel of scientists over a period of 2 years. Once each panel had formulated its document regarding the state-of-science (i.e., knowns and uncertainties) regarding DDO, the CRRC requested written input from the public on what to add, remove or change about these statements. Finally, each panel reviewed the public input and decided upon its final statements of knowns and uncertainties for each of the five topics. This paper will present a summary of these statements and their implications for the use of dispersants in oil spill response in U.S. Arctic waters, but this has a very direct impact for the Gulf of Mexico as well, since a tremendous amount of scientific data resulted from DWH.



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## Session 002: Decision Support and Integration Tools for Response and Restoration

### Using Mechanistic Models to Maximize Ecosystem Service Benefits for Coastal Ecosystem Restoration Projects

**E. Blancher**, M. Goecker
Moffatt & Nichol, Mobile, AL

Through settlement of the Deepwater Horizon oil spill the Gulf of Mexico region will receive unprecedented amounts of restoration money for ecosystem level restoration. To maximize the success of this restoration opportunity, it is imperative that decisions on appropriate restoration projects are backed by good science of the current value of projects and future value due to climate change or storm driven physical changes. One way of maximizing ecosystem success of coastal restoration projects is by the use of mechanistic models to predict potential future environmental changes that may be different than any that have been currently observed at habitat landscape positions. Mechanistic models have better predictive abilities than their empirical counterparts in that they can reasonably predict system changes beyond those that have occurred in observational history. Also they can predict the success of the reestablishment of habitats given current and future environmental conditions. AQUATOX 3.1 NME was calibrated for Northern Gulf Coast coastal submerged habitats along Mississippi and Alabama, and used to predict both the baseline productivity and injury from Deepwater Horizon oil. The model has been successfully calibrated for a number of habitats including oyster reef, marsh edge (with and without SAV), beach edge (low and high energy) and estuarine soft bottom. The calibrated model can be used to simulate both physical changes (such as increase reef complexity or marsh edge) as well as typical estuarine ecological forcing functions such as temperature, salinity, total suspended solids or oxygen. It can also predict the success or restoration projects under a variety of stressor conditions. We describe the current model calibrations and illustrate model response under changing physical, chemical and biological conditions. We also compare production estimates from AQUATOX baseline simulations for a series of potential restoration sites in Mississippi Sound and Mobile Bay.

### A Spatial Decision-Support Tool for Marine Biodiversity and Petrochemical Vulnerability in the Gulf of Mexico Large Marine Ecosystem

**B. Polidoro**[1], K. Strongin[1], G. Ralph[2], K. Carpenter[2]
[1]Arizona State University, Glendale, AZ, [2]Old Dominion University, Norfolk, VA

The vast majority of marine species present across the Gulf of Mexico Large Marine Ecosystem (LME), which includes U.S., Mexican and Cuban exclusive economic zones, have not been systematically reviewed for population status and relative risk to major threats, including petrochemical exposure and sensitivity. There is a need for improved comprehensive species information, including species risk assessments, in order to more effectively select and prioritize species, habitats and ecosystems for improved management, restoration and recovery. The oil and gas industries operating in the Gulf of Mexico recognize the need to maintain sustainable business practices and to reduce their impact on marine biodiversity, while also protecting their return on investment and managing business risk. A prototype spatially explicit decision-support tool, that will incorporate trait-based species petrochemical vulnerability rankings, has been developed for the purposes of expanding current efforts to include species-specific data for more than 2,000 marine species present in the Gulf of Mexico LME



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(including all known vertebrates, primary habitat producers, and complete clades of selected invertebrate groups). The resulting data and species vulnerability rankings, along with other species-specific information, can be integrated into several existing marine biodiversity decision-making tools currently in use across the region by conservation organizations, the oil and gas industry and regulatory agencies. Integration of these data and the petrochemical vulnerability index into currently existing species' databases and decision-tools will transform the current capacity of oil and gas industries, as well as conservation organizations, to effectively prioritize geographic areas, ecosystems, and specific species for improved management, restoration, recovery, mitigation and research across the Gulf of Mexico LME.

Numerical Study on Louisiana Coastal Marsh under Hurricane Induced Wave and Current

**M. Shahriar***, J. Wang
Louisiana Tech University, Ruston, LA

Considering the past history and future risk of hurricane in the USA, well understood storm protection plans are needed to shelter the important areas of the population and economy, specially within southeastern Louisiana. It is extensively assumed that marshes offer protection from hurricane though the degree of this protection is not well measured due to the complex physics involved in this overall system. Consequently, a particular method to quantify the effect of marshes on coastal hurricane damage prevention is required. A Delft3D wave flow coupled model was applied on the Louisiana coastal marsh near Calcasieu Lake to access the contribution of marsh vegetation in reducing hurricane induced wave and current action. The objective of this study is to develop an integrated wind, current, wave modeling system for the Louisiana coast under hurricane conditions. Hurricane Ike in 2008 is chosen as an example to study the marsh contribution during hurricane. Results suggest that the marshes do have the potential to reduce hurricane induced stresses. It has also been found that the marsh with lower elevation experienced less damage than higher elevation marsh. However, lower elevation marsh will allow more flood water to propagate inland from coast. This indicates that for extreme hurricane, two segments of marsh lower elevation marsh near coast and higher elevation marsh near inland may offer comparable surge protection to that of an only high elevated marsh.

Novel Spatio-Temporal Tools for Simulating Oil Spills, Measuring Impacts, and Understanding Response Needs

**L. F. Romeo**
National Energy Technology Laboratory, Albany, OR

Substantial amounts of data and information on oil spills are being developed by numerous sources resulting in a great deal of data, ranging in format and size. Researchers at the Department of Energy's National Energy Technology Laboratory (NETL) and Pacific Northwest National Laboratory (PNNL) have created a suite of spatio-temporal tools to synthesize information from these aforementioned disparate sources that are critical for robust offshore oil spill preparedness and planning efforts. This suite includes the Blowout and Spill Occurrence Model (BLOSOM), Cumulative Spatial Impact Layers (CSILs) and the Spatially Weighted Impact Model (SWIM). These tools underpin a workflow, enabling users to quickly evaluate potential spills and assess where and when areas are most vulnerable. BLOSOM is a comprehensive 4-dimensional model, enabling users to follow the fate and transport of offshore oil spills and blowouts. CSILs are a set of GIS-based tools that are used to consume impact and response-related data, and assess the potential environmental and socio-economic impacts associated



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with offshore oil spills. SWIM is a multi-attribute decision analysis tool that leverages BLOSOM and CSIL outputs, to compare and rank different spill scenarios and incorporate weights for assessing stakeholder priorities. Each of these innovative tools have been designed to work in conjunction with one another for a streamlined approach, and have been implemented with some simulations similar to past events and others modeling worst case discharge scenarios of offshore oil spills in U.S. waters. This presentation will demonstrate the functionality of BLOSOM, CSILs, and SWIM, and focus on how these tools efficiently digest big data from an array of sources and create consumable outputs for a range of users. Example scenarios will be presented for multiple regions, including the Gulf of Mexico, showcasing how the tools allow enable better decision-making by responders and resource managers.

Synthesizing Ocean Observing and Modeling to Guide Estimates of Human Exposure and Risk

**H. M. Solo-Gabriele**[1], A. Ferguson[2]
[1]University of Miami, Coral Gables, FL, [2]University of Arkansas for Medical Sciences, Little Rock, AR

During and after the Deepwater Horizon oil spill, tourism suffered throughout the Gulf of Mexico including areas not impacted by the spill. This was partially due to limitations in estimating and communicating oil spill chemical trajectories, subsequent coastal impacts, and ultimately potential human exposure and health risks. Here we propose a method for synthesizing oceanography and health risk assessment data for the purpose of simulating human exposures and risks from oil spills. This presentation will focus on the approach, data needs, and how the data synthesis approach would benefit the community and officials. The proposed approach combines environmental data and an existing oceanographic fate and transport model (NOAA's GNOME/TAP) to estimate contaminant concentrations relevant to human exposures. These concentrations can be further synthesized with new activity and uptake databases, stratified by population-level socio-cultural factors, to estimate exposure and health risks. Three scenarios are to be considered: first responders, children playing at the beach, and shellfish consumers. To validate the new approach, we propose evaluating the DWH oil spill retrospectively by comparing simulated human exposure and health risks against available health data and health-based decisions implemented during the DWH event. Results are to be shown on an easy to understand map illustrating the spatial distribution of health risks for each scenario considered. By mapping health risks, better decisions will be facilitated through the visualization of safe versus hazardous areas. Ultimately through improved visualization of risks, the results of the proposed approach will contribute toward optimizing emergency response, minimizing human health impacts, and reducing economic losses of future events.

Can Social Media Inform Disaster Response?

**M. Allaire**[1, 2]
[1]Columbia University, New York, NY, [2]University of North Carolina at Chapel Hill, Chapel Hill, NC

This paper is the first to investigate the role of online information and social media in enabling communities to reduce disaster impacts. The historic 2011 Bangkok flood is utilized as a case study to assess how internet use allowed households to mitigate flood losses. This event was one of the first major disasters to affect a substantial population connected to social media. The role of online information is investigated with a mixed methods approach, using both quantitative (propensity score matching and multivariate regression analysis) and qualitative (in-depth interviews) techniques. The study relies on two data sources survey responses from 469 households and in-depth interviews with internet users who are a subset of the survey participants. Propensity score matching indicates that



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social media use enabled households to reduce mean total losses by 37%, using a nearest neighbor estimator. Average loss reductions amounted to USD 3,708 to USD 4,886, depending on the matching estimator. In addition, regression analysis suggests that social media use is associated with lower flood losses (average reduction of USD 2,784).

Social media offered information that was not available from other sources, such as localized and nearly real-time updates of flood location and depth. With knowledge of current flood conditions, households could move belongings to higher ground before floodwaters arrived. These findings suggest that utilizing social media users as sensors could better inform populations during natural disasters, particularly in locations that lack real-time, accurate flood monitoring networks. There is also an enormous opportunity for disseminating government disaster communication through social media. Overall, the study reveals that online information can enable effective disaster preparedness and reduce impacts.

Proactively Planning for Extreme Oil Spill Events and Optimizing Response Efforts

**T. Grubesic**[1], R. Wei[2], J. Nelson[1]
[1]Arizona State University, Phoenix, AZ, [2]University of Utah, Salt Lake City, UT

In the United States, there is a growing interest in the vulnerability of complex social, economic and environmental systems. For example, consider the impacts of the BP Deepwater Horizon oil spill of 2010. In addition to the release of ~4.5 million barrels of oil into the Gulf of Mexico (GOM), eleven workers on the platform died, the spill lasted nearly three months, and, at its peak, almost 87,000 square miles of fishable waters were closed. With 537,000 ocean sector employees and nearly $98 billion in gross domestic product (GDP) tied to these waters, the impacts of the Deepwater Horizon explosion and oil spill on the U.S. economy, environment, and hundreds of communities ringing the GOM were significant. Questions pertaining to the resilience of coastal communities, broadly defined (e.g., social, economic, environmental, cultural), are important when developing mitigation strategies for extreme events. So too are the operational challenges associated with allocating and dispatching human resources, equipment and supplies to areas impacted by a disaster. The purpose of this paper is to illustrate the development and application of advanced oil spill simulation techniques in combination with a mathematical model to optimize the allocation of response crews and equipment in both marine and terrestrial environments. Further, given the sensitive nature of the Gulf of Mexico coastline, the developed mathematical model is explicitly structured to account for “hotspots” of vulnerable areas for prioritizing response efforts. 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.



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Improving Environmental Information Sharing Through a Collaborative Environmental and Project Data Platform

**B. Shorr**[1], A. Merten[1], D. Hudgens[2], A. Jones[3], N. Etre[2], M. McGuire[4], M. Peccini[5]
[1]NOAA, Seattle, WA, [2]IEc, Cambridge, MA, [3]IEc, IEc, MA, [4]NOAA, St. Petersburg, FL, [5]NOAA, Silver Spring, MD

The Deepwater Horizon oil spill in the Gulf of Mexico in 2010 and the resulting Natural Resource Damage Assessment (NRDA) have generated unprecedented amounts of environmental data and analysis. As a trustee for Natural Resources, NOAA's Damage Assessment, Remediation and Restoration Program addressed this challenge by leveraging "big data" techniques and developing a data warehouse and information portal built with Open Source tools for ingesting, integrating and organizing information. We have now re-developed our NRDA focused data management application known as DIVER (Data Integration Visualization Exploration and Reporting) to fully support NRDA funded restoration projects and team collaboration. In addition to data models that explicitly integrate data from many different sources, and tools to support data integration, we directly connect to field collected information with lab results and supporting information. We further developed custom query tools (called DIVER Explorer) which facilitate searching across all data holdings with an interactive dashboard of charts, tables, a map, and ISO metadata. This novel data management and query approach forms a primary portal for searching the injury assessment and restoration monitoring data and projects, and also supports the delivery of project information through simple web mapping applications, such as the Restoration Story Map (http://www.restoration.noaa.gov/DWH/storymap/?). Our team has also recently updated the publicly accessible Deepwater Horizon DIVER application (https://www.diver.orr.noaa.gov), providing the scientific community with the ability to explore and export a vast amount of environmental data, analysis and results, in addition to Restoration project information.

Tools for Managing the Wealth of DWH Monitoring Data Associated With Early and Ongoing Restoration

**A. S. Jones**[1], N. Eckhardt[2], J. Redding[3], B. Shorr[2]
[1]Industrial Economics, Cambridge, MA, [2]NOAA, Seattle, WA, [3]NOAA, Silver Spring, MD

The DWH natural resource trustees are undertaking a massive restoration program in the Gulf, applying an ecosystem restoration approach. Restoration project monitoring ensures that project goals are being met, and supports adaptive management. 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. In particular, we have developed a series of templates, standardized fields, and valid values to bring in data consistent with DIVER's common models.

Monitoring data consists largely of field-based assessments of habitat and resource restoration projects. These data provide a wealth of information to the general restoration community on the trajectories and expectations for different project types. DIVER employs a system of flexible data templates to collect these field measurements and present them for querying and export. The templates provide a target structure and valid values to produce data with a consistent format, while also including flexibility adapt to changes in the data types and organization needs, or integration of



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existing data structures. The system allows for either preparation of templates which specifically match field forms to facilitate transcription, or conversion guides to convert existing data sources to the DIVER field measurement structure. On export, users have access to raw files and supporting project documentation. DIVER can also provide control over the sharing status of files and data. These same data types and templates are relevant to field-based injury assessments, remediation evaluation, and routine monitoring.

Satellite-based decision-support tools to monitor algal blooms and assess water quality in near real-time

**C. Hu**[1], B. B. Barnes[1], B. Murch[1], P. Carlson[1], R. Weisberg[1], L. Zheng[1], K. Atwood[2], J. Lenes[1]
[1]University of South Florida, St. Petersburg, FL, [2]Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL

There are a variety of pressing needs by different user and research communities for ocean observing, for example to detect and track algal blooms as well as to monitor coastal and inland water quality in near real-time. However, such needs are often hindered by lack of resources to perform routine field surveys. On the other hand, the technology used to detect and quantify harmful algal blooms (HABs, commonly known as red tides), macroalgal blooms (e.g., *Sargassum* blooms, Ulva blooms), and to quantify the various water quality states from satellite remote sensing has improved considerably in the past decade. A remaining challenge is effective delivery of the information generated from these advances in a user-friendly way to a diverse group of stakeholders. Here, we demonstrate a near real-time satellite based system to detect and track algae blooms and monitor coastal and inland water quality in several coastal regions, which has been operated for several years. The system integrates different data products through a custom-made web interface. Specifically, three sub-systems have been established: A *Sargassum* Watch System to integrate data products for detecting and tracking pelagic *Sargassum* rafts in the Intra-Americas Sea and Atlantic, a red tide monitoring system to integrate field observations, satellite imagery, and numerical modeling results, and a Virtual Buoy System to monitor current water quality states in estuaries and coastal waters. These near real-time integrated data products are updated daily or weekly with full Google-Earth compatibility, thus providing useful tools for observing the coastal and inland water environments.

The Gulf of Mexico Coastal Ocean Observing System: Data and Product Portals

**M. K. Howard**[1], F. C. Gayanilo[2], S. Kobara[1], R. D. Currier[1], M. Stössel[1], S. K. Baum[1]
[1]Texas A&M University, College Station, TX, [2]Texas A&M University, Corpus Christi, TX

The Gulf of Mexico Coastal Ocean Observing System Regional Association (GCOOS-RA) is one of 11 regional observing systems which comprise the non-federal portion of the U.S. Integrated Ocean Observing System (IOOS). The IOOS vision is to deploy and maintain automated and largely-unattended data systems which deliver high-quality data and model output to end users in preferred forms and formats free of charge. GCOOS' initial focus was on near real-time and historical observations of physical oceanographic, marine meteorological, biogeochemical and river discharge data. Since then we have added observations of fish and plankton and we may soon add observations of marine mammals. Our holdings include: data from more than 1500 near real-time sensors, historical data from large and small oceanographic field studies, comprehensive reanalyses for offshore physical oceanographic, dissolved oxygen and nutrients and hindcast/forecasts of atmospheric and ocean circulations models. In addition to the Data Portal, GCOOS maintains a Products Portal that contains



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information on: current environmental conditions, sea level rise scenarios, invasive species, bathymetry and coastlines, and pages of interest to boaters, citizen scientists and others. GCOOS-RA has been renewed until 2021 and is keeping abreast of opportunities to serve the Restoration community along with the Gulf of Mexico Research Initiative Information and Data Cooperative and NOAA's Office of Response and Restoration.

Tools for Understanding Large Marine Vertebrate Population Status, Trends and Connectivity in the Gulf of Mexico and Beyond

**F. Gayanilo**[1], R. Currier[2], M. K. Howard[2], B. Kirkpatrick[2], C. Simoniello[2], S. Watson[3]
[1]Texas A&M University, Corpus Christi, TX, [2]Texas A&M University, College Station, TX, [3]Consultant in Ocean Observing Systems, Coastal Management, and Data Management, Mandeville, LA

The Gulf of Mexico Coastal Ocean Observing System Regional Association (GCOOS-RA) is a partner in several initiatives, which are developing tools to improve the understanding and protection of large marine vertebrate populations in the Gulf of Mexico. In this presentation, we will provide overviews of the following activities to support restoration of large marine vertebrate populations:

- Marine Mammal Health Monitoring and Analysis Platform (MMHMAP) - an initiative of the Marine Mammal Commission to design an information system to collect, curate and distribute data on marine mammal health for the public, scientists and resource managers. The information system will enable the use of marine mammals as sentinel species to help identify potential public and animal health risks and prioritize management, restoration, and conservation efforts.
- Integrated Tracking of Aquatic Animals in the Gulf of Mexico (iTAG) - a web-based tool developed to enhance data sharing for the animal telemetry network in the Gulf of Mexico, as part of the national Animal Telemetry Network. The network data include not only the locations and tracks of aquatic animals, but also the associated oceanographic conditions.
- GCOOS Data Portal - A Gulf of Mexico data portal providing access to data collected from 1600+ sensors reporting hourly or more often; and
- Sperm Whale Seismic Study Data Portal - a data portal providing access to data and information on sperm whales and their responses to seismic exploration in the Gulf of Mexico collected through a public-private collaborative research effort from 2002-2005.

We will conclude with a summary of how the GCOOS-RA can continue to partner with other initiatives to improve the understanding of large marine vertebrate populations in the Gulf of Mexico.



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## Session 003: Understanding Ocean Surface Currents in Relation to Oil Spill Response

Concentration of Floating Material by Frontal Convergence
**E. D'Asaro**[1], T. CARTHE[2];
[1]University of Washington, Seattle, WA, [2]University of Miami, Miami, FL

An array of ~300 surface drifters drogued to follow the top 0.6m of the ocean were deployed in the northern Gulf of Mexico near the Deep Water Horizon spill site in January of 2016 as part of the LASER experiment. As expected, the array spread from its initial 15x15km scale with the second moment increasing at a rate roughly consistent with historical dispersion curves. More surprisingly, a large fraction of the drifters accumulated within a km-scale submesoscale eddy and grouped into clusters often only a few meters apart. This occurred due to surface convergence, as opposed to purely confluence, with convergence rates of many f feeding downward-going subduction zones with vertical velocities of a few centimeters per second. These convergences preferentially occurred at density fronts and in particular at junctions of density fronts on the periphery of submesoscale eddies. These observations complement the traditional view of lateral dispersion of surface particles by mesoscale eddies with a competing submesoscale convergence. They provide a mechanism to concentrate oil at such convergence zones and a framework for computing the statistics of its km scale distribution.

Diagnosing the Surface Dynamical Balance from Massive Drifter Release
**A. Y. Shcherbina**, E. A. D'Asaro
University of Washington, Seattle, WA

The recent Gulf of Mexico Lagrangian Submesoscale Experiment (LASER) has demonstrated that massive drifter releases are an effective way to sample ocean surface currents at the scales of 0.1-100 km. In addition to highlighting coherent structures within the surface turbulence, drifter trajectories can be used to gain insight into the ocean surface dynamics.

The drifters are idealized as Lagrangian particles whose motion is determined by the balance of wind stress, pressure (or sea-surface height) gradient, and Coriolis force. Instantaneous balance of these terms can be inferred from the trajectory of each drifter. Dominating terms allow us to classify the dynamics into a number of classic balance approximations, such as geostrophy, cyclostrophy, gradient-wind, Ekman, or inertial flows.

A dense “bunch” of drifter trajectories allows drawing of synoptic maps of the dynamical balance. These maps expose the dynamical backbone of the surface material transport and reveal particular combinations of forces responsible for formation of coherent structures of the surface flow.

Aerial Observations of Submesoscale Flows
**J. Molemaker**
UCLA, Los Angeles, CA

During the LASER experiment, aerial observations of SST were made over the Gulf of Mexico during the wintertime. A total of about 400,000 infrared images were collected with a spatial resolution of a few



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meters. A highly accurate GNSS assisted IMU recorded position and attitude data that allowed the mosaicing of these images in maps spanning scales of tens of kilometers. On board processing made it possible to provide real time geo-referenced SST information to the surface vessels over a radio based ethernet connection. The aerial imagery was an essential part of the LASER campaign to assist in the targeting of flow features for drifter deployments. This his unique approach has revealed structures in the SST field and the underlying surface flow field that have not been observed before

Near Surface and Mixed Layer Turbulence Measurements in LASER 2016 Experiment
**D. Bogucki**, B. Mohammad, M. Segler, M. Segler, L. Francis
Texas A&M University-Corpus Christi, Corpus Christi, TX

As a part of the LAgrangian Submesoscale ExpeRiment (LASER) we have collected turbulence profiles from aboard the R/V F.G. Walton Smith in the Northern part of the Gulf of Mexico (near the DeSoto Canyon) in January 2016.

In the experiment used two instruments to characterize upper ocean turbulence: OTS (Optical Turbulence Sensor) operating 0- 2.5 m below surface and the Vertical Microstructure Profiler (VMP) operating from 5m down to 100 m (downcast) from 30m to ~0.5 m below surface while in the upcast mode.

We have collected comprehensive upper ocean microstructure data set, 70 VMP vertical profiles during 2 days and OTS over 10 million OTS temperature spectra during day long deployment. Preliminary results show existence of a number of strongly dissipating layers with typically strongest one extending from 2m to 10 m below surface.

The horizontal TKE variability exhibited variability on the scale of 100m possibly related to submesoscale structures. In the presentation we discuss the observed turbulent variability in the context of turbulent dispersion and remote sensing.

Small-scale Structure and Dynamics of Surface Oil Spills in the Presence of Dispersants: Laboratory Experiment and Numerical Simulation
**A. V. Soloviev**[1], B. K. Haus[2], M. G. McGauley[1], C. W. Dean[1], D. G. Ortiz-Suslow[2], N. J. M. Laxague[2], T. M. Ozgokmen[2]
[1]Halmos College of Natural Sciences and Oceanography, Nova Southeastern University, Dania Beach, FL, [2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL

Propagation of oil spills is a complex process involving capillary effects, dispersion, evaporation, dissolution, adsorption, emulsification, photo oxidation, and biodegradation. As seen during the Deepwater Horizon event in the Gulf of Mexico during 2010, one critical problem remaining for the prediction of oil transport and dispersion in the marine environment is the small-scale structure and dynamics of surface oil spills. To address this problem, we are conducting a series of laboratory and numerical experiments. The experiments are performed in a small air-sea interaction tank, which is a part of the SUrge STructure Atmosphere INteraction (SUSTAIN) facility at the University of Miami. The first set of laboratory experiments focused on understanding the differences between the surface dynamics of crude and weathered oil spills and the effect of dispersants. A drop of crude oil deposited on the still water surface quickly spread into a thin slick; in contrast, a drop of weathered oil did not



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significantly evolve in time. The crude and weathered oil slicks also responded differently to the application of dispersant - the crude oil slick either quickly contracted or fragmented into narrow wedges and tiny drops, while the weathered oil slick did not show significant change in size or topology. We have implemented an ANSYS Fluent multi-phase volume of fluid computational fluid dynamics (CFD) model incorporating capillary forces to explain features observed in laboratory experiments. The laboratory experiments aid in verification of the CFD model. We are in the process of implementing the same approach for studying the effect of emulsification with and without the application of dispersants for fresh and salt water. We are also planning to implement this approach to investigate other physical-chemical processes associated with the propagation of oil spills with the ultimate goal of improving oil spill transport models and response strategies.

Observations and Simulations of Thermohaline Stratification and Surface Currents on the Central Louisiana Continental Shelf (LCS)

**J. K. Jolliff**, E. Jarosz, T. Smith, S. Ladner, J. Dykes
Naval Research Laboratory, Stennis Space Center, MS

Over a two-week period in June 2015, an array of ADCP moorings was deployed in the central LCS/South Timbalier Federal lease block area. Anomalous atmospheric conditions and associated prevailing winds forced the withdraw and return of the surface Mississippi River plume into the main study area during the field experiment. Surface swell associated with Tropical Storm Bill resulted in near shore significant wave heights in excess of 3.5 meters. The contrast between the presence and absence of the river plume, and the associated thermohaline stratification, enabled a comparative analysis of the surface Ekman layer and vertical current shear under these contrasting conditions. A series of numerical experiments using the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) were then performed under various scenarios of two-way coupling to additional models: a bio-optical submodel and the Simulating Waves Nearshore (SWAN) model. The impact of optical attenuation contributions to surface buoyancy as well as the impact of turbulence from elevated sea state upon the surface ocean circulation were evaluated in the context of the model results and the dataset. Understanding these impacts is important for potential forecasting of spilled oil trajectories because (1) many ocean circulation models do not resolve or parameterize these impacts; and (2) these same circulation models are often used as the basis for oil trajectory forecasts.

Observing the Air-Sea Interface in Gulf of Mexico Frontal Zones

**B. K. Haus**
University of Miami, Miami, FL

The air-sea interface is of primary importance for prediction of the transport of most oil spills. Buoyant material collects on the interface where it can form layers ranging from a single molecule thick to a few mm in thickness. This oil can then be transformed by the evaporation of volatile components, degradation by solar radiation and bacteria and mixing by turbulent motions. At the surface the oil is also accessible for various response methods including dispersant application, burning and skimming. It is therefore very important to understand the manner in which winds, waves and currents combine to move the surface layer and to create lines of convergent flow that trap oil as was commonly observed during the Deepwater Horizon event. Unfortunately the transport of this very near-surface layer is very difficult to measure and model using existing technologies. Here we exploit innovative Lagrangian drifter, optical and radar sensing approaches to measuring this very near surface layer of the ocean.



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These techniques were developed by CARTHE consortium researchers through extensive laboratory studies in the University of Miami's SUrge-STructure-Atmosphere INteraction (SUSTAIN) laboratory and then implemented in the Lagrangian Submesoscale Experiment (LASER) in January 2016. Very near surface ( within less than 1 cm) currents and short surface waves were obtained using shipboard polarimetric imaging techniques over m-scale spatial domains, while larger scale (up to 3 km) flows were mapped with radar imaging techniques. Simultaneous long wave as well as momentum, heat and vapor fluxes were observed. Combination of this information with simultaneous large scale drifter releases provided unprecedented insight into the transport of the ocean surface layer which was observed to respond to the wind even in opposing mean currents.

Weather Conditions and Sea States during LASER

**S. S. Chen**[1], M. Curcic[2], F. Judt[2]
[1]RSMAS, University of Miami, Miami, FL, [2]University of Miami, Miami, FL

Recent observations and numerical model simulations over the Gulf of Mexico have advanced our understanding the ocean circulation and transport. However, the variability of the winds and waves and their impacts the ocean circulation, especially on submesoscale and mesoscale upper ocean circulation, are still not well understood. The LAgrangian Submesoscale Experiment (LASER) took place in early spring 2016. Several strong winter storms passed through the northern Gulf, which has significant impacts on the ocean circulation during LASER. This study investigate the interactions among the extreme weather conditions (e.g., strong winds with rapid changes in wind direction and decreasing in air temperature associated with cold fronts), sea states (large waves), and upper ocean circulation using both observations and a cloud-resolving high-resolution coupled atmosphere-wave-ocean model. We will examine both thermodynamic and dynamic processes of the atmospheric and ocean boundary layers in presences of large surface waves and their impacts on the upper ocean circulation.

Open Ocean Observations of Small-Scale Near-Surface Dispersion using the Ship-Tethered Aerostat Remote Sensing System (STARRS)

**D. F. Carlson**[1], J. Mensa[2], G. Novelli[3], C. Guigand[3], T. Ozgokmen[3], M. Curcic[3], E. Ryan[3], S. Mehta[3], M. Rebozo[3], E. D'Asaro[4]
[1]Florida State University, Tallahassee, FL, [2]Yale University, New Haven, CT, [3]University of Miami, Miami, FL, [4]University of Washington, Seattle, WA

Observations of small-scale (10-100 m and minute to hours), near-surface dispersion are currently lacking as existing in situ and remote sensing systems cannot resolve these scales in the deep, open-ocean environment. Such observations, however, are crucial for understanding transport and mixing of tracers, like oil, and for the development of improved parameterizations of unresolved mixing in ocean models. The Ship-Tethered Aerostat Remote Sensing System (STARRS) was developed to make the first such observations of small-scale, near-surface dispersion. STARRS uses a high-lift-capacity aerostat to acquire sequences of high-resolution imagery. Drift cards seeded in the field of view are used to compute dispersion ellipses. STARRS experiments were conducted during the Consortium for Advanced Research on the Transport of Hydrocarbons in the Environment's (CARTHE) LAgrangian Submesoscale ExpeRiment (LASER) in January-February 2016 in the northern Gulf of Mexico and results from selected experiments are presented here. To our knowledge, these observations constitute the first quantitative measurements of the ocean velocity field in the upper few millimeters, and therefore are very relevant to oil spill response efforts.



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Clustering and Dispersion at the Ocean Surface in the Presence of Langmuir Circulation
**H. Chang**[1], H. S. Huntley[1], A. D. Kirwan[1], D. Carlson[2], J. Mensa[3], G. Novelli[4], S. Dalziel[5], A. Poje[6], L. CARTHE team[4]
[1]University of Delaware, Newark, DE, [2]Florida State University, Tallahassee, FL, [3]Yale University, New Haven, CT, [4]University of Miami, Miami, FL, [5]University of Cambridge, Cambridge, United Kingdom, [6]City University of New York, New York, NY

During the recent Lagrangian Submesoscale Experiment (LASER), hundreds of biodegradable bamboo plates were released on the ocean surface and tracked via a high resolution aerostat-mounted camera. Spatial separations of 0.1 m to 0.1 km were observed on time scales of 15 seconds to several hours. This provides the unique opportunity to study clustering and dispersion on these scales. We describe the formation, evolution, and redistribution of clusters of plates in the presence of Langmuir circulation. The results presented here provide insight into dispersive processes at these scales that also significantly impact oil at the ocean surface.

How Do Surface Floats and Drift Cards Move Compared to Oil?
**G. Novelli**[1], C. M. Guigand[1], T. M. Özgökmen[1], M. C. Boufadel[2]
[1]University of Miami, Miami, FL, [2]New Jersey Institute of Technology, Newark, NJ

Marine oil spills are known to spread at the sea surface as thin slicks where they are advected by currents, but their fate is also significantly coupled to winds and wave conditions. Oil trajectories are not well predicted because the ocean's surface layer, at the interface between the ocean and atmosphere, is currently not well described in numerical models. One of the goals of the Lagrangian Submesoscale Experiment (LASER) was to measure the velocity and dispersion of material at the surface layer, by tracking the motion of thousands of bamboo plates (drift cards) from a high-resolution aerostat-mounted camera and hundreds of GPS-tracked floats. But how do these Lagrangian instruments move with respect to oil slicks?

In order to understand that, we released side-by-side oil, drift cards, and surface floats under controlled wave conditions at the Ohmsett facility, while aerial images of the trajectories were collected. The motion of these materials for selected waves will be compared in terms of their velocities and relative dispersion properties, at scales ranging from 1 m to 30 m and 1 s to 200 s. The results will allow us to use the LASER data-set to improve oil spill models predictions.

A laboratory study on the impact of breaking waves on near-surface processes
**W. Drennan**[1], L. Shen[2]
[1]University of Miami, Miami, FL, [2]University of Minnesota, St. Anthony Falls, MN

As part of GoMRI project "Investigation of Oil-Spill Transport in a Coupled Wind-Wave-Current Environment using Simulation and Laboratory Studies" (GoMRI 2015-V-258), we use the University of Miami's SUSTAIN laboratory to study wind-wave-current interactions at high winds. While the project ultimately focuses on the transport of oil near the interface in these conditions (and on the impact of oil on the surface process themselves), here we report the early results on high wind processes in a clean environment. In particular, we report on near surface (aqueous) profiles of current and



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turbulence in a variety of wind-wave-current conditions, as well as on vertical profiles of spray distribution.

The Mississippi River Void

**G. Jacobs**[1], A. Bracco[2], E. D'Asaro[3], C. Dean[4], A. Soloviev[5], R. Harcourt[3], T. Ozgokmen[6], P. Spence[7], I. Soto Ramos[8], S. Parra[1]
[1]Naval Research Laboratory, Stennis Space Center, MS, [2]Georgia Tech, Atlanta, GA, [3]University of Washington, Seattle, WA, [4]Nova Southeastern University, Fort Lauderdale, FL, [5]Nova Southeastern University, Fort Lauderdale, FL, [6]Rosentiel school for Marine and Atmospheric Science, Miami, FL, [7]Vencore, Stennis Space Center, MS, [8]University of Southern Mississippi, Stennis Space Center, MS

Numerical model experiments reveal a mechanism that allows large ocean areas to be stripped of surface material rapidly. This occurs through an interaction of winds on a surface fresh water layer such as the Mississippi River plume. While the river outflow can transport material away from the river mouth, this is a small effect compared to the action of wind stress over the area covered by the fresh water plume. The strong stratification beneath the fresh water plume inhibits the vertical mixing of momentum injected into the ocean from the atmosphere. Surface currents in areas of fresh water reach substantially higher speeds than surrounding waters during wind events. This mechanism transports surface material toward the salinity front at the edge of the plume. An additional mechanism plays a role in the front where high speed fresh water meets low speed salty water. In this area of confluence, a surface convergence front forms due to frontogenesis, and the convergence pulls material into the front. The convergence front dissipates by two mechanisms. Since wind bursts create the effects, the strong fresh water currents rotate as inertial oscillations. When the fresh water currents align with the front, the confluence and convergence cease. As mixing beneath the fresh water intensifies, the fresh water current speeds decrease and the confluence and convergence cease.

The effects are examined during the CARTHE LASER experiment in January, 2016. During this time, the Mississippi River outflow was substantially higher than normal due to large rainfall events, and observed river transports were incorporated into the model experiments. Also, a week long calm wind period preceded the LASER experiment. These resulted in a large well stratified river plume in the model experiments. Surface drifter evolution is consistent with this mechanism. Glider and mooring data during the CONCORDE experiments also provide information that is consistent with the mechanisms observed in the model results.

Impacts of Mississippi riverine input on submesoscale features in the northern Gulf of Mexico: Lagrangian perspective

**J. Choi**[1], R. Barkan[2], A. Bracco[1], J. C. McWilliams[2]
[1]Georgia Institute of Technology, Atlanta, GA, [2]University of California Los Angeles, Los Angeles, CA

The impact of the Mississippi riverine input on the transport and mixing properties of Lagrangian tracers in the northern Gulf of Mexico is investigated in summer (August) and winter (February). In order to isolate the riverine effects in both representative months, Lagrangian passive tracer are advected into simulations performed with the Regional Ocean Modeling System (ROMS) with and without riverine input at 500m and 1500m horizontal grid resolutions. Different deployment strategies and the dependence of the statistics on the number of tracers and their release location are investigated. We focus on traditional dispersion statistics, Finite Size Lyapunov exponents, and on the



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evolution of the probability density function of velocity, divergence, vorticity and strain sampled by particles. The presence of a diurnal cycle of submesoscale properties and its implications for the Lagrangian tracers are also discussed.

River induced fronts and influence of shelf and mesoscale circulation on offshore removal of riverine waters: implications for hydrocarbon transport

**V. Kourafalou**[1], Y. Androulidakis[1], M. Le Henaff[1], H. Kang[1], O. Garcia[2], C. Hu[3], L. Hole[4], C. Wettre[4]
[1]University of Miami, Miami, FL, [2]Water Mapping, LLC, Tallahassee, FL, [3]University of South Florida, Saint Petersburg, FL, [4]Norway Meteorological Institute, Bergen, Norway

The complex topography in the Gulf of Mexico promotes interaction of coastal and shelf flows with the basin-wide mesoscale circulation. We focus on the dynamics of river induced fronts and the associated near-surface circulation regimes, under the influence of buoyancy-driven and wind-driven flows and the variability of the Loop Current and associated eddies, especially anticyclonic LCEs (Loop Current Eddies) and cyclonic LCFEs (Loop Current Frontal Eddies). We seek to understand a) how such interactions influence the transport and fate of riverine waters and b) how the resulting fronts influence hydrocarbon transport. In addition to major near surface circulation patterns and density fronts induced by the Mississippi River (under variable river discharge and wind conditions), the role of smaller rivers on shelf break exchanges will be discussed. These were found to influence the event of unusual coral mortality in the Flower Garden Banks during summer 2016. The related pathways of nutrient-rich riverine waters were a unique case. The results expand the understanding of multiple scenarios of hydrocarbon transport in case of oil spills.

A Navy Coastal Ocean Model of the Gulf of Mexico with Observed River Transport

**B. P. Bartels**[1], P. L. Spence[1], G. A. Jacobs[2], S. M. Parra[2], J. W. Book[2]
[1]Vencore, Inc., Chantilly, VA, [2]Naval Research Laboratory, Stennis Space Center, MS

Riverine discharge plays an important role in creating and shaping frontal features in ocean modeling. Improved prediction of fresh water plums will lead to more accurate forecasts of the upper layer dynamics of an ocean model. An effort is underway to implement observed river discharge into a regional Navy Coastal Ocean model of the Gulf of Mexico (GoM). Initiated in May 2012, a 1 km horizontal resolution NCOM of the GoM has been running in real-time in support of Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE). NCOM uses a global river climatology to estimate riverine discharge into the model basin. In this study, river discharge (and temperatures where available) along the northern GoM (coasts of Florida, Alabama, Mississippi, Louisiana) were replaced by river discharge observations published by the US Geological Survey. Obtaining these observed river transports from the USGS website and coupling to NCOM was integrated into the real-time processing. Ocean observations are assimilated using the Navy Coupled Ocean Data Assimilation system with 3DVar. This NCOM GoM generates forecasts of ocean state out to 72 hours in 3 hour increments. Two real-time NCOM simulations of the GoM were maintained from 10 January through April 2016, one using the climatological river transports for the entire GoM and one using observed river transports in the NGoM with climatological river transports in the remainder of the GoM (Texas, Mexico). During this time, field surveys by CARTHE and CONsortium for oil spill exposure pathways in COastal River-Dominated Ecosystems (CONCORDE) were conducted. Initial comparisons with subsurface observations from these surveys indicate improvement of stratification metrics of the NCOM using observed river transports in the NGoM. A description of the



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implementation of the observed river transports in the real-time processing of NCOM and comparisons of the models with these observations will be presented.

The Dynamical Coupling between 3D Turbulence and 2D Eddies and Its Effects on Oil Transport in the Upper Ocean

**B. Chen***[1], M. Chamecki[2], D. Yang[3], C. Meneveau[4]
[1]Pennsylvania State University, University Park, PA, [2]University of California, Los Angeles, Los Angeles, CA, [3]University of Houston, Houston, TX, [4]Johns Hopkins University, Baltimore, MD

As the oil from deep-water blowouts reaches the ocean mixed layer (OML), the plume experiences considerable horizontal and vertical dilution due to the action of Langmuir turbulence, submesoscale eddies and Ekman transport. Previous studies using large-eddy simulation (LES) have shown that Langmuir turbulence can impact the transport direction, lateral diffusion and geometry of surface oil plume, depending on the size of oil droplets. However, the large range of relevant length scales, from submesoscale eddies down to small-scale three-dimensional Langmuir turbulence, makes it challenging to accurately capture the long-term evolution of oil plumes using LES. The Extended Nonperiodic Domain LES for Scalars (ENDLESS) framework has been developed as a multi-scale approach for oil transport to overcome the above challenges. The basic idea is to simulate the Langmuir turbulence on a small horizontal domain while simulating the oil plume over an effectively large extended domain. In particular, this approach permits the superposition of large-scale two-dimensional motions on the oil advection, providing a framework for coupling LES with regional circulation models. However, this superposition approach requires the dynamic interactions between large-scale eddies and small-scale turbulence to be disregarded. In the present work, the importance of these interactions in the flow field is quantified by comparing ENDLESS with a fully coupled simulation. The effects of the dynamical coupling between large-scale eddies and small-scale turbulence on oil transport are discussed. This research was made possible by a grant from The Gulf of Mexico Research Initiative.

Large eddy simulations of buoyant tracers at submesoscale fronts

**J. R. Taylor**
University of Cambridge, Cambridge, United Kingdom

Here, we discuss large-eddy simulations of the accumulation, mixing, and subduction of passive, buoyant tracers. The simulations are initialized with a mixed layer overlying a strongly stratified thermocline with a large scale horizontal density gradient. The computational domain is 1km in both horizontal directions, and large enough to capture one submesoscale eddy. The grid spacing is about 2m, and fine enough to resolve the largest three-dimensional turbulent overturns. Turbulence in the simulations is generated through a down-scale energy transfer from the developing submesoscale fronts and eddy, and by cooling applied to the surface. Four passive buoyant tracers are simulated in the model, with vertical slip velocities corresponding to oil droplets ranging in size from approximately 30-300μm. The buoyant tracers are evenly distributed in the horizontal at the start of the simulations, but quickly cluster near the surface and in regions of surface convergence. The most buoyant tracers cluster preferentially in near-surface convergence zones where downwelling is also very strong. As a result of the correlation between negative vertical velocity and high tracer concentrations, the diagnosed vertical tracer diffusivity for the most strongly buoyant tracer is increased by nearly a factor of 10 compared with a non-buoyant tracer.



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Submesoscale surface dispersion in the De Soto Canyon in summer and winter

**A. C. Poje**[1], T. M. Ozgokmen[2], A. C. Haza[2]

[1]City University of New York - College of Staten Island, Staten Island, NY, [2]University of Miami, Miami, FL

The Grand Lagrangian Deployment (GLAD) program was a modeler-designed surface dispersion experiment that released over 300 GPS-tracked in the DeSoto Canyon region during July 2012 with the specific goal of measuring multi-point velocity statistics at the submesoscale. The Lagrangian Surface Experiment (LASER), conducted in January-February 2016, revisited the region with two research vessels and multiple arial observing platforms. During the experiment, over 1,000 surface drifters were released including two near simultaneous, large-scale launches of 300 instruments. In this talk we compare and contrast submesoscale surface dispersion properties observed in the two experiments, concentrating on both standard, two-point drifter statistics, and also on multipoint statistics available from the high density of drifters in the LASER clusters. The observations allow, perhaps for the first time, scale dependent, drifter-based estimates of surface horizontal gradients and quantification of the competing roles of horizontal divergence and strain in the dispersion of surface tracer fields.

Velocity Gradients from LASER Drifters

**A. D. Kirwan, Jr.**[1], H. S. Huntley[1], H. Chang[1], G. Jacobs[2], B. Bartels[2], A. Griffa[3], M. Berta[3], L. CARTHE team[4]

[1]University of Delaware, Newark, DE, [2]Naval Research Laboratory, Stennis, MS, [3]CNR ISMAR, Forte S. Teresa, Pozzuolo di Lerici, Italy, [4]University of Miami, Miami, FL

Ocean velocity gradients are critical factors in transport processes of oil and pollutants. They can be estimated from general circulation models, but such estimates come with large uncertainties, often even getting the sign wrong. Alternatively, velocity gradients can be estimated from drifters. However, in the past, these have been judged suspect because of sizable position uncertainty and coarse sampling rates. In LASER, approximately $10^3$ units were deployed in the Northern Gulf of Mexico. The positions were obtained at 5-minute intervals with an accuracy on the order of a few meters. We use this unprecedented dataset to derive velocity gradient estimates using two distinct approaches, one statistical using drifter clusters (Molinari and Kirwan, 1975), the other relying on line integrals around the convex hull of drifter groups.

Submesoscale Shape Evolution of Surface Drifter Triplets in the Gulf of Mexico

**M. Berta**[1], A. Griffa[1], T. Ozgokmen[2], A. Poje[3]

[1]Consiglio Nazionale delle Ricerche – Istituto di Scienze Marine, La Spezia, Italy, [2]RSMAS (UM), Miami, FL, [3]CUNY, New York, NY

Information on the dispersion of hydrocarbons by ocean currents are usually investigated using one or two particle statistics. However, neither absolute nor relative dispersion directly inform responders on the shape evolution of a tracer patch advected by ocean currents. Aspects of the geometry of the two dimensional surface dispersion can be quantified by simultaneous observations of at least three Lagrangian drifters. Drifter triplets are also the minimal configuration required for directly estimating kinematic properties of the underlying velocity gradient field. Traditional data constraints on drifter triad availability have been overcome by a particular launch strategy used during the Grand LAgrangian Deployment (GLAD) Experiment in the northern Gulf of Mexico. Here we study the initial evolution of



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120 surface drifter triplets, configured as equilateral triangles with sides of 100 m and 500 m, launched during summer in the DeSoto Canyon. Triangle shape metrics are analyzed to quantify the evolution of submesoscales in the area. The observations are compared to synthetic drifters advected by geostrophic velocity fields derived from satellite altimetry. Observed submesoscale triads evolve rapidly, reaching highly-elongated configurations on timescales of 6 hours to 2 days, in contrast to 6 days or longer for altimetry-derived synthetic data. Estimates of horizontal divergence and strain rate from the drifter triplets indicate the relative importance of compressibility in the evolution of triangle shape. Horizontal divergence is scale-dependent, on the order of the local Coriolis parameter, and 2 to 3 times larger for initial 100-m scales compared to initial 500-m scales.

The Relationship of Near Surface Flow, Stokes Drift and Wind Stress
**A. Clarke**, S. VanGorder
Florida State University, Tallahassee, FL

In the presence of near-surface turbulence and dissipation, Stokes drift is not cancelled by an Eulerian flow and thus acts as a near-surface flow that can transport oil spills across the continental shelf to the coast. Stokes drift and wind stress calculations using wind and directional wave-spectra from coastal and deep sea moored buoys in the Gulf of Mexico show that the Stokes drift and wind-stress vectors are well-correlated, and that the Stokes drift is a leading contributor to the transport of surface particles to the coast. The observed directional spectra were only accurate for frequencies less than 0.35 cps, and the above buoy calculations thus underestimate the Stokes drift. Independent observations and theory were used to estimate the non-negligible contributions to Stokes drift at frequencies higher than 0.35 cps, and so obtain an empirical relationship between the total Stokes drift and the wind stress. In this way Stokes drift in the Gulf of Mexico can be estimated directly from the wind stress and used in model prediction of oil spill movement.

Observed Air-Sea Interactions in Tropical Cyclone Isaac over Loop Current Mesoscale Eddy Features
**B. Jaimes de la Cruz**, L. K. Shay, J. K. Brewster
University of Miami, Miami, FL

The 3-dimensional velocity response of the Loop Current (LC) and its complex eddy field to hurricanes is critical to accurately evaluate dynamical loading on marine oil facilities, mixing and dispersion of oil products through the water column, as well as oceanic feedbacks on storm intensity. Direct velocity measurements of ocean current, temperature and salinity fields, and atmospheric conditions in hurricanes is critical to better understand these complex physical processes, and acquire reference data sets to initialize, evaluate, and validate numerical forecast models of hurricanes and their potential dispersion of oil products throughout the upper ocean. In this context, air-sea interactions during the intensification of tropical storm Isaac (2012) into a hurricane, over LC warm mesoscale eddies are investigated using airborne oceanographic and atmospheric profilers. Isaac strengthened as it moved over a LC warm-core eddy (WCE) where sea surface warming of ~0.5°C (positive feedback mechanism) was measured over a 12-h interval. Enhanced bulk enthalpy fluxes were estimated during this intensification stage due to an increase in moisture disequilibrium between the ocean and atmosphere. These results support the hypothesis that enhanced buoyant forcing from the ocean is an important intensification mechanism in tropical cyclones over warm oceanic mesoscale eddies. Larger values in equivalent potential temperature were measured inside the hurricane boundary layer over the WCE, where the vertical shear in horizontal ocean currents remained stable and the ensuing upper-



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ocean cooling vertical mixing was negligible. A key aspect of these enhanced air-sea interactions over oceanic mesoscale eddy features is that the resulting wind field strength and structure directly affects the upper ocean wind-driven currents; wind-driven currents directly affect the transport of hydrocarbons as well as current shear induced mixing events in the upper ocean, which is central to a subsurface oil spill such as Deepwater Horizon.

Submesoscale Statistics in the Northern Gulf of Mexico: the Role of River Outflow

**R. Barkan**, A. Shchepetkin, J. C. McWilliams, J. Molemaker
University of California Los Angeles, Los Angeles, CA

Realistic, submesoscal-resolving, numerical simulations are used to characterize statistics and geography of surface submesoscale currents in the Northern Gulf of Mexico. We focus on the role of the Mississippi-Achafalya river system in driving submesoscale currents during winter and summer, on and off the shelf. We analyze vorticity, horizontal divergence, available potential to eddy kinetic energy conversion, and velocity and buoyancy frontal tendencies and show that river forcing has an important effect on the spatial distribution and magnitudes of submesoscale currents in both seasons. During winter, all of the analyzed fields in solutions without river forcing show an increase in seasonal-mean values compared with solutions with river forcing. On the contrary, during summer, seasonal-mean values are larger in solution with river forcing. The river effects can be rationalized qualitatively in terms of scaling arguments that relate submesoscale current magnitudes to the surface boundary layer depth and lateral buoyancy gradients. River outflow enhances submesoscale currents by increasing lateral buoyancy gradients but suppresses them by decreasing the boundary layer depth. Specific submesoscale generating mechanisms during each season determine whether the enhancement effect overcomes the supression effect or vice versa. Geographically, sumbesoscale currents are stronger offshore and to the east of the bird's foot during winter and closer to the shelf and to the west of the Bird's foot during summer. The importance of river forcing to the surface dynamics is further illustrated through salinity-temperature compensation analysis which indicates that the river forcing sustains a compensated and salinity dominated signal.



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## Session 004: Understanding Population Status, Trends and Connectivity of Gulf of Mexico Large Marine Vertebrates as Sentinels for Ecosystem Health in the Context of Restoration

### Sea turtle habitat use in the northern Gulf of Mexico

**K. M. Hart**[1], M. M. Lamont[2], M. S. Cherkiss[1], A. S. Iverson[1], A. G. Crowder[1], D. Nemire-Pepe[1], J. Mallindine[3], M. Miner[3]
[1]USGS, Davie, FL, [2]USGS, Gainesville, FL, [3]BOEM, New Orleans, LA

Determining distribution, seasonal movements, vital rates and habitat use for all life-stages of marine turtles has been identified by the US Fish and Wildlife Service and US National Marine Fisheries Service as a major action required to achieve recovery for these endangered species. Because turtles come ashore to nest, the adult (female) life-stage is most easily studied, however much less information is available about habitat use and movements of sub-adults and juveniles; both the Kemp's ridley and loggerhead Recovery Plans call for monitoring population abundance, trends and demographic parameters of these life-stages. Only recently has information become available about sea turtle high-use areas along the GoM coast. However, fine-scale information on dive profiles is still lacking for sea turtles in the GoM. Such information can provide key data on time spent per individual in various portions of the water column, in specific locations. The current study directly addresses those recovery and protection goals and provides information on in-water aggregations of immature and adult marine turtles of both sexes in the northern GoM. USGS and BOEM are collaborating to utilize trawling operations to opportunistically tag sea turtles and collect biological samples to inform management decisions related to trawling and dredge operations. Turtle tracks are providing data needed to validate the distance required for relocation which could help examine the economic feasibility of contracted dredge projects and prevent multiple handlings of the same turtle. This information can also be applied to inform other program areas such as decommissioning of oil rigs (i.e., by evaluating dive times) and optimization of current sea turtle visual and aerial survey efforts using data gathered on time spent in upper two meters of water column. The study is generating information on sea turtle use of discrete foraging areas; genetic origin of sea turtles sampled at foraging areas; general sea turtle distribution patterns across space and time; and sea turtle dive profiles and patterns.

### Analysis of Leatherback Turtle Movement in the Gulf of Mexico

**K. T. Aleksa***[1], C. R. Sasso[2], D. R. Evans[3], R. M. Nero[4]
[1]University of Southern Mississippi, Stennis Space Center, MS, [2]NOAA-NMFS, Miami, FL, [3]Sea Turtle Conservancy, Gainesville, FL, [4]NOAA-NMFS, Stennis Space Center, MS

Leatherback turtles (*Dermochelys coriacea*) are the largest and most migratory species of sea turtles. Their migrations are driven by the requirement to find productive foraging or reproductive/nesting locations. Satellite tags deployed at nesting beaches in Costa Rica and Panama (10) and in-water in the northern Gulf of Mexico (6) were combined to create the largest telemetry study of leatherbacks in the Gulf of Mexico (GoM). A switching state space model (SSSM) was applied to the satellite tracks to expose the possible behavioral modes expressed by the turtles in the GoM. The SSSM tracks were then compared to mesoscale circulation in the GoM using sea surface height anomalies on a weekly time scale to analyze if there was any relationship between behavior and oceanographic features. The SSSM showed both transit and area restricted search (ARS) behaviors and two ARS high use areas; one south of the Florida Panhandle and the other west of the Yucatan Peninsula in Campeche Bay. Analysis of the



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ocean circulation revealed an association between leatherback ARS behavior and mesoscale cyclonic circulation features.

Cooperative Monitoring Program for Spawning Aggregations in the Gulf of Mexico: Vulnerability Assessment of 28 Fish Species to Aggregation Fishing

**B. Erisman**[1], W. Heyman[2], S. Kobara[3], C. Biggs[1], N. Farmer[4], S. Lowerre-Barbieri[5], M. Karnauskas[6], J. Brenner[7]

[1]University of Texas at Austin, Port Aransas, TX, [2]LGL Ecological Research Associates, Inc., Bryan, TX, [3]Gulf of Mexico Coastal Ocean Observing System, Texas A&M University, College Station, TX, [4]NOAA Fisheries Southeast Regional Office, St. Petersburg, FL, [5]Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL, [6]NOAA Fisheries Southeast Fisheries Science Center, Miami, FL, [7]The Nature Conservancy, Corpus Christi, TX

Many of the most important fish species harvested by commercial and recreational fisheries throughout the Gulf of Mexico (GOM) are known to form fish spawning aggregations (FSAs). However, management and conservation efforts are hampered by the fact that the GOM is one of the world's least studied areas for the biology and fisheries of FSAs. Through the support of the NOAA RESTORE Act Science Program, our research team seeks to: (1) compile and evaluate existing information on FSAs in the GOM as the basis to design a cooperative, Gulf-wide conservation and monitoring program focused on existing knowledge, data gaps, monitoring techniques, and priorities for future research related to FSAs and the management of their fisheries in the region; and (2) engage in a comprehensive outreach and data-sharing program to ensure all data and outputs are available to inform research and management efforts. As part of this process, we will provide an update on the status of our project, including preliminary results of a vulnerability assessment of 28 species of marine fishes of recreational, commercial, or conservation importance based on a suite of intrinsic (biological) and extrinsic (e.g. fishing behavior, socio-economic) factors. Results of this analysis will serve to identify those species for which an understanding of FSAs and their fisheries should be a priority for monitoring, management, and conservation in the GOM.

Determining Life History Parameters of Deepwater Sharks: Can We Detect Organismal-Level Effects of Hydrocarbon Exposure from Deepwater Horizon Oil?

**C. F. Cotton**[1], R. Grubbs[1], J. J. Gelsleichter[2]

[1]Florida State University, St. Teresa, FL, [2]University of North Florida, Jacksonville, FL

In order to model the population-level effects of ecological injuries such as the Deepwater Horizon Oil Spill, scientists need species-specific life history information, particularly related to age, growth, and reproduction. The depth of this spill resulted in ecological impacts to groups of species for which little or no published biological information existed, hence, the majority of life history information documented for deepwater sharks in this region is based on a potentially compromised population. In addition, the lack of baseline biological, toxicological, and physiological data, as well as the unknown magnitude of background hydrocarbon exposure has exacerbated the interpretation of results of life history studies conducted in this region after the oil spill. Herein we present the first life history parameters for the dominant shark species inhabiting the Desoto Canyon region: gulper shark (*Centrophorus granulosus*), little gulper shark (*Centrophorus* cf. *uyato*), Cuban dogfish (*Squalus cubensis*) and an undescribed dogfish (Squalus cf. *mitsukurii*). Our results show a wide range in life history parameters for these deepwater sharks, challenging the long-held characterization of



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deepwater sharks as a group as exhibiting “extremely long-lived” or “K-selected” life histories. Additionally, we propose a simple analysis to compare empirical toxicological data with individual life history parameters across individuals to determine whether toxicant load is correlated with a measureable effect on individual life history parameters, such as fecundity, embryonic sex ratio, mean embryo size, size-at-maturity, and size-at-age. Finally we suggest future research initiatives that would further clarify the organismal effects of hydrocarbon exposure resulting from the Deepwater Horizon Oil Spill.

Impacts of the Deepwater Horizon Oil Spill on Genetic Diversity of a Demersal, Sedentary, Deepwater-Burrowing Fish

**S. J. O'Leary**, J. R. Gold, D. S. Portnoy
Texas A&M Corpus Christi, Corpus Christi, TX

Golden tilefish, *Lopholatilus chamaeleonticeps*, (tilefish) inhabit vertical burrows in clay substrates on the shelf-slope break and exhibit sedentary behavior and intimate association with the sediment. Subsequent to the Deepwater Horizon oil spill, high concentrations of biomarkers, consistent with an extended period of oil exposure, were detected in tilefish samples from oil-impacted areas. To determine possible genetic impacts on tilefish and tilefish populations, we used restriction-site-associated DNA sequencing to create a reduced-representation library consisting of several thousand genetic markers (SNPs). This approach allowed us to characterize both adaptive and neutral genomic variation. We compared spatial (northern/southern Gulf and Atlantic) and temporal (pre/post oil spill) patterns of genomic variation to assess patterns of population structure in the Gulf. Further, we searched for evidence of demographic changes suggesting a population-level genome-wide response associated with the oil spill indicated by changes in allele frequencies. We also searched for $F_{ST}$ outlier loci potentially under divergent selection, evaluated genetic-environmental associations, and looked for measurable temporal shifts at specific loci which might indicate gene specific responses to the oil spill.

Evidence for a top-down ecosystem effect of seabird and marine mammal mortalities caused by the Deepwater Horizon blowout

**J. Short**[1], H. Geiger[2], J. Haney[3], C. Voss[4], M. Vozzo[5], V. Guillory[6], C. Peterson[4]
[1]JWS Consulting LLC, Juneau, AK, [2]St. Hubert Research Group, Juneau, AK, [3]Terra Mar Applied Sciences LLC, Carson City, NV, [4]Institute of Marine Science, University of North Carolina at Chapel Hill, Morehead City, NC, [5]Department of Biological Sciences, Macquarie University, North Ryde, AUSTRALIA, [6]296 Levillage Drive, Larose, LA

The Deepwater Horizon blowout caused widespread mortality of seabirds and other predators of juvenile fishes. Release from control by these predators substantially increased survival of the 2010 year class of Gulf menhaden, contributing to unprecedented recruitment that exceeded the prior 39-year mean by more than 4 standard deviations near the Mississippi River. Resulting biomass as augmented by recruits in 2011 was more than twice the highest population biomass of Gulf menhaden previously recorded. This high biomass was associated with exceptionally poor physiological condition and low lipid content of the 2010 Gulf menhaden year class, which persisted through 2012. The exceptionally high density of poor-condition Gulf menhaden during 2011 - 2012 implies similarly atypical high predation pressure on their mainly zooplankton prey, which include the early life stages of countless other aquatic species, some of which are important ecologically or commercially. Also, the



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poor condition of Gulf menhaden reduced their value as prey to the many predators that consume them, including surviving seabirds, bottlenose dolphins, and piscivorous fishes.

This sequence of results reflects operation of a classic trophic cascade, wherein an abrupt reduction of predators killed by contact with oil resulted in increased abundance of their Gulf menhaden prey, likely associated with a corresponding reduction in the survival of zooplankton life stages of other organisms in waters inhabited by Gulf menhaden. These linked trophic effects illustrate a major new ecological damage pathway, heretofore little appreciated, operating at the broad ecosystem level in the coastal and estuarine waters near the Mississippi River in 2011 and 2012. Moreover, continued hyperabundance of Gulf menhaden may lead to a population that continues to exceed the carrying capacity of its habitat, indefinitely extending their depressed nutritional value as prey for the species that consume them.

Investigating Mechanisms for Reproductive Failure among Bottlenose Dolphins in the Aftermath of the Deepwater Horizon Oil Spill

**C. R. Smith**[1], T. K. Rowles[2], S. Venn-Watson[1], B. C. Balmer[3], E. S. Zolman[3], K. M. Colegrove[4], F. I. Townsend[5], R. S. Wells[6], M. C. Tumlin[7], L. H. Schwacke[3]

[1]National Marine Mammal Foundation, San Diego, CA, [2]National Marine Fisheries Service, Office of Protected Resources, NOAA, Silver Spring, MD, [3]National Centers for Coastal Ocean Science, Hollings Marine Laboratory, NOAA, Charleston, SC, [4]University of Illinois, Zoological Pathology Program, Maywood, IL, [5]Bayside Hospital for Animals, Fort Walton Beach, FL, [6]Chicago Zoological Society, c/o Mote Marine Laboratory, Sarasota, FL, [7]Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA

In the aftermath of the Deepwater Horizon (DWH) disaster, impacts to bottlenose dolphins (*Tursiops truncatus*) in coastal areas of the northern Gulf of Mexico (NGOM) were well documented. Studies of live dolphins and necropsies of recovered carcasses within the DWH oil spill footprint confirmed lung injury and adrenal gland lesions consistent with known effects of oil or petroleum-associated compounds. Reproductive impacts were also studied in both live and dead dolphins, with a focus on the heaviest oiled coastal regions. For live animal studies, reproductive failure rates were evaluated for five years during and after the spill (2010-2015) in two NGOM bottlenose dolphin stocks exposed to DWH oil (Barataria Bay, LA, and Mississippi Sound, MS/AL). Pregnancy was determined from either ultrasound examinations during capture-release health assessments or endocrine evaluations of blubber tissue collected from dart biopsies. Follow-up photo-identification surveys of the two stocks were used to track the status of pregnant females and any associated neonate calves for a minimum of one year after the initial pregnancy detection. For all pregnant females tracked, individuals seen with a calf (reproductive success) and without one (reproductive failure) were recorded. The resulting estimated reproductive success rates for dolphins living in areas not impacted by the DWH oil spill (i.e., Sarasota Bay, FL; Indian River Lagoon, FL; and Charleston Harbor, SC) were three-fold higher than the reproductive success rates for both NGOM stocks within the DWH oil spill footprint. Results from the stranded animal studies showed that dead perinate dolphins in the oil spill footprint had a higher prevalence of atelectasis (88% vs. 15%), fetal distress (87% vs. 27%), and in utero pneumonia (65% vs 19%) compared to reference perinates. This indicates that most perinates died prior to or shortly after birth, experienced adverse conditions *in utero*, and most had *in utero* infections. Findings from both the live and dead animal studies confirmed low reproductive success from heavily oiled estuaries when compared with other populations. Follow-up studies were conducted in the summer of 2016 to better



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understand the potential recovery of dolphins in Barataria Bay and, by extension, other Gulf coastal regions impacted by the spill.

Analysis of Lethal and Sublethal Impacts of Environmental Disasters on Sperm Whales Using Stochastic Modeling

**A. S. Ackleh**[1], R. A. Chiquet[1], B. Ma[2], T. Tang[1], H. Caswell[3], A. Veprauskas[1], N. Sidorovskaia[1]
[1]University of Louisiana at Lafayette, Lafayette, LA, [2]Millersville University, Millersville, PA, [3]Woods Hole Oceanographic Institution, Woods Hole, MA

The Deepwater Horizon (DWH) oil rig explosion in April of 2010 has encouraged substantial research efforts to better understand how such environmental disasters affect the resilience of the Gulf of Mexico (GoM) ecosystem. This study is focused on how such disasters affect the dynamics and persistence of marine mammal populations in the Northern GoM. First an autonomous matrix population model is developed to study lethal and sublethal impacts of environmental disasters on the GoM sperm whales. This model focuses on the effects of reductions in survival probabilities (lethal impacts) and in fecundity (sublethal impacts) on the GoM sperm whale population. Then by assuming that the lethal and sublethal effects due to such disasters last for a period of time, after which the vital rates begin to recover to their original values, a nonautonomous matrix model is constructed. This model, combined with demographic stochasticity, is used to study the long term recovery process following an environmental disaster. In particular, recovery probabilities and recovery times of the population after the impact are computed and formulas are derived to compute the sensitivity of the recovery time to changes in 1) the initial population distribution, 2) reduction in fecundity and survivorship due to the disaster, and 3) changes in duration of the disaster impact. The results suggest that while the recovery time is independent of the initial population size it is sensitive to the initial population structure. Our analysis highlights the difficulty of projecting impacts and recovery in the absence of detailed demographic data, and the value of population models in exploring scenarios and identifying important processes and general relationships. [This research was made possible by a grant from The Gulf of Mexico Research Initiative.]

Long term impact assessment of the 2010 oil spill impact on deep diving marine mammals: Beaked whales

**T. Tang***[1], A. S. Ackleh[1], N. Sidorovskaia[1], K. Li[1], C. Tiemann[2], J. Ioup[3]
[1]University of Louisiana at Lafayette, Lafayette, LA, [2]R2Sonic LLC, Austin, TX, [3]University of New Orleans, New Orleans, LA

To assess the long term impact of Deepwater Horizon oil spill on marine mammal, we utilize the acoustic data collected by Littoral Acoustic Demonstration Center (LADC) from three locations (9 miles, 25 miles and 50 miles away from the oil spill site) during 2007, 2010 and 2015. We use passive acoustic data to estimate and compare the abundance of beaked whale in Northern Gulf of Mexico in 2007, 2010 and 2015. The weekly beaked whale density from June 26$^{th}$ 2015 to October 25$^{th}$ 2015 for each location and all three sites combined is calculated to explore possible movement patterns of the beaked whales. Our results suggest that the beaked whale density in the study areas suffered a 37% decrease from July 2007 to September 2010, then tripled from September 2010 to September 2015. We also investigate the day/night activity pattern for three beaked whale species 1) Cuvier 2) Gervai and 3) BWG. Significantly more nighttime activity is observed for BWG in all locations during the 2007, 2010 and 2015 years. Our findings also indicate that the beaked whales are very mobile and there are



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movements between the different locations. Thus, to better understand the possible seasonality of the beaked whale activity, in September 11th 2016, the GOMRII funded LADC-GEMM consortium deployed a long term buoy to collect acoustic data during the entire winter season. [This research was made possible in part by a grant from The Gulf of Mexico Research Initiative, and in part by SPAWAR, ONR, NSF, and Greenpeace.]

Evaluating the Current Approach for Imposing Limits to Human-caused Mortality of Marine Mammals using Management Strategy Evaluation

**P. T. Moreno**[1], A. E. Punt[2], J. R. Brandon[3], R. R. Reeves[4]
[1]University of Southern Mississippi, Ocean Springs, MS, [2]University of Washington, School of Aquatic and Fishery Sciences, Seattle, WA, [3]Independent Consultant, San Francisco, CA, [4]Okapi Wildlife Associates, Quebec, QC, Canada

Limits on human impacts on marine mammal populations are based on the Potential Biological Removal (PBR) approach, which aims to maintain stocks at/above their "optimum sustainable level". The current PBR formula was developed using Management Strategy Evaluation (MSE), which involves using simulation to compare alternative PBR formulae in terms of their performance relative to management objectives. We extend the earlier MSE to evaluate performance for small populations and to explicitly model the consequences of different levels of observer coverage in terms of the ability to correctly classify stocks as being 'strategic' and fisheries in terms of their expected impact on the recovery rate of depleted populations. The implications of different levels of observer coverages of each fishery that impacts the population are evaluated, along with those of different levels of survey precision. The current MSE framework focuses on bycatch effects; we show how this framework can be extended to include other impacts such as oil spills and would be useful to understand recovery trajectories of injured bottlenose dolphin populations that are subject to multiple stressors.

Marine Mammal Institute
**B. Mate**, L. Irvine
Marine Mammal Institute, Oregon State University, Newport, OR

Argos (satellite) tags were used to study the movements of sperm whales in the Gulf of Mexico (GOM) from 2001 to 2005 and from 2010 to 2013. Advanced Dive Behavior tags deployed in 2011 and 2013,recorded GPS position, dive duration and depth, while 3-axis accelerometers described underwater behavior for up to 45 continuous days. Tagged whales dove to various depths, with many reaching the seafloor. Jerks, a proxy for foraging effort, were highly variable from dive to dive, suggesting sparsely distributed, high-density prey aggregations. An oblong area of low-use habitat (LUH) covering ~4,000 sq.km, and including the Macondo spill site, was identified from 2011 tagged whale movements. The area had a SW-NE axis between the distributions of whales on the continental slope and deeper waters. The LUH coincides with modeled surface distribution of spilled oil and the distribution of 1,000m deep oil droplets. In 2013, one tagged whale circumnavigated most of the LUH in 3 days, during which there was a 90% reduction in foraging effort compared to outside the LUH. Deep-water squids likely forage on demersal fish and may be preferred sperm whale prey if they are sufficiently abundant and easier to catch near the bottom. We hypothesize sperm whales did not use the LUH because bottom oil contamination reduced bottom-dwelling fish density, thus affecting the distribution of squids and hence whales. These new findings indicate oil effects on the benthic community, which would be otherwise very difficult to monitor directly, but can be evaluated by



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studying sperm whales as an indicator species of this benthic food web. If the observed effect represents a long-term loss of habitat, subsequent spills may have cumulative effects, resulting in population consequences at multiple trophic levels. The baseline distribution and foraging insights of sperm whales in the GOM represent a unique opportunity to evaluate the duration of benthic oil impact on the food web and habitat recovery.

Monitoring marine mammals via passive acoustic monitoring from long-endurance autonomous vehicles

**M. Baumgartner**
Woods Hole Oceanographic Institution, Woods Hole, MA

Over the past two decades, passive acoustic monitoring has proven to be an effective means of estimating the occurrence of marine mammals. The vast majority of applications to date involve archival recordings from bottom-mounted instruments or towed hydrophones from moving ships. The Woods Hole Oceanographic Institution has developed the capability to monitor marine mammals via passive acoustics from two autonomous vehicles, Slocum gliders and wave gliders, by (1) recording audio in-situ and analyzing those data after glider recovery, and (2) detecting, classifying, and remotely reporting in near real time the calls of marine mammals. The profiling Slocum glider can simultaneously measure marine mammal occurrence and oceanographic conditions, making it well suited for studying both marine mammal distribution and habitat. Surface-bound wave gliders can move much faster than the Slocum glider, allowing observations of marine mammal occurrence over larger spatial scales. The near real-time reporting capability of the gliders enables follow-up visual observations, on-water research, or responsive management action. These vehicles are currently being used to monitor baleen whales in near real-time off the east coasts of the U.S. and Canada. Enhancements to the passive acoustic instrumentation and detection algorithms are now making this technology available for long-term monitoring of marine mammals in the Gulf of Mexico. Accurate assessment of the impacts of disasters like the Deepwater Horizon oil spill on marine mammals and the effectiveness of restoration efforts require an understanding of changes to the animals' distribution and habitat over time scales of many years to decades. The expense and complexity of traditional ship- and aerial-based marine mammal surveys make collection of visual observations over these time scales challenging. However, long-endurance autonomous vehicles are ideally suited to augment visual surveys by providing cost-effective and persistent observations during times when or in locations where visual observations are not feasible.

Passive Acoustic Monitoring of Cetaceans in the Northern Gulf of Mexico using Ocean Gliders

**D. K. Mellinger**[1], S. L. Nieukirk[1], S. L. Heimlich[1], E. T. Küsel[2], M. Siderius[2], N. Sidorovskaia[3]
[1]Oregon State University, Newport, OR, [2]Portland State University, Portland, OR, [3]University of Louisiana at Lafayette, Lafayette, LA

Passive acoustic monitoring (PAM) is frequently used to assess the seasonal occurrence and population density of cetaceans. It has long been done using hydrophone arrays towed behind vessels as well as fixed moored recorders, but in recent years other platforms have become available. Here we describe cetacean PAM research from ocean gliders of the LADC-GEMM project in the Northern Gulf of Mexico. Gliders are buoyancy-driven vehicles that use very little power and can thus endure autonomously at sea for long periods of time. As part of an effort to assess impacts on cetaceans of the Deepwater Horizon (DWH) oil spill, gliders equipped with passive acoustic recording systems were flown in



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summer and fall 2015 in an area just west of the DWH site. We describe glider operations; the sound recordings made; analysis methods, including automated and manual detection and classification; and detection along the glider track of sperm whales, several species of beaked whales, and several species of dolphins. Gliders are examined for their efficacy at cetacean PAM in comparison to other platforms. [Funding from GoMRI.]

Declining Pelagic Dolphin Detection Rates in the Gulf of Mexico: 2010 to 2015
**K. E. Frasier**, R. E. Cohen, V. I. Hernandez, S. M. Wiggins, J. A. Hildebrand
Scripps Institution of Oceanography, San Diego, CA

Dolphins are apex predators in Gulf of Mexico (GOM) food webs and can serve as indicators of environmental health. Two species, Bottlenose and Atlantic spotted dolphins, are typically found from the coast to the continental shelf, while at least 11 pelagic delphinid species are found beyond the shelf break. Monitoring these populations can provide insights into the health of offshore GOM ecosystems, which are otherwise difficult to observe.

High-frequency Acoustic Recording Packages (HARPs) have been used to monitor GOM dolphin populations nearly continuously at five passive acoustic monitoring sites since 2010. From 2010 to 2015, recordings from sites on the continental slope (depths > 900 m) documented declines between 10 and 23% in daily numbers of dolphin echolocation clicks detected. However, the amount of time that dolphins were present at the monitoring sites each day remained largely unchanged. Click detection rates remained unchanged at shallow sites (depths < 300m) on the continental shelf.

The apparent decline in pelagic dolphin detection rates may indicate (1) decreasing click detectability due to changing sound propagation conditions, (2) a shift in the dominant dolphin species or behaviors at slope sites, or (3) decreases in average pelagic dolphin group sizes. We use sound propagation models to determine whether changes in environmental factors including sea surface temperature, and mixed layer depth, as well as background noise could have significantly affected click detectability during the monitoring period. We also examine rates of occurrence of different click types over time to evaluate whether this trend can be explained by a shift in dolphin species or to behaviors with lower click rates. We conclude that declining group size among pelagic dolphin species is likely the main driver of decreasing detection rates.

Spatial Exposure of Sea Turtle Critical Habitats to Seismic Surveys for Oil Exploration in Mexican Waters of the Gulf of Mexico
**E. Cuevas**[1, 2], M. Liceaga-Correa[1], A. Uribe-Martinez[1], G. Mendez-Gutierrez[2], M. Lopez-Castro[2]
[1]CINVESTAV-IPN, Merida, Merida, Mexico, [2]Pronatura Peninsula de Yucatan, AC, Merida, Mexico

The Gulf of Mexico (GoM) harbors critical habitats for the completion of all life stages of sea turtles. This group acts as an umbrella group for other species of ecological and economical interest cohabiting the same space, and interconnects the GoM. The GoM also harbors oil and natural gas deposits that are exploited by the nations occurring in it. One of the exploration activities are seismic surveys using air guns which have brought controversy regarding its potential impacts on marine fauna. The potential negative impacts on sea turtles have been recognized as an information gap, as it may increase their vulnerability to other disturbances. Concern over this activity has made the Inter-American Convention for the Protection and Conservation of Sea Turtle to call its parties to attend this information gap. The



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identification and protection of sea turtle critical habitats, as well as the connection they sustain, is of the highest importance to recover their populations inside and outside the GoM. One initial recommended step is to evaluate the spatial overlay of areas where seismic surveys have been done and the location of those sea turtle habitats. Our objective was to quantify the spatial overlap of seismic survey polygons and critical sea turtle habitats in the GoM. We found spatial coincidence of zones where seismic surveys have been done and sea turtle critical habitats. Although the available input data doesn't allow to robustly evaluate temporal coincidences, this is a first documentation of the potential interactions between oil exploration and sea turtles in the GoM. We agree with other authors that there is an urgent need to go deeper in evaluating the temporal and spatial coincidence of sea turtles and seismic surveys, to evaluate behavior of sea turtles during seismic surveys, to delimit spatiotemporal no-survey areas for these technologies, and to get a consensus of standardized precautionary and mitigation protocols for seismic surveys in the GoM

Trends in Deep-Diving Whale Populations in the Gulf of Mexico: 2010 to 2015

**J. A. Hildebrand**, K. E. Frasier, S. M. Wiggins
Scripps Institution of Oceanography, La Jolla, CA

The offshore Gulf of Mexico (GOM) provides habitat for a diverse array of deep-diving whales including: sperm whales, beaked whales and dwarf and pygmy sperm whales. 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 five years of acoustic monitoring data collected since 2010; animal densities 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 at higher densities in the northern GOM. Sperm whales are found at their highest densities in the Mississippi Canyon region. Beaked whale species include Gervais' (*Mesoplodon europaeus*), Cuvier's (*Ziphius cavirostris*), Blainville's (*Mesoplodon densirostris*) and an unknown species (*Mesoplodon sp*.) of 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 - 2015.



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## Session 005: Recovery from the Bottom Up: Rates, Processes, and Connectivity in the Deep Gulf of Mexico

### Shifts in the Abundance of Pelagic Fishes in the Gulf of Mexico: Natural Variability or a Consequence of the Deepwater Horizon Oil Spill?

**J. Rooker**
Texas A&M University, Galveston, TX

Data collected over nearly a decade were used to investigate temporal shifts in the distribution and abundance of pelagic fish larvae (e.g., billfish, dolphinfish, flyingfish, tuna, swordfish) in the Gulf of Mexico (GoM) before (2007-2009), during (2010), and after (2011-2016) the Deepwater Horizon oil spill. For several numerically dominant species, density (larvae per 1000$m^3$) was lower the summer immediately following the Deepwater Horizon oil spill relative to years prior to the event; however, for many taxa larval abundance in 2010 was statistically similar to one of the other years sampled in the pre-spill baseline. More recent sampling through the DEEPEND consortium has indicated a return to pre-spill abundances for the majority of pelagic species examined, although abundances of certain taxa remained low relative to pre-spill years. The spatial coverage of surface oil associated with Deepwater Horizon overlapped to varying degrees with the location of high quality habitat of pelagic taxa in the GoM, possibly indicating that reduced abundance observed in 2010 and subsequent years may be related to this event. Still, the primary driver (natural variability vs. oil spill) of observed temporal shifts in abundance is undefined. Shifts in the distribution of spawning adults is another factor known to influence the distribution and abundance of pelagic eggs and larvae, and the spatial occurrence of adult pelagic predators (blue marlin and white marlin) before, during, and after the oil spill were characterized using electronic tags. While adults of both species were common to the area impacted by the oil spill before and after the event, their occurrence in this area in 2010 was reduced markedly, suggesting that indirect effects (spatial shifts in spawning stock biomass) may be partly responsible for observed reductions in the abundance of larvae.

### DEEPEND: Characterizing Pelagic Habitats in the Gulf of Mexico Using Model, Empirical, and Remotely-Sensed Data

**M. W. Johnston**[1], R. J. Milligan[1], C. G. Easson[1], S. de Rada[2], B. Penta[2], T. T. Sutton[1]
[1]Nova Southeastern University, Dania Beach, FL, [2]Naval Research Lab, Stennis Space Center, MS

Pelagic waters of the Gulf of Mexico (GOM) are dominated by mesoscale features such as cyclonic and anticyclonic eddies and the strongly flowing Loop Current. These GOM features may be important drivers of population structure and trophic linkages within the water column. It is important, therefore, to classify water bodies associated with these features to allow quantitative evaluation of community assemblages. We first used an algorithm that integrated sea surface height anomaly and water velocity gradients to classify GOM surface waters between the years 2011-2016, founded on ocean condition data from the 1/25 ° GOM HYbrid Coordinate Ocean Model (HYCOM). The water bodies were segregated into anti-cyclonic, cyclonic, anti-cyclonic boundary, cyclonic boundary, and common water units. Next we compared these classifications to empirically derived ocean conditions as measured by CTD casts within each unit that were collected during the same period on cruises by the Deep Pelagic Nekton Dynamics of the Gulf of Mexico (DEEPEND) consortium. The classification scheme was further cross-validated by comparing the identified water bodies to the depths of the 20° and 22° isotherms, microbial community assemblages within each unit, and chlorophyll concentrations derived from



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satellite measurements. We found good agreement of the classification scheme between model (i.e., HYCOM), empirical (i.e., CTD and microbial assemblages), and remotely sensed (i.e., chlorophyll) data. Going forward, the classification scheme will be used to characterize assemblages of pelagic fauna that were collected by DEEPEND cruises in the GOM between 2010-2017.

PAH biomarker levels in deepwater sharks impacted by the Deepwater Horizon Oil Spill from 2011-2016: Evidence of recovery?

**J. Gelsleichter**[1], R. Grubbs[2], A. Leary[1], M. Heithaus[3], C. Cotton[2]
[1]University of North Florida, Jacksonville, FL, [2]Florida State University Coastal & Marine Laboratory, St. Teresa, FL, [3]Florida International University, North Miami, FL

As the largest oil spill in history in U.S.-controlled waters, the Deepwater Horizon (DWH) Oil Spill resulted in extensive contamination of Gulf of Mexico waters. This posed significant health risks to numerous marine wildlife populations, particularly deepwater species residing in offshore waters within and/or adjacent to the primary contamination zone. Given the population-level impacts that have occurred in some wildlife species as a result of chronic exposure to oil constituents from prior oil spills (e.g., Exxon Valdez oil spill), it is critical to monitor the health of Gulf fish to assess the full impacts of the DWH Oil Spill on these animals. Therefore, to address this problem, we have examined biomarkers of exposure to polycyclic aromatic hydrocarbons (PAHs), the most toxic constituents of crude oil, in deepwater Gulf sharks for the past 5 years. Data on the activity of the PAH-metabolizing biotransformation enzymes, cytochrome P450 1a1 (Cyp1a1) and glutathione-S-transferase (GST), biliary concentrations of PAH metabolites, and levels of hepatic lipid peroxidation in 3 deepwater shark species (*Squalus mitsukurii*, *Squalus cubensis*, and *Centrophorus granulosus*) suggest that sharks residing in oil-exposed locations exhibited physiological responses to increased oil exposure up to 2-3 years after the spill occurred. However, more recent data provide evidence for reduced oil exposure as PAH biomarkers levels in sharks collected 4-5 years after the spill have been among the lowest observed in this study. We explore whether reductions in PAH biomarker levels in sharks from oiled sites represent a recovery trend.

Toxicity of 1-methylnaphthalene to *Americamysis bahia* and Comparison with an Established Critical Body Burden Using the Target Lipid Model

**N. Turner***[1], D. Renegar[1], T. Frank[1], B. Riegl[1], G. Bera[2], G. Gold Bouchot[2], J. Sericano[2], S. Sweet[2], A. Knap[2]
[1]Nova Southeastern University, Dania Beach, FL, [2]Texas A&M University, College Station, TX

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. To test the functionality of the exposure system that will be used in experiments with deep sea organisms, the effects of 1-methylnaphthalene on *Americamysis bahia* were assessed in a 48 h constant-exposure multi-concentration toxicity test utilizing a passive dosing system. This study also served to verify the effects of salinity and temperature on the partitioning of 1-methylnaphthalene between the polymer (PDMS) and surrounding aqueous phase. Determination of the critical body burden (CBB) was completed using the experimentally derived $LC_{50}$ and the target lipid model (TLM). The calculated CBB was used to compare results with a previously established CBB for *A. bahia*, and due to the ubiquitous toxic mode of action for all type 1 narcotic chemicals, can also be compared between species even if different



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chemicals were used. The calculated CBB from this study will serve as the basis for toxicity estimates for future experiments utilizing ecologically important deep-sea micronekton and other petroleum hydrocarbons.

DEEPEND: Comparative Population Genomics of Mesopelagic Shrimp to Diagnose Long-Term Changes to Ecosystem Health and Resilience in the Gulf of Mexico

**L. Timm***, H. Bracken-Grissom
Florida International University, North Miami, FL

Population genomics analyses can provide crucial insights into genetic diversity and connectivity. When focused on key species situated at the base of the trophic web, such insights may be used as proxies to diagnose the health and resilience of a species, community, and ecosystem. This comparative population genomics study surveys three species of mesopelagic shrimp (two oplophorids: *Acanthephyra purpurea* and *Systellaspis debilis*; and a sergestid: *Sergia robusta*) to 1) analyze changes in genetic diversity to determine the extent to which midwater shrimp are vulnerable to massive pollution events and 2) assess the ability of these species to recover from such events by measuring levels of genetic connectivity across major oceanic basins. These genomic proxies allowed us to diagnose changes to ecosystem health and infer ecological resilience in the Gulf of Mexico (GOM). Samples were collected from the GOM closely following the DWHOS spill in 2011. Under the DEEPEND project, specimens were collected during the wet and dry seasons of 2015-2016, with additional sampling scheduled for 2017. To address inter-basin connectivity, specimens of each species were also collected from the Northern Atlantic Ocean and the Florida Straits. Given the small geographic range and relatively short timescale, traditional population genetics methods were unlikely to capture genetic diversity at the target level. Instead, this study utilized a next-generation sequencing method, double-digest Restriction-site Associated DNA sequencing (ddRADseq), which generated orders of magnitude more data than traditional methods. The results challenge the assumption that mesopelagic shrimp species form one large, well-mixed population in the GOM. This study quantifies relative health and recovery over a six-year period in the GOM midwater. Focusing on this frequently over-looked habitat fills a large data gap in understanding the state and flux of genetic diversity in ecologically important species in the GOM and informs future spill outcomes.

DEEPEND: First Evidence for Vertical Migration by the Gulf Bathypelagic Fauna and its Relationship to the DWHOS Deep Hydrocarbon-Dispersant Plume

**T. T. Sutton**, A. B. Cook, R. J. Milligan
Nova Southeastern University, Dania Beach, FL

The classical paradigm of the vertical ecology of the pelagic ocean is that the bathypelagic fauna (below 1000 m daytime depth of residence) do not vertically migrate on a daily basis, unlike most of the mesopelagic fauna (200-1000 m daytime depth). This paradigm is supported by several factors: the primary driver of daily vertical migration is thought to be sunlight, which is absent at bathypelagic depths; there is a fundamental change in assemblage composition below 1000 m; and the energetic costs of bathypelagic migration are thought to be prohibitive. Nonetheless, there remains a huge gap in our understanding of the bathypelagic realm since the vast majority of deep-pelagic studies do not sample below 1000 m. Pursuant to the Natural Resource Damage Assessment (2010-11) and the current GoMRI DEEPEND Consortium (2015-17), two large-scale, discrete-depth sampling programs were implemented, both having a goal of sampling above, within, and below the depth of the trapped



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plume of dissolved DWHOS contaminants and fine oil droplets, which was centered at c. 1100 m. These data provide an unprecedented amount of information about bathypelagic ecology, and reveal that bathypelagic fishes do undertake active daily migrations. Potential cues for this migration in the absence of solar light will be discussed. Vertical migration from the bathypelagic realm, combined with bathypelagic foraging of some marine mammals, represents a potential vector of contamination from the deep plume to the meso- and epipelagic (above 200 m depth) food webs. These findings suggest that previous paradigms about deep pelagic fauna may need to be reconsidered and underscores the urgent need to better understand connectivity through the water column when assessing injuries to large marine ecosystems such as the Gulf of Mexico.

Trophic Structure of Mesopelagic and Bathypelagic Micronekton in Relation to Mesoscale Oceanographic Features in the Northern Gulf of Mexico

**T. Richards***[1], T. Sutton[2], D. Wells[1]
[1]Texas A&M University at Galveston, Galveston, TX, [2]NOVA Southeastern University, Halmos College of Natural Sciences and Oceanography, Dania Beach, FL

The Deepwater Horizon oil spill, which released hydrocarbons into the deep-pelagic environment of the Gulf of Mexico (GoM), revealed significant data gaps with respect to the Gulf's largest habitat including a paucity of information regarding the trophic structure of meso- and bathypelagic food webs. Gaining a better understanding of trophic dynamics is important to understanding ecosystem functioning and can provide insight into ecosystem resiliency in the face of large-scale perturbations. Describing trophic structure of pelagic assemblages in the GoM is complicated by diel vertical migration of many species and the presence of mesoscale oceanographic features (loop current, anticyclonic, cyclonic eddies) which can persist for months and have been shown to affect food web structure in pelagic systems. To better understand the spatial and temporal dynamics of deep pelagic food webs in the GoM we used stable isotope analysis ($\delta^{13}C$ & $\delta^{15}N$) to examine the trophic dynamics of particulate organic matter (POM) and meso- and bathypelagic micronekton in relation to mesoscale anticyclonic and cyclonic features in the GoM. At each sampling location POM samples were taken at four depths throughout the water column while micronekton samples were collected using a 10-$m^2$ MOCNESS midwater trawl sampling specific stratified depths from the surface to 1500 m. POM samples were found to be enriched in $^{15}N$ with increasing depth regardless of feature type which was reflected in the $\delta^{15}N$ of consumers. Deeper dwelling non-migratory species were enriched in $^{15}N$ compared to migratory taxa despite known dietary and trophic similarities suggesting an increased reliance on deep suspended carbon sources by non-migratory species. By describing vertical and horizontal patterns in trophic structure of deep pelagic micronekton this project will provide baseline trophic data that can be used to inform spatially explicit ecosystem models and will provide insight into the structure and functioning of the northern GoM pelagic ecosystem

DEEPEND: Complex vertical movements of mesopelagic scattering layers: from taxonomic-based migration decisions to global biological fluxes

**G. Rieucau**[1], M. D'Elia[1], J. D. Warren[2], T. T. Sutton[3], K. M. Boswell[4]
[1]Florida International University, North Miami, FL, [2]Stony Brook University, Southampton, NY, [3]Nova Southeastern University, Dania Beach, FL, [4]FIU, North Miami, FL

Diel vertical migrations (DVM) of mesopelagic animals, organized in depth-discrete acoustic scattering layers (SLs) between the surface to the deep ocean, represent the largest mass movement of animals



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on the planet. DVMs are recognized to play a pivotal role in structuring ecological and physicochemical processes in oceanic ecosystems. Mass animal migrations reflect adaptive decisions made by organisms in response to spatiotemporal variations in resources, conferring foraging or reproductive advantages while reducing predation risk. However, there is a paucity of data to elucidate the fine-scale behavioral patterns of mesopelagic migrants during DVMs. Here, we studied the migration patterns of SLs using acoustic data collected during DEEPEND cruises in the Gulf of Mexico (GoM). We examined the characteristics of the migrating layers (timing, speed) connecting SLs during DVMs, and applied acoustic models to classify the dominant scatterers of the migrating mesopelagic nekton community to quantify their contributions to the ascending and descending threads. Our results highlight the complex dynamics of these vertical migrations and reveal that DMVs, during both descending and ascending phases, are comprised of multiple threads differing in speed, length, and taxonomic composition; suggesting that different groups of mesopelagic organisms rely on different adaptive migration strategies. Predictions from an acoustic-based carbon flux model parameterized with DEEPEND catch data indicate that taxonomic categories greatly differ in their contribution to the vertical transport of carbon, with differences reaching several orders of magnitude, implying important biogeochemical consequences. Our study helps to better understand the dynamics of DMVs and their role in trophic interactions, vertical connectivity of food-webs, and GoM biological pump.

Response to Oil and Dispersant Exposure of *Lophelia pertusa*

**A. M. Weinnig***, E. E. Cordes
Temple University, Philadelphia, PA

*Lophelia pertusa*, a scleractinian cold-water coral, acts as the foundation for benthic ecosystems throughout most of the world's oceans, including the Gulf of Mexico. These organisms are under increasing threat due to anthropogenic intrusion into their natural habitats. For example, the Deepwater Horizon oil-spill of 2010 deposited oil and, during the response, chemical dispersants into deep waters for the first time. The effects of both oil and chemical dispersants on these ecosystem builders are unknown. This study assessed the effects of bulk oil as well as the water-accommodated fractions (WAF) of oil and dispersant on *L. pertusa* from the Gulf of Mexico. Short-term toxicological assays (0-96h) were performed to monitor the polyps' responses to both oil and dispersant separately, as well as the combination of oil and dispersant together. Elucidating *L. pertusa*'s stress responses to oil and dispersants will provide vital information on how deep-water communities will respond in the event of future oil spills and assist in developing the most ecologically-sound response plan.

Horizontal & vertical transport of marine snow in the Gulf of Mexico

**G. Liu***[1], A. Bracco[1], U. Passow[2]
[1]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, [2]Marine Science Institute, University of California Santa Barbara, Santa Barbara, CA

Marine snow formed in oil-contaminated seawater (marine oil snow) contains various small organic & inorganic particles such as plankton, detritus, bacteria, minerals, & oil. Sinking velocity of this marine oil snow varies widely, depending on size, porosity & component particle composition, ranging between 10's to 100's of m $d^{-1}$. Sinking velocity & other characteristics of marine oil snow determine its distribution & fate, & impact organisms & habitats in pelagic & benthic ecosystems. Here the transport & mixing processes determining the settling of marine snow in the northern Gulf of Mexico are discussed using a regional ocean model at a horizontal resolution of 1km. Through inverse calculations,



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the trajectories of about 6000 Lagrangian tracers is reconstructed multiple times & for different months from three locations, OC 26 (28$^{o}$40.8 N, 88$^{o}$ 21.7 W), GC 600 (27$^{o}$22.5 N, 90$^{o}$ 30.7 W) and AT 357 (27$^{o}$31.5 N, 89$^{o}$ 42.6 W), in correspondence to sediments trap locations used by the ECOGIG consortium. These particles are backtracked for about 30 days with different upward velocities. The results indicate that the horizontal extent of rapidly sinking particles (>100 m/day) is limited to a small area nearby the trap locations (10's of km), but that the slower particles (e.g. 50 m $d^{-1}$) reaching the traps originate from several hundred kilometers far away. Additionally, the role of mesoscale & submesoscale structures in influencing the particle residence time in the water column is discussed.

Drivers of pelagic microbial community dynamics in the northern Gulf of Mexico

**C. Easson**, J. Lopez
Nova Southeastern University, Dania Beach, FL

The pelagic environment in the Gulf of Mexico (GOM) is a dynamic ecosystem influenced by a variety of natural and anthropogenic forces such as the gulf Loop Current that brings in tropical oligotrophic water, and the Mississippi River which inputs large amounts of nutrient-rich freshwater into the system. These forces converge in the pelagic ecosystem of the GOM leading to heterogeneous and dynamic habitat conditions for the resident organisms. Microbial communities form the base of highly diverse and complex food webs in the GOM and are likely the most responsive organisms to changes in environmental conditions. However, the community dynamics of these organisms is not well characterized. In the current study, the dynamics of these communities in relation to changes in environmental conditions associated with season, depth, meso-scale oceanographic features, and anthropogenic inputs was investigated. Seawater samples representing three pelagic depth zones were collected across 23 offshore stations on biannual cruises in 2015 and 2016. Next-generation sequencing on an Illumina MiSeq was used to characterize the microbiome of from each sample. Variation in microbial community diversity and composition was assessed in relation to CTD measured environmental data. Strong depth partitioning among pelagic zones in microbial composition was broadly observed, and the communities in each zone had distinct environmental drivers. For example, in epipelagic communities, chlorophyll *a* concentration was strongly associated with variation in composition, whereas meso- and bathypelagic communities were more influenced by changes in temperature and oxygen. The combination of environmental and microbial data provides insight into the biological influence of the many natural and anthropogenic forces that converge in the pelagic ecosystem of the GOM, and allows for a better understanding of how this ecosystem will respond to future perturbations.

Vertical Abundance of Marine Snow in response to MS River Plume Water

**A. R. Diercks**[1], V. Asper[1], K. Ziervogel[2], U. Passow[3]
[1]University of Southern Mississippi, Stennis Space Center, MS, [2]University of New Hampshire, Durham, NH, [3]University California Santa Barbara, Santa Barbara, CA

Size, abundance and settling speed of marine snow in the ocean are linked to the availability of material that is accumulated in these aggregates. Spatial and temporal availability of this source material highly influences the vertical and spatial distribution of the aggregates, affecting their size, densities and their residence times within the water column. Suspended particles introduced by river runoff and through resuspension events are the primary source of lithogenic material within these aggregates. We will present here profiles of volumetric particle size and abundance from different



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parts of the northern Gulf of Mexico combined with size specific settling speeds. These profiles, acquired near natural and anthropogenic hydrocarbon seeps, on the shelf near the Mississippi River and offshore in the deep Gulf of Mexico, will show how complex and highly variable the distribution of marine snow within the water column of the Northern Gulf of Mexico is. A short time series of detailed profiles of aggregate abundance and beam attenuation acquired near the anthropogenic hydrocarbon seepage at the Taylor Energy site will illustrate the short term variability and emphasize the need for long term time series monitoring near this site.

Using image-based long-term monitoring to determine the fate of impacted deep-sea coral communities after the Deepwater Horizon oil spill

**F. Girard***, B. Fu, T. B. Boyer, T. D. McElroy, C. R. Curtis, C. R. Fisher
Pennsylvania State University, University Park, PA

In April 2010, the Deepwater Horizon blowout led to one of the largest oil spills in history. Within months three impacted coral communities were discovered. We developed a method to quantify the long-term impact of the spill on deep-sea coral communities in the Gulf of Mexico and assess their recovery. *Paramuricea* spp. colonies were imaged every year between 2011 and 2016 at five different sites, and the images digitized to quantify impact, identify hydroid overgrowth, and track recovery patterns. Observed recovery between consecutive years was negatively correlated with the level of impact apparent on corals in 2011. Significant branch loss was observed throughout the study period; most often occurring in impacted areas of the colonies but sometimes resulting in the loss of apparently healthy portions. This method not only allowed us to better understand the coral's response after impact from a spill, but also helped answer fundamental questions about the biology of these organisms. We were able to measure growth rates for both *Paramuricea biscaya* and *Paramuricea sp. B3*, as well as characterize the relationship between corals and their associate ophiuroids. On average, *P. biscaya* had slow growth rates compared to *P. sp. B3*, and growth was negatively affected by the level of total visible impact. Impacted branches were also less likely to form new branches. The presence of ophiuroid associates was found to have strong positive effects on these corals. Ophiuroids mitigated the effects of the initial impact and enhanced recovery of the colonies hosting them.

Recovery watch for mesophotic corals of the Pinnacle Trend

**I. R. MacDonald**, M. Silva
Florida State University, Tallahassee, FL

The Pinnacle Trend is an important coral habitat on the continental shelf offshore from Mississippi and Alabama. The carbonate reef structures, which formed during last glacial low sea level periods, host divers sea fans, solitary corals, and sessile invertebrates, as well as significant populations of fish. The Pinnacles are economically significant as destinations for commercial and recreational fishing. Following the 2010 oil spill, surveys documented hundreds of pathologies among several species of sea fans at two principal locations: Alabama Alps Reef and Roughtongue Reef. A follow-up survey in 2014, tracked the fate of injured corals at both sites and found no evidence for recovery. There are a number of major obstacles for developing an effective recovery strategy for this offshore resource base. Conceptually, there may be few alternatives for promoting recovery of individual colonies or their associated ecosystem, but the regional importance of the Pinnacle Reefs and examples of marine sanctuary protection elsewhere in the Gulf argue for implementation of a rigorous monitoring



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program. Assessment of injury was limited to a few, previously studied sites. Therefore, the full extent of the ecosystem injury is poorly constrained. A maximum entropy model of potential coral habitat predicts that over 400 km2 of hard grounds are suitable for coral colonization in water depths from 50 to 80m. These results are largely consistent with previous studies and provide a basis for delineating the area of concern for recovery monitoring. Considering the broad and complex habitat, a cost-effective strategy of random point photography by small ROVs or simple drop camera systems is indicated.

Temporal variability of deep-sea coral-associated polychaete communities in Gulf of Mexico sediment after the Deepwater Horizon oil spill

**A. W. J. Demopoulos**[1], J. R. Bourque[1], E. Cordes[2], C. R. Fisher[3]
[1]US Geological Survey, Gainesville, FL, [2]Temple University, Philadelphia, PA, [3]Pennsylvania State University, State College, PA

Deep-sea corals create complex habitats that support distinct sediment communities. Several deep-sea coral habitats were impacted by the 2010 Deepwater Horizon spill, and recovery of associated sediment communities may take several years. While spill-associated organic enrichment may lead to increased abundances of tolerant taxa, toxic effects of the spill may lead to declines in sensitive groups. However, temporal variability in coral-associated sediment macrofauna is unknown and represents an important consideration for post-spill community assessments. Here we examine how the polychaete communities change over time at impacted and reference sites and assess if particular taxa and/or functional groups may serve as indicators of impact at these sites. From 2010 to 2014, we examined polychaete communities at multiple impacted and reference deep-sea coral sites to quantify post-spill temporal changes in community metrics coupled with sediment characteristics (e.g., grain size and organic carbon). Densities at impacted sites varied over time, while diversity was lower than at reference sites. Polychaete communities differed among years within impacted sites but not within reference sites. Specifically, the relative proportion of sensitive and tolerant taxa varied among years as did key sediment parameters. Feeding group composition changed significantly within impacted sites, with an increase in deposit feeders and decrease in omnivores over time since the spill. Within reference sites there was a notable, yet small difference in feeding group composition over time, with a similar decrease in the proportion of omnivores. Additional community and environmental data from 2015 and 2016 will be included and presented. These multi-year data provide an unprecedented 7-year post-spill baseline for assessing changes in coral-associated sediment communities in natural habitats than can help inform future monitoring and restoration activities.

Deep-sea fish species diversity in the northern Gulf of Mexico - a DNA Barcode View

**A. Bernard**[1], K. Finnegan[1], T. Sutton[1], J. Moore[2], R. Hanner[3], M. Shivji[1]
[1]Nova Southeastern University, Dania Beach, FL, [2]Florida Atlantic University, Jupiter, FL, [3]University of Guelph, Guelph, ON, Canada

The limited information available on pre-oil spill deep-sea biodiversity has been a severe impediment to properly assessing impacts of the DWH event on the meso- and bathypelagic ecosystems of the Gulf of Mexico. Furthermore, available pre-spill information is based mainly on static “snap-shots” surveys of this still incompletely documented biodiversity. It is now becoming apparent that the deep pelagial contains an immensely diverse, dynamic and potentially functionally novel ichthyofaunal community uniquely adapted to this ecosystem. A key component of the DEEPEND Consortium project is to 1)



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expand knowledge of the diversity of this ichthyofaunal community, 2) resolve the substantial uncertainties in taxonomic affinities and descriptions of taxa inventoried before the spill, and 3) provide DNA barcodes to assist biodiversity surveys related to general ecosystem function and potential, future oil-spill impacts. We report here on our assessment of the deep ichthyofaunal diversity based on COI DNA barcoding of samples collected during DEEPEND cruises in 2015 and 2016. Of the 1,136 fish samples barcoded to date, nearly 60% demonstrated a concordance between assigned morphotaxonomy and DNA barcodes available in the Barcode of Life Database (BOLD), providing confidence in their morphospecies descriptions and assignment. Five percent of samples, comprising fish early life stages (ELF), were able to be assigned to species level based on barcode matches with adult stages, thus providing an opportunity to develop morphological taxonomic keys for these ELFs. Nearly 21% of the samples, however, provided DNA barcodes that either did not match any species, matched more than one species, or demonstrated lack of concordance between morphospecies identified by DEEPEND taxonomy experts and morphospecies in the BOLD. These uncertainties highlight the incomplete nature of deep-sea fish taxonomy in the Gulf of Mexico, including the presence of cryptic species.

Community and population level effects of the DWH oil spill on deep demersal fishes: Six years monitoring recovery in sharks, teleosts and hagfishes

**D. Grubbs**[1], C. Cotton[1], J. Gelsleichter[2]
[1]FSU Coastal and Marine Lab, St. Teresa, FL, [2]University of North Florida, Jacksonville, FL

Prior to the Deepwater Horizon (DWH) oil spill, knowledge was limited concerning the deep-sea communities of the northern Gulf of Mexico (GoM), particularly for the large demersal fishes that are not adequately sampled using trawls. During the past six years, we used novel capture techniques to assess the potential effects of DWH on the larger, more mobile fishes in the northern GoM at depths of 200 to 2,000 m. Edge habitats such as submarine canyons and the upper continental slope tend to be areas of elevated biomass and biodiversity for many taxa in the deep sea. Submarine canyons also function as conduits linking water masses of the continental shelf and the deep ocean, funneling organic matter, nutrients, and contaminants into these areas. Our sampling covered more than 600 KM continental slope habitat from the Louisiana slope west of the Macondo wellhead, east throughout Desoto Canyon and along the continental slope offshore of the Florida's panhandle and Big Bend region (North Florida Slope) and south to the West Florida Slope offshore of southwest Florida. Between April 2011 and April 2016, 16 research cruises were conducted and nearly 5,000 fishes from more than 100 species of large demersal teleosts, elasmobranchs and hagfishes were used to discern spatially and depth-mediated patterns of abundance and community structure over time. Our data suggest some species experienced population level changes following the spill but ecology, taxonomy and life histories influence the magnitudes of the effects as well as recovery trajectories. Community structure among deep-sea fishes is spatially heterogeneous within the Gulf of Mexico and is linked to edaphic factors, habitat type, and sources of primary production. Spatial heterogeneity in community structure limits the use of spatial controls for oil-spill effects and highlights the need for baseline data concerning deep sea populations and communities in other areas where deep water oil spills may occur.



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Simulating the Biological Dynamics of Spilled Oil in the Deep Gulf of Mexico

**G. T. Rowe**[1], C. Elfrink[2], G. Ansari[2], T. Heathman[1], S. Petrone[2]
[1]TAMUG, Galveston, TX, [2]University of Texas Medical Branch, Galveston, TX

Future oil spill management policy needs to include information on the fate and effects of complex hydrocarbons on the highly diverse fauna in deep-ocean habitats. We build on a hierarchy of numerical simulations that estimate the relative fate of four major components of the DWH oil spill (saturates, aromatics, resins and asphaltines) in deep water. These simulations assume mass balance between the total BPH spill (ca. 5E6 barrels), and the fraction of the total that has been estimated to be incorporated in deep-water habitats. The models include uptake and depuration of PAHs in a wide range of taxa, based on shallow water studies. The simulations suggest that PAHs are cycled through the biota over periods of weeks to months. Knowledge of the time-dependent persistence of toxicants within the biota could assist managers in determining the need for, or extent of, fisheries closures following oil spills.



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## Session 006: Processes in the Near Field of a Blowout

Experimental studies of gas hydrate dissociation in a Deep Sea Water Simulator
**J. R. Agudo**[1], J. Y. Ko[1], R. Saur[1], G. Luzi[1], S. Loekman[1], C. Rauh[1, 2], A. Wierschem[3], A. Delgado[3]
[1]University of Erlangen-Nuremberg, Busan, KOREA, REPUBLIC OF, [2]Technische Universität Berlin, Berlin, Germany, [3]University of Erlangen-Nuremberg, Erlangen, Germany

During the last decade, Gas Hydrates (GHs) have attracted the interest of the scientific community. Carbon dioxide hydrate (CO2H), for instance, may be of vital importance for capture and sequestration methods in order to reduce global climate change. The transport phenomena involved on the physical-chemical processes taking place during GH formation-dissociation, however, are not yet fully understood. An exhaustive study is thus required to ensure a safe and ecological manipulation of GH. For that purpose, we have installed a pressure vessel (Deep Sea Simulator) which mimics the submarine conditions of GH deep oceanic deposits. The simulator allows pressures up to 150 bars, a minimum temperatures of 4°C, and a seawater volume of 475 liters. This vessel includes 8 sapphire windows for using non-invasive optical methods. In this study, we focus on GH dissociation process during depressurization. GH samples with different levels of gas saturation are illuminated with an impulse Nd: Yag laser and recorded with a CCD camera during dissociation at different water temperatures. We observe that the gas relief is characterized by a continuous dissociation column of micro-bubbles together with a sporadic relief of macro-bubbles with diameters ranging between 1 and 10 mm. The frequency and size of macro-bubbles depends on the initial gas saturation level of the samples. The total dissociation time is strongly affected by the water temperature. Besides, Particle Image Velocimetry (PIV) measurements are carried out during the process. The results reveal a strong impact of the gas bubble column on the bulk of water surrounding the samples. This side-effect should be considered in a hypothetical large-scale production system of natural gas hydrates.

Experimental Simulation of effect of dispersants on Oil-Water Partitioning of low-molecular weight compounds during a deep submarine oil spill
**A. Jaggi***, R. W. Snowdon, J. R. Radovic, S. R. Larter, T. B. P. Oldenburg
University of Calgary, Calgary, AB, Canada

The traditional methods for determining partitioning behavior of organic species into water following petroleum spillage fail to accurately model the conditions of high pressure, low temperature and dissolved gas found in submarine oil spill scenarios. To experimentally simulate the partition behavior of water soluble oil components using live oils (methane-charged) with saline waters under subsurface oil spill conditions, a unique, customized oil-water partitioning device was developed. The partitioning behavior of low- molecular weight species was determined along the depth of the water column over a range of pressure (2 - 15 MPa) and temperature (4 - 20 °C) reflecting water depths between 200 m and 1500 m. Within these investigated ranges, the partitioning of BTEX compounds showed a 'salting-out' effect with the increase in pressure with 'live oils', resulting in lower BTEX partitioning into the water phase. In addition, BTEX compounds partitioning also showed an increase proportionally with the increase in temperature, and inversely with increase in alkylation.

To understand the effect of dispersants on the partitioning of oil constituents, the system was run under similar conditions with the addition of dispersant Corexit 9500 at 1:1000 dispersant to oil ratio. The addition of dispersants increased the extent of BTEX partitioning from the oil to water - the



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increase was high at near surface conditions, while it was within the experimental error limits at higher pressure conditions.

This data will aid in near-field and far-field distribution modeling of the environmental fate of crude oil components of interest and assist in the prediction of component migration pathways from potential oil spills.

Refractive Index-matched Turbulent Immiscible Buoyant Oil Jet Breakup in Water
**X. Xue***, J. Katz
Johns Hopkins University, BALTIMORE, MD

Subsurface oil well blowouts create buoyant, immiscible turbulent jets/plumes containing droplets with sizes ranging from several millimeters to sub-microns. To predict the fate of this oil, it is critical to quantify the fragmentation mechanism and droplet size distribution as a function of flow condition and oil properties. It is difficult to visualize and quantify the fragmentation process in opaque crude oils plumes, especially in the breakup region, where the droplet concentration is high. Refractive index matching of two immiscible fluids with relevant properties are used to overcome this challenge. When silicone oil serving as surrogate for crude oil is injected into 60.48% by weight sugar water, the matched refractive index (1.4015) allows unobstructed view on across the entire jet. These fluids closely match the interfacial tension as well as the kinematic viscosity and density ratios of crude oil and seawater. High speed planar laser-induced fluorescence and particle image velocimetry (PIV) are implemented simultaneously to study plume/jet structure along with the fragmentation process and associated phase distribution at varying Reynolds and Weber numbers. Results clearly show that breakup occurs closer to the nozzle, the spreading angle of the oil jet increases and the droplet sizes decrease with increasing jet Reynolds and Weber number. These trends could be explained in terms of variations in initial shear stresses, and resulting droplet-size dependent buoyancy. As oil ligaments stretch and break into droplets, they often entrain water, resulting in secondary water droplets encapsulated within oil droplets. Multiple layering also occurs, creating a “Russian Doll” like phenomenon. Consequently, the buoyancy and inertia of these droplets differ from those of pure droplets of the same size, affecting their transport. The PIV measurements provide detailed statistics on the evolution of mean flow and turbulence within this jet.

High-Pressure Measurement of Oil Droplet Sizes in a Sapphire Autoclave
**Z. M. Aman**[1], V. W. Lim[1], C. B. Paris[2], M. Schluter[3]
[1]University of Western Australia, Perth, AUSTRALIA, [2]University of Miami, Miami, FL, [3]Hamburg University of Technology, Hamburg, Germany

The uncontrolled release from deepwater hydrocarbon reservoirs will result in the dispersion of oil and gas into the water column, where the oil droplet size distribution is a controlling factor to the ultimate fate of the oil; large droplets tend to rise rapidly to the surface, while smaller droplets may form a stratified oil layer at depth and remain sequestered. To date, most experimental measurements of the oil droplet size distribution have been constrained to laboratory-scale blowout systems with nozzle diameters between 0.5 and 3 mm. In this study, we have deployed two high-pressure sapphire autoclave cells with mixing length scales of 25.4 and 50.8 mm, where oil and water were mixed at a constant angular velocity with a vane-and-baffle geometry. Oil droplet sizes were measured visually using a 1500 fps high-resolution camera with a minimum detectable droplet size of 15 microns. Using



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both medium- and high-viscosity crude oil samples, the results show that droplet sizes decreased in both cells as a function of mixing velocity, toward a mean diameter of approximately 100 microns. When chemical dispersants (ionic or nonionic surfactants) were used, the measured oil droplet sizes exhibited minimal dependence on mixing velocity, independent of the mixing length scale; this result suggests that, during high-velocity blowouts, systems may naturally produce droplets that are sufficiently small to disperse in the water column without the use of chemical dispersants. Comparing both sapphire autoclave cells illustrates that neither the Reynolds or Weber number-based scaling methods appropriately the breadth of reported data, and neither appropriately capture the limiting case of dispersant application.

Rapid Decompression - Influence of Dissolved Gases and Pressure Drop on Drop Size Distributions during a Deep-Sea Blowout

**K. Malone***, S. Pesch, M. Schlüter, D. Krause
Hamburg University of Technology, Hamburg, Germany

In oil spill modeling, one of the important input parameters is the particle size distribution of the oil and gas entering the water column. While there is a sound understanding of the drop formation processes of “dead”, i.e. solely liquid crude oil, the influence of gaseous hydrocarbons on the liquid phase is not yet understood. During the Deepwater Horizon Oil Spill, however, huge amounts of short-chained hydrocarbons (mainly consisting of methane) have been released alongside the liquid crude oil. These emerged from the wellhead as a free gaseous phase as well as dissolved into the liquid oil phase. When oil and gas entered the water column at the wellhead, their physico-chemical properties changed quickly and significantly due to the rapid pressure drop at the vent.

To investigate this highly dynamic process, laboratory experiments have been conducted at Hamburg University of Technology, under artificial deep-sea conditions with hydrostatic pressures up to 200 bar and low temperatures. Jets of pure, “dead” crude oil and of crude oil pre-saturated with methane have been generated at different ambient (ocean) and reservoir pressures. The droplet size distribution has been analyzed using an endoscopic high-definition camera system. Results show a strong influence of both the gaseous components dissolved in the crude oil and the pressure drop at the well head on the resulting droplet size distribution.

Droplet size distributions and characteristics of the experimentally generated jets are being compared with regard to the influence of methane saturation, physico-chemical properties and pressure drop at the vent. Possible mechanisms of drop formation influenced by these factors and their effect on modeling approaches are discussed.

Gas Saturation Effects on the Rise Behavior of Oil Droplets under Deep-Sea Conditions

**S. Pesch***[1], G. Kenne[1], P. Jäger[2], K. Malone[1], T. Oldenburg[3], M. Hoffmann[1], D. Krause[1], M. Schlüter[1]
[1]Hamburg University of Technology, Hamburg, Germany, [2]Eurotechnica GmbH, Bargteheide, Germany, [3]University of Calgary, Calgary, AB, Canada

The buoyancy-driven rise velocity of crude oil droplets through the water column as a consequence of deep-sea blowouts is an important input parameter for modeling the fate of the oil throughout the ocean. Therefore the knowledge of the rise behavior is crucial for both predicting the oil distribution in different depths and implementing appropriate response strategies.



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During the past years, the influence of the high pressure in the deep sea as well as the “live oil” properties of the gas-saturated oil on the drop formation process and the resulting droplet size distribution became evident. But the elevated pressure and the dissolved gas also influence the further propagation of the droplets in the water column, since the solubility of the natural gas in the oil is highly pressure-dependent. As the pressure decreases from 15 MPa to ambient for a complete drop rise in case of the Deepwater Horizon blowout, the amount of gas that can stay dissolved in the oil decreases dramatically, which leads to degassing of the oil and thus occurrence of a gaseous phase within the droplets. Results of both modeling and experiments using new high-pressure facilities are presented and a comparison of degassing “live oil” and non-pressure-sensitive “dead oil” is drawn. The mechanism of degassing and its influence on the droplet rise velocity are discussed.

This research was made possible by a grant from the Gulf of Mexico Research Initiative (GoMRI), C-IMAGE II.

Investigating the Impact of the Release on the Oil Droplet Size Distribution from a Blowout: A review and a Numerical Investigation

**M. Boufadel**[1], F. Gao[1], L. Zhao[1], T. King[2], B. Robinson[2]
[1]New Jersey Institute of Technology, Newark, NJ, [2]Bedford Institute of Oceanography, Dartmouth, NS, Canada

The droplet size distribution (DSD) of oil from blowouts such as the Deepwater horizon has been the focus of numerous studies. However, whether the study is experimental or numerical, replicating the conditions of the DWH well is not achievable in the lab nor numerically. For this reason, various researchers addressed certain aspects of the release. The purpose of this paper is to first review these studies, and to report the results of a numerical investigation using computational fluid dynamics that aims on setting bounds on the potential range of the DSD under various scenarios. We addressed in particular the following conditions: live oil, dead oil, impact of temperature, impact of degassing, impact of bubbles, the gas to oil ratio and the dispersant to oil ratio. We found that using live oil is crucial for accurate prediction of early breakup, but the DSD at 200 m from the release is close to that obtained by assuming dead oil. We found the impact of the oil temperature on the DSD to be negligible. We also found that increasing the GOR reduces the DSD. The addition of dispersant was found to reduce the size of the oil droplets, but the model is not capable of accurately predicting dispersant effectiveness in the presence of gas.

Evolution of gas bubbles and oil droplets in subsea oil and gas blowouts

**L. Zhao**[1], M. Boufadel[1], S. Socolofsky[2], F. Gao[1], T. King[3], B. Robinson[3], K. Lee[3]
[1]New Jersey Institute of Technology, Newark, NJ, [2]Texas A&M, College Station, TX, [3]Bedford Institute of Oceanography, Fisheries and Oceans Canada, Dartmouth, NS, Canada

Underwater blowouts often involve the simultaneous release of oil and gas, and the presence of gas in the jet could influence the oil droplet size distribution (DSD). We investigated numerically the interaction between gas bubbles and oil droplets in jets at various gas to oil ratios (GOR). We developed for this purpose, a new numerical scheme in VDROP-J to account for the motion of bubbles and the turbulent energy they introduced into the system. The scheme provides thus a direct coupling between the evolution of gas bubbles and the evolution of oil droplets. The model VDROP-J with this



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new module was then calibrated to various experimental data of oil and gas release, where the agreement was good. We considered then various release scenarios at various GORs, and we found that the presence of bubbles increases the mixing energy of the jet, and result in smaller oil droplets. This new development will allow for better prediction of blowouts containing both oil and gas.

Dynamic Coupling of Near Field and Far Field Models Hones Predictions of Oil Dispersion from Deep Sea Blowout

**C. B. Paris**[1], A. C. Vaz[1], A. Dissanayake[2], J. Gros[2], S. A. Socolofsky[2]
[1]Rosenstiel School of Marine & Atmospheric Science, Miami, FL, [2]Texas A&M University, College Station, TX

Deep-water spills pose a unique challenge for reliable predictions of oil transport and fate, since live oil spewing under very high hydrostatic pressure has characteristics remarkably distinct from oil spilling in shallow water. It is thus important to describe in details the complex thermodynamic processes occurring in the near field, meters above the wellhead, and the hydrodynamic processes in the far field, up to kilometers away. However, these processes are typically modeled separately since they occur at different scales. Here we directly couple two oil prediction applications developed during the Deepwater Horizon blowout operating at different scales: the near field Texas A&M Oilspill Calculator (TAMOC) and the far field oil Connectivity Modeling System (oil-CMS). The dynamic coupling of these two models is using measured CTD and velocity profiles in the near field computations to capture the formation of deep intrusions, while the individual oil droplets formed in the near field are used as initial conditions for the far field computations of transport and fate based on GoM-HYCOM currents in the far field. To realize this coupling, new CMS modules were developed to read TAMOC output, which consists of the description of distinct droplet sizes composed of a pseudo-component mixture which cross at a variable mass flux at a given time and position over the far field, relative to the wellhead. These variables are transformed for use in the individual-based framework of CMS, where each droplet type fits into a droplet size distribution (DSD). In these simulations, we used 19 pseudo-components representing a large range of hydrocarbon compounds, explicitly considering polycyclic aromatic hydrocarbons (PAHs). Simulation results show that the dispersion pathway of different droplet types varies significantly, some droplet types remain suspended in the subsea over months, while others accumulate in the surface layers. In addition, the decay rate of oil components alters significantly the dispersion, denoting the importance of more biodegradation and dissolution studies of treated and untreated oil at high pressure. This new modeling tool shows the potential for improved accuracy in predictions of oil partition in the water column, and of advancing impact assessment and response during a deep-water spill.

Large-eddy simulation of nearfield oil/gas plume in stratified flow with cross current

**D. Yang**[1], S. Xiao[1], B. Chen[2], M. Chamecki[3], C. Meneveau[4]
[1]University of Houston, Houston, TX, [2]Pennsylvania State University, University Park, PA, [3]University of California, Los Angeles, CA, [4]Johns Hopkins University, Baltimore, MD

Dynamics of the oil/gas plume in the nearfield of a subsea blowout are strongly affected by the seawater stratification and cross current. When the plume blows out from an oil well, it entrains stratified ambient seawater and lifts it up to higher elevations. During this process, the net buoyancy of the plume decreases due to the increasing density difference between the entrained and ambient seawater in the stably stratified ocean environment. This eventually results in a detrainment of the



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entrained seawater as well as small oil droplets at a height of maximum rise (peel height), and a downward plume formed outside the rising inner plume. The outer plume falls to a neutral buoyancy level (trap height), and then disperses horizontally to form a quasi-horizontal intrusion layer. The presence of a cross current causes the inner plume to tilt, and the detrained outer plume mainly falls along the downstream side of the inner plume with respect to the cross flow. In this study, the complex nearfield plume dynamics is studied using an Eulerian-Eulerian large-eddy simulation (LES) model. The current LES model employs the full 3D Coriolis force instead of the horizontally projected 2D Coriolis force used in many previous numerical modeling studies of ocean geostrophic flows. The combination of a large vertical rise velocity of the plume and the 3D Coriolis force results in non-negligible differences between plumes rising through Eastern and Western cross currents. Turbulence statistics of the nearfield plume are also systematically quantified, leading to some useful insights for modeling the mean plume dynamics using integral plume models. 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.

Up-Scaling Oil Droplet Sizes from the Laboratory to the Field

**Z. M. Aman**[1], C. Booth[1], J. Leggoe[1], C. B. Paris[2], M. Schluter[3]
[1]University of Western Australia, Perth, AUSTRALIA, [2]University of Miami, Miami, FL, [3]Hamburg University of Technology, Hamburg, Germany

The accurate description of oil-in-water droplet size distributions is critical to correctly predicting the migration of crude oil during deepwater blowout. There are only a few laboratory datasets reported in the literature for such systems at high-pressure, using either a miniaturised blowout geometry or a rotational autoclave system; in both cases, the length scale of mixing resides on the order of 1-10 mm, while blowout plumes in the field may extend to diameters of 10 m. Conventionally, the dimensionless Reynolds and/or Weber numbers have been used to scale results from the laboratory to the field. In this work, we have compared the breath of suggested scaling methods to available data in the literature, illustrating that no presently-suggested scaling method is able to describe the reported data within an acceptable uncertainty. Rather, the results illustrate that a new scaling method is required, based on a fundamental description of the turbulence in the system. We introduce several computational fluid dynamics (CFD) results of both blowout and rotational autoclave mixing geometries, which have enabled the direct assessment of turbulent mixing energy. In this presentation, we compare the droplet sizes reported from each experimental setup to the mixing energy as assessed by CFD. The results demonstrate that the rate of energy dissipation provides a fundamental pathway to estimate the probable oil droplet size distribution generated during deepwater blowout, without the empirical limitations of current methods.



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## Session 007: Use of Ecological and Socioeconomic Indicators to Demonstrate Ecosystem Recovery

Identification of Gulf of Mexico Ecosystem Indicators using an Ecological Resilience Framework

**K. L. Goodin**[1], D. Faber-Langendoen[1], J. Brenner[2], K. Dunton[3], C. Stagg[4], R. Ruzika[5], R. Day[4], C. Shepard[6], M. Love[7], D. Reed[5]

[1]NatureServe, Arlington, VA, [2]The Nature Conservancy, Houston, TX, [3]University of Texas, Austin, TX, [4]Geological Survey Wetland and Aquatic Research Center, Lafayette, LA, [5]Florida Wildlife Research Institute, St. Petersburg, FL, [6]The Nature Conservancy, Punta Gorda, FL, [7]Ocean Conservancy, New Orleans, LA

To achieve the goal of sustaining healthy diverse, and resilient coastal and marine habitats and living marine species in the Gulf of Mexico, resource managers need a way to take the pulse of this vast ecosystem, to evaluate its health and its ability to provide needed ecosystem services. A comprehensive set of indicators that inform this need is not available. The indicators of ecosystem health and condition measured by current monitoring programs is at best uneven across the range of ecosystems in the Gulf, hindering our ability to support sustainable ecosystem and living marine resource (LMR) management. We employ a structured Ecological Resilience Framework (ERF) to evaluate and portray the indicators collected by existing monitoring programs, assess their strengths and weaknesses and make recommendations for a set of scientifically rigorous, practical, and cost-effective indicators for five key ecosystems (salt marsh, mangrove, seagrass, oyster beds/reefs, and coral reefs) across the Gulf. We developed conceptual ecological models to identify key environmental drivers, ecological condition indicators, and socio-economic indicators. The indicators are organized within the ERF to provide information on metrics for evaluation, field measures, and assessment point ratings that allow the practical evaluation of ecosystem health at multiple scales. The knowledge gained from this indicator based framework will help direct management activities such as LMR management, damage assessment and recovery, restoration planning and evaluation, and vulnerability assessment across the Gulf of Mexico.

Indicators and Assessment Framework for Ecological Health and Ecosystem Services

**M. A. Harwell**[1], J. H. Gentile[2], L. D. McKinney[3], J. W. Tunnell, Jr.[3], R. H. Kelsey[4], W. C. Dennison[4]

[1]Harwell Gentile and Associates LC, Port Orange, FL, [2]Harwell Gentile and Associates LC, Cape Cod, MA, [3]Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX, [4]University of Maryland Center for Environmental Studies, College Park, MD

The Harte Research Institute for Gulf of Mexico Studies has undertaken a multi-faceted project to develop and implement an integrated indicators and assessment framework, termed the *Gulf EcoHealth Metrics*, to characterize the health of the ecosystems of the Gulf, including their linkages to human communities, in support of restoring and sustaining a healthy Gulf of Mexico. Our vision is a characterization of the environmental condition of the Gulf that is scientifically based and widely accessible and understandable by policy-makers, managers, stakeholders, scientists, and the public. Our objective is to provide the scientific information and understanding necessary to evaluate the health of the Gulf, clearly demonstrate how well it is or is not progressing towards desired long-term goals, and inform the decision-making process on the policies needed to achieve sustainability of a healthy Gulf of Mexico. To demonstrate the utility of this framework, we have initiated a series of EcoHealth Metrics for the coastal systems of Texas. Additionally, an important component of this



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initiative is to enhance the EcoHealth Metrics conceptual framework with explicit connections among ecological processes and ecosystem services and human well-being in coastal communities. In this coupled human-ecological framework, anthropogenic and natural drivers, pressures, and stressors impinge on ecosystems, causing effects on ecological health (i.e., changes to ecological structure, processes, and/or diversity) and associated effects on ecosystem services that link ecological and societal systems. This extended framework is embedded within a decision-making process, aimed at providing science-based information and understanding to identifying and assessing management policies and actions. We are testing this approach to support management decisions in a proof-of-concept application, funded by the NOAA RESTORE Science Program, to the Mission-Aransas National Estuarine Research Reserve.

Mission-Aransas Pilot Study: A Proof-of-Concept Demonstration of the *Gulf EcoHealth Metrics* Decision-Support Framework

**J. H. Gentile**[1], M. A. Harwell[2], J. W. Tunnell[3], K. Stanzel[4], L. D. McKinney[5], J. W. Tunnell, Jr.[5]
[1]Harwell Gentile and Associates LC, Cape Cod, MA, [2]Harwell Gentile and Associates LC, Port Orange, FL, [3]Mission-Aransas National Estuarine Research Reserve, Port Aransas, TX, [4]Green Wing Environmental LLC, Victoria, TX, [5]Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX

The Mission-Aransas National Estuarine Research Reserve was selected to conduct a “proof of concept” pilot study to demonstrate the utility of the *Gulf EcoHealth Metrics* assessment and decision-support framework to inform management decisions. The goals of the pilot study are to assess management alternatives for enhancing nesting, breeding, and/or foraging habitat for breeding resident and migratory avian fauna while providing ecosystem services and enhanced well-being to a range of beneficiaries. The decision-support framework is employed to assess the trade-offs inherent in understanding and managing the complex interactions of coupled human-ecological systems. This study examines two management alternatives: the management and enhancement of existing rookery islands and the design of new multifunctional artificial islands that will provide a range of habitat types and ecosystem services. Stress-response matrices are used to rank the relationship between environmental stressors and the structural and functional attributes of existing rookery islands to identify the stressors of most importance to achieving desired goals. The ecological attributes of the islands are also used to identify important ecosystem services and their contributions to well-being. Geospatial analysis of historical patterns of colonial water bird population abundance and distribution will provide insight as to why birds colonize and remain on some islands rather than others and, coupled with specific physical design criteria, will be used to identify sites where new rookery islands will have the highest likelihood of success for enhancing water bird habitat, ecosystem services, and benefits to humans. The application of the decision-support framework will illustrate the integration of management goals, indicators of ecological, ecosystem services, and well-being condition, and geospatial scenario analyses to provide managers with a suite of alternatives for addressing their management goals.



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Evaluations of NRCS's Migratory Bird Habitat Initiative (MBHI)

**B. Davis**[1], R. M. Kaminski[2], F. J. Vilella[1], P. J. Barbour[3], E. Webb[4]
[1]Mississippi State University, Mississippi State, MS, [2]James C. Kennedy Waterfowl and Wetlands Conservation Center Baruch Institute, Georgetown, SC, [3]USDA Natural Resources Conservation Service Central National Technology Support Center, Fort Worth, TX, [4]USGS Missouri Cooperative Fish and Wildlife Research Unit, Columbia, MO

In response to the April 2010 Deepwater Horizon Gulf Oil Spill, the Natural Resources Conservation Service (NRCS) boldly established and funded the Migratory Bird Habitat Initiative (MBHI), providing private landowners in eight U.S. states $40 M in cost-share assistance to create and manage wetland habitats for migratory birds on 177,000 acres *inland* from the spill through 1- to 3-year contracts. Through a Cooperative Ecosystem Study Unit Agreement between NRCS and Mississippi State University (MSU), MSU was commissioned by NRCS to lead a 3-year evaluation (2010-2013) of waterbird use and food abundance in rice fields and natural wetlands in response to private-land management through the MBHI. A team of 9 graduate students from 3 universities conducted research in 6 states and 3 ecoregions in southern United States. Analyses are ongoing but preliminary results indicate that MBHI has been significantly beneficial ecologically, environmentally, and economically. During 2011-2012, MBHI managed wetlands in Louisiana and Mississippi attracted nearly 3 times more waterfowl and other waterbirds than did non-managed wetlands in the same or nearby Wetland Reserve Program (WRP) tracts. In Arkansas and Missouri, MBHI wetlands that were flooded in fall and held water during winter attracted significantly greater numbers of dabbling ducks than wetlands not flooded through MBHI incentive payments. The amount of waste rice in ratoon rice fields in Louisiana was 3 times greater than the amount of waste grain estimated available in rice fields of the Mississippi Alluvial Valley (MAV). Rice production fields and fields taken out of production temporarily (i.e., idled rice lands) both contained abundant natural seeds; when both active rice and idled fields were flooded, ducks and geese dominated production rice fields, while shorebirds, waders, and other waterbirds used idled fields. We detected a total of 11 Families of waterbirds across all habitats provided under MBHI. The MBHI was especially effective in supporting wintering waterfowl and other waterbirds away from oil-impacted coastal wetlands. For example, in the 9,300,000-acre south Louisiana Gulf Coast Joint Venture area, approximately 25% of the wintering waterfowl energy demand was estimated available on the 177,000 acres of MBHI lands in southwest Louisiana. Thus, nearly one-fourth of the potential winter food energy for waterfowl was estimated available on less than 2% of the GCJV area under MBHI management. The NRCS allocated $5.3 M for MBHI management on the 177,000 acres in southwest Louisiana, which equates to a cost of ~$30/acre. When $5.3 M is divided by the duck foraging potential on these 177,000 MBHI acres, the cost per duck-energy day was less than 2 cents. Other aspects of our study that we are currently evaluating include collection of blood and other tissue samples from shorebirds to detect any compound-specific material from the Deepwater Horizon Oil Spill, and water samples collected from seasonal wetlands on MBHI and WRP sites to determine orthophosphate level discharge.

Ocean Weather Laboratory - Identifying Events and Abnormal Bio-optical and Physical Properties in the Gulf of Mexico

**R. A. Arnone**, B. Jones, I. Soto Ramos, M. Cambazoglu, S. Howden
University of Southern Mississippi, Stennis Space Center, MS

The dynamic biological and physical conditions within the Gulf of Mexico (GoM) have been identified by the Ocean Weather Laboratory as interaction of river discharge and the offshore currents. Ocean



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properties derived from VIIRS satellite ocean color (Chlorophyll and Bio-Optics) and Sea Surface Temperature (SST) products and physical properties from ocean-circulation models (currents, SST and salinity) were used to identify dynamic changing properties. Methods were developed for characterizing the degree of environmental changes in the GoM which are defined using the Dynamic Anomaly of bio-optical and physical environmental properties. Results have identified locations where normal and abnormal bio-optical and physical ocean properties occur within a two-month period to determine ecological and physical hotspots in the GoM. Methods to characterize the abnormal environmental properties are described using a Dynamic Anomaly Tool, to depict significant differences between daily and weekly mean oceanic properties and previous 2 month mean with a 2 week lag. The intensity of the environmental product anomaly is characterized by defining levels with respect to the standard deviation of the mean. The tool provides the spatial variability of the abnormal properties for a research and decision-support visual dataset of changing environment for the Gulf of Mexico. The similarity in locations between anomalies of different products suggests the interaction of the physical and biological activity and can be used to provide decision support for sampling. The variability locations of abnormal products help characterize the evolution of ecosystem to changing events. Results identify regions in the GoM for optimal sampling to reduce data gaps and provide improve monitoring of environmental conditions.



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## Session 008: Ecosystem Structure, Function, and Services: Legacies of the Deepwater Horizon Oil Spill

Synthesis Modelling of the DWH Oil Spill
**C. Ainsworth**
University of South Florida, St. Petersburg, FL

Field sampling, laboratory analysis and physical modeling from a wide range of collaborators is combined in a synthetic Atlantis ecosystem model for the Gulf of Mexico. We aim to analyze ecosystem-scale impacts of the Deepwater Horizon oil spill and forecast recovery time in a variety of species. Model training uses a historical reconstruction from 1980 to 2010 driven by time series of catch and spatial-temporal fishing closures and restrictions. Forecasts from 2010 to 2030 include oil spill effects derived from dose response models. These incorporate growth effects from otolith measurements, mortality estimates from examination of pathology, and recruitment effects based on larval sampling. Oil spill effects are modelled using spatial forcing functions on growth, mortality and recruitment for about 20 fish functional groups. Work in preparation will expand to invertebrate effects. We developed a new Atlantis code module for this study. Location of the oil relies on oil fate model coupling, which accounts for degradation. Oil spill projections show a strong impact on the forage base, starvation in predators and shifts in age composition. Food web effects translate impacts to areas far from the plume. Oil avoidance behavior seems important for pelagic species. Reef fish are significantly impacted in agreement with ROV surveys. A second Atlantis model is in development to represent the IXTOC oil spill as an analog of the DWH. This study focuses on the combined effects of fishing and oil contamination over several decades.

NanoSIMS Characterization of Methane Assimilation and $N_2$-fixation in Response to Oil and Gas Release in Offshore Waters
**J. Montoya**[1], S. C. Weber[2], A. Vogts[2], M. Voss[2]
[1]Georgia Institute of Technology, Atlanta, GA, [2]Institut für Ostseeforschung, Warnemünde, Germany

We have found a clear linkage between methane consumption and $N_2$-fixation in deep waters of the Gulf of Mexico during a series of cruises beginning shortly after the Deepwater Horizon (DWH) spill in 2010 and continuing at roughly annual intervals. These cruises allowed us to sample oligotrophic waters across a range of depths, and to explore the connections between the C and N cycles mediated by release of oil and gas (petrocarbon) from natural seeps as well as anthropogenic sources (e.g., the DWH). A combination of experimental rate measurements and stable isotope ($^{15}N$ and $^{13}C$) natural abundance measurements of particles and zooplankton demonstrate that methane consumption and $N_2$-fixation make a measurable contribution to the planktonic food web around large natural seeps and following large anthropogenic releases of oil and gas (e.g., the DWH incident). Although these complementary approaches provide evidence for both the mechanism and pathway of movement of petrocarbon and recently fixed N into the plankton, the identity of the organisms responsible for these fluxes remains unknown. We used nano-scale Secondary Ion Mass Spectrometry (nanoSIMS) to image and characterize the organisms responsible for these processes in experimental incubations with $^{13}CH_4$ and $^{15}N_2$. In general, deep water $N_2$-fixation was carried out by relatively large (0.5 to 1.0 μm) cells associated with aggregates and large particles, while $CH_4$ assimilation was associated with smaller, apparently free living cells. The segregation of $N_2$-fixation and methane assimilation implies that these processes are carried out by distinct organisms and that the linkage between the two processes



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involves community level interactions. The ability to resolve elemental fluxes on the scale of individual cells is a critical part of identifying and characterizing the organisms responsible for the biogeochemical response of communities exposed to oil and gas released into oceanic environments.

Compound Specific Stable Isotope Analysis Reveals Terrestrial-Aquatic Linkages in a Northern Gulf of Mexico Salt Marsh

**J. J. Johnson***, M. J. Polito
Louisiana State University, Baton Rouge, LA

Salt marshes provide critical habitats for many species in the northern Gulf of Mexico. However, the precise manner in which the high primary productivity found in salt marshes links to the productivity of the larger Gulf ecosystem has long eluded researchers. The use of compound specific stable isotope analysis, specifically the carbon stable isotopes of essential amino acids, is becoming an increasingly popular method of tracking the flow of primary production through complex food webs. This study presents the first application of CSIA to the analysis of Gulf of Mexico coastal food webs and is the first to use CSIA to make quantitative estimates of carbon pool contributions to salt marsh consumers. We looked at a number of salt marsh taxa, both terrestrial and aquatic, in order to determine the relative importance of salt marsh plants, benthic microalgae and estuarine phytoplankton in supporting higher trophic levels. Organisms were largely divided into two groups: those which derive the majority of their carbon from C4 grasses, namely *Spartina alterniflora*, and those which derive most of their carbon from phytoplankton and benthic microalgae combined. The former group comprises the terrestrial insects, *Littoraria irrorata*, and the seaside sparrow *Ammodramus maritimus*. The latter group comprises most fish analyzed, *Callinectes*, as well as Penaeid and Palaemonid shrimp. We found that some species, such as the Gulf killifish (*Fundulus grandis*) and the rice rat (*Oryzomys palustris*), derived carbon from a mix of plant and microalgal sources. C3 plants, such as *Juncus roemerianus*, appear to play little to no role in supporting the marsh food web. Quantifying carbon source pools represents the first step in a dynamic understanding of the high production of Gulf of Mexico coastal systems. This research provides critical baseline data on ecosystem structure that was not available prior to the Deepwater Horizon Oil Spill and will aid in informed restoration decisions.

Plant diversity impacts *Spartina alterniflora* resilience to Deepwater Horizon oil pollution

**R. A. Zerebecki***[1], A. R. Hughes[1], K. L. Heck, Jr.[2, 3], J. Cebrian[2], B. Mortazavi[4], P. Sobecky[4], N. Flournoy[4], W. Scheffel[2, 3], J. Goff[2]
[1]Northeastern University, Nahant, MA, [2]Dauphin Island Sea Lab, Dauphin Island, AL, [3]Department of Marine Sciences, University of South Alabama, Mobile, AL, [4]University of Alabama, Department of Biological Sciences, Tuscaloosa, AL

Biodiversity can influence a variety of marine ecosystem functions and services. For example, both increased species diversity and genetic diversity can increase community stability (i.e. resistance and resilience) in response to environmental fluctuations or disturbance. Thus, wetland plant diversity may have affected ecosystem responses to oiling from the Deepwater Horizon incident. To test this hypothesis, we conducted a 1-yr experiment in 3,785 L outdoor flow-through mesocosms to examine the interactive effects of emulsified weathered oil exposure, plant genetic diversity, and plant species diversity on several ecosystem processes. Experimental tubs within the mesocosms (N=24-25 per) were assigned to a no-plant control or one of five plant diversity treatments: *Spartina alterniflora* genotypic monoculture, *S. alterniflora* genotypic polyculture, *S. alterniflora* genotypic monoculture + *Avicennia*



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*germinans*, *S. alterniflora* genotypic polyculture + *A. germinans*, or *A. germinans* only. In the two oil-exposed mesocosms, we used a 5-day repetitive dosage procedure, with each experimental tub receiving an initial 1 L $m^{-2}$ of a 1:1 oil-water mixture. In the two non-oiled mesocosms, seawater was added using the same procedure. During each of our four post-oil sampling events (Dec. 2015 - Sept. 2016), we quantified plant growth, morphology, and productivity of both *Spartina* and *Avicennia* as a function of plant diversity and oiling. In addition, we also measured *Spartina* reproductive output (i.e. number of flowers) and seed germination success. Overall, our results indicated negative impacts of oiling on *Spartina* survival, growth, and flowering, as well as *Avicennia* leaf number and canopy area. However, the timing of the negative impacts of oil varied between plant species, with immediate negative effects on *Spartina*, but delayed impacts on *Avicennia* (when *Spartina* is already recovering). Furthermore, the magnitude of oiling effects on *Spartina* was dependent on diversity treatments: there was a reduced effect in mixed species (*Avicennia* + *Spartina*) and in genetic polyculture treatments. This suggests that increased plant diversity can play a positive role in the resilience of wetlands exposed to oiling.

Coupled Effects of Oil Spill and Hurricane on Saltmarsh Terrestrial Arthropods

**W. Bam***, L. M. Hooper-Bui, R. M. Strecker, P. L. Adhikari, E. B. Overton
Louisiana State University, Baton Rouge, LA

Saltmarshes are impacted by continuous multiple stressors - land loss, erosion, oil spills and tropical storms - affecting the ecological community inhabitants. Terrestrial arthropods play important roles in ecology of saltmarshes, affecting primary production and decomposition. Insects and spiders have the potential to be a good indicator of overall marsh environment's health as they are differentially sensitive to oil exposure. Insects were sampled between April and June of 2013 and 2014 to determine impacts of the Deepwater Horizon oil spill on the saltmarsh terrestrial arthropods. The analysis of total PAHs the sediment showed that the oil was redistributed in coastal Louisiana Saltmarsh by Hurricane Isaac in 2012. Overall, the terrestrial arthropods were negatively affected by the oil and Hurricane Isaac, and some arthropods showed recovery in 2014. The abundance of terrestrial arthropods was significantly higher in 2014 compared to 2013 which suggest positive recovery of terrestrial arthropod community. The community structure of terrestrial arthropods in reference sites was found to be distinctive from lightly oiled and heavily oiled sites in 2013 and 2014. Our data indicate that the ecosystem appears to be oscillating around intermediate disturbance due to the hurricane and the redistribution of oil. Although the slow recovery of certain terrestrial arthropods was observed, long term monitoring of arthropod communities would help better understand the recovery and succession of the marsh ecosystem.

Diel Vertical Migration of Zooplankton: Numerical Modeling of the Effect of Oil Emulsions and Freshwater Lenses

**C. W. Dean***, A. V. Soloviev
Nova Southeastern University, Hollywood, FL

Diel vertical migration (DVM) of zooplankton is believed to be the largest animal migration on Earth. DVM may have an impact on ocean mixing, though few details are known about the hydrodynamics of this process. Even less is known about DVM of zooplankton during oil spills. Zooplankton can impact oil transport through the water column and oil can negatively affect the ability to vertically migrate due to the highly viscous nature of oil emulsions. Furthermore, oil and dispersants can have a negative or even



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lethal effect on zooplankton. DVM patterns may also be altered by the upper ocean restratification by freshwater inflow due to convective rains or river runoff. Freshwater lenses in the upper ocean have a tendency to produce spatially intermittent patterns. We have implemented a computational fluid dynamics model to simulate the turbulence signature of DVM in the upper ocean, including emulsified oil spills and freshwater lenses. The model was initialized with vertical density (CTD) and velocity (ADCP) profiles in the De Soto Canyon collected in January and February 2016 during the CARTHE LAgrangian Submesoscale Experiment (LASER) cruise of the R/V *Walton Smith*. The freshwater lenses are localized (in space) salinity and temperature anomalies, spreading as density (gravity) currents. Freshwater lenses eventually mix with the environment and affect vertical stratification. The model results suggest that propulsion speed of some organisms may somewhat change due to the effects of buoyancy resulting from varying salinity stratification in the upper layer of the ocean. The effect of oil emulsions on DVM is modeled by increasing the molecular viscosity of water in the upper ocean. Presence of oil emulsions during oil spills and application of dispersants, however, can have a more dramatic effect on the DVM of zooplankton and dire consequences for marine ecosystems.

Impacts of oil exposure on mahi-mahi: from the subcellular and molecular level through populations and ecosystems

**M. Grosell**[1], J. D. Stieglitz[1], C. Pasparakis[1], L. Sweet[2], L. S. Schlenker[1], R. M. Heuer[2], S. Kloeben[1], A. Roberts[2], D. Crossley[2], D. D. Benetti[1]
[1]RSMAS, University of Miami, Miami, FL, [2]University of North Texas, Denton, TX

Mahi-mahi are high performing pelagic fish sensitive to oil exposure at all life stages. Extensive studies of oil impacts on mahi-mahi have revealed important information about the basic biology of these rarely studied top predators that are economically and ecologically important. Mahi-mahi have high heart rates (~160 bpm), similar to those reported from tuna, high maximal oxygen consumption (~ 1350 mg $O_2$ $h^{-1}$ at 1 kg), and thus high energy demand and high maximal sustained swim speed (10 Bl $sec^{-1}$ or 130 cm $sec^{-1}$). In addition, mahi-mahi have some of the highest growth rates recorded for fish and reach sexual maturity within three months post hatch. Furthermore, mahi-mahi are highly fecund; males are capable of spawning daily whereas females spawn every other day and release up to 5% of their body mass in eggs per event. For early life stages, sublethal oil exposure results in elevated metabolic demand and depletion of embryo energy stores, as well as early onset of negative buoyancy, which normally occurs immediately prior to hatch. Altered buoyancy of embryos will result in altered vertical distribution and thereby altered dispersal with possible population level impacts. For later life stages, sublethal exposures lead to reduced swim performance, with implications for predator avoidance, prey capture, migration and spawning. This reduced performance is due, at least in part, to reduced cardiac output dictated by a decrease in cardio-myocyte sarcomere shortening. In addition, sensory systems including olfaction and vision are impacted by short term and low level exposures. The hypothesis that oil exposure will impair performance in the wild due to reduced cardiac function and impairment of sensory systems critical for foraging is currently being tested. 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).



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Eco-physiological implications of acute embryonic and juvenile oil exposure in marine fish

**A. Esbaugh**
University of Texas Marine Science Institute, Port Aransas, TX

Oil exposure has a well catalogued suite of effects on early life stage fishes. These effects are largely caused by the polycyclic aromatic hydrocarbon (PAH) compounds within oil, and include pericardial edema, craniofacial deformities, spinal curvature and mortality. Pericardial edema has been repeatedly demonstrated as the most sensitive measure of PAH exposure in fishes, and ostensibly leads to reduction in cardiorespiratory performance. Similar inhibition is also thought to occur in older life stages by interfering with cardiac excitation-contraction pathways. Cardiorespiratory performance governs the ability of vertebrates to transport oxygen from the environment to the tissues; a process even more limiting in aquatic organisms due to the proportionally low amount of oxygen in water. As such, a compromised cardiorespiratory system can result in a suite of sub-lethal eco-physiological complications. Here we will discuss the impacts of environmentally relevant sub-lethal oil exposure on a variety of ecologically relevant performance measures in larval and juvenile red drum. This will include direct measures of eco-physiological performance such as swimming and aerobic scope, as well as predator-prey and routine foraging dynamics. We will also discuss additional measures of ecological performance that manifest through competitive scenarios, including direct dyadic social interactions, group social behavior, individual behavioral syndromes and long-term growth and survival.

Toxicological testing with an estuarine icon, the bay anchovy, *Anchoa mitchilli*

**E. Chesney**[1], R. Munnelly[1], C. Windecker[1], T. Duffy[2], S. Webb[3], R. Portier[4]
[1]Louisiana Universities Marine Consortium, Chauvin, LA, [2]Northeastern University, Boston, MA, [3]Arkansas State University-Newport, Newport, AR, [4]Louisiana State University, Baton Rouge, LA

The Deepwater Horizon oil spill resulted in an unprecedented effort to understand the effects of oil exposure on key species within the Gulf of Mexico (GOM) ecosystem, including the early life history (ELH) stages of many fishes and invertebrates. The ELH stages of the bay anchovy dominate estuarine ichthyoplankton during the spring and summer when DWH oil reached coastal estuaries throughout the nGOM. Laboratory exposures of bay anchovy embryos and larvae under a variety of conditions showed that bay anchovy ELH stages are highly sensitive to exposure to crude oil. Apparent sub-lethal concentrations and short duration exposures to crude oil affected growth and swimming performance. During a post exposure period of larval growout, survival was significantly reduced relative to control treatments. Low concentration and short duration exposures also caused a variety of malformations in newly hatched anchovy larvae including erosion of the finfolds, malformed yolksacs, malformed eye buds and cardiac edema. Results of these studies suggest that standard toxicological testing can underestimate effects of oil on ELH stages of fishes and that the ELH stages of bay anchovy make an excellent test species for environmental assessments of toxicants.



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Impact of PAH at Fish Sub-individual Level and Resiliency Consequences.
**A. Gracia**[1], S. A. Murawski[2], H. M. Alexander-Valdés[1], S. Snyder[2], I. M. López-Durán[1], E. Pulster[2], P. Ortega-Tenorio[1], A. Frausto-Castillo[1]
[1]Instituto de Ciencias del Mar y Limnología, Mexico City, Mexico, [2]University of South Florida, St. Petersburg, FL

Fish gonad and livers of Red Snapper, Yellowedge Grouper and Red Grouper collected in the Southwestern Gulf of México during September, 2015 onboard R/V *Weatherbird II* were examined through histological sections to analyze the impact of PAH hydrocarbons. Fish gonads were found healthy in 94 % of organisms analyzed, only red snapper presented gonad anomalies. Liver histopathologycal analysis indicated a high incidence of liver damage (79%). PAH are among the agents causing this leisures. Hepatic damage was analyzed with respect to PAH fish muscle content that varied between 17-157 µg/Kg. Hepatic damage degree showed an apparent relationship with muscle PAH concentrations in red snapper, but was not found in groupers. Consequences at individual and population levels and stock resiliency are discussed

What can bile tell us about the environmental health of the Gulf of Mexico
**E. L. Pulster**[1], S. Snyder[1], R. Struch[2], B. Carr[1], A. Gracia[3], S. Murawski[1]
[1]University of South Florida, St. Petersburg, FL, [2]University of California, Davis, CA, [3]Universidad Nacional Autónoma de México, Mexico City, Mexico

In efforts to evaluate the environmental consequences following the Deepwater Horizon subsurface blowout, extensive scientific longline surveys have been conducted in the northern Gulf of Mexico since 2011 and were extended to include the southern Gulf of Mexico in 2015. The southern Gulf of Mexico suffered a similar subsurface blowout in 1979, known as the Ixtoc I. This study aims to compare biliary levels of polycyclic aromatic hydrocarbon metabolites in 30 species of fishes, sharks and eels collected in both the northern and southern Gulf of Mexico in order to compare Gulf-wide levels of PAH exposures. Levels in the northern Gulf have been demonstrating a declining trend in a number of species since 2011. However, levels measured in the northern Gulf are significantly higher than those of the same species caught in the southern Gulf of Mexico. With thousands of active oil and gas platforms throughout the Gulf of Mexico, this Gulf-wide data set is critical for understanding exposure and recovery rates in fish occupying different habitats.

Taxonomic and Distributional Appraisal of Deep-Sea Sergestid Crustaceans in the Northern Gulf of Mexico after Deepwater Horizon
**R. Hartland***, E. Burdett, C. Fine, T. Sutton, A. Cook, T. Frank
Nova Southeastern University, Fort Lauderdale, FL

This study is the first to describe the sergestid assemblage in terms of abundance, biomass and, species rank around the site of the Deepwater Horizon Oil Spill (DWHOS). Prior knowledge of the species was limited in the GOM as all previous studies were performed solely at one location in the eastern Gulf. Data were analyzed from samples collected on the M/V *Meg Skansi* cruises of April to June, 2011 and DEEPEND cruises in May of 2015 and 2016. There are no data available from the area before the oil spill; therefore, the data from 2011, collected one year after the DWHOS, were compared with the DEEPEND data of 2015 and 2016. Statistical analyses were conducted to determine if significant changes in the assemblage occurred between 2011 and 2016, which, if present, would be indicative of



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a significant impact of the DWHOS. Due to the increased understanding of depth distributions, migratory behavior and reproductive seasonality of the study species, this study also provides valuable data on deep-sea crustacean assemblages needed to model potential impacts of future disasters.

Disturbance of Northern Gulf of Mexico Reef Fish Communities: The Deepwater Horizon Oil Spill and the Lionfish Invasion

**K. A. Dahl***[1], W. F. Patterson, III[1], J. H. Tarnecki[2], R. A. Snyder[3]
[1]University of South Alabama, Dauphin Island, AL, [2]Florida Fish and Wildlife Conservation Commission, St Petersburg, FL, [3]Virginia Institute of Marine Science, Wachapreague, VA

A baseline dataset of northern Gulf of Mexico (nGOM) reef communities revealed widespread declines in fish abundance following the Deepwater Horizon Oil Spill (DWH). Declines in abundance of 30 to >90% were observed for a broad range of species from large (>30 cm) piscivores (e.g., snappers and groupers) to small (<10 cm) demersal fishes (e.g., damselfishes and wrasses). While some species or trophic guilds began showing signs of recovery by year three post-spill, small demersal fish densities continue to be depressed in some habitats. However, the invasion of red lionfish, *Pterois volitans*, is a confounding factor for interpreting chronic oil spill effects on these fishes. Lionfish were first documented in the nGOM in summer 2010, and small demersal fishes are the predominant prey of lionfish in other systems. Lionfish populations in the nGOM have increased exponentially, and by 2013, their densities on nGOM artificial reefs were among the highest reported in the entire western Atlantic (~20 fish 100 $m^{-2}$), although their densities on natural reefs remain an order of magnitude lower. We will report trends through 2016 in lionfish density, diet, and trophic position, as well the incidence of cannibalism, in the context of interpreting acute and chronic effects of the DWH on reef fish communities. Lastly, we will discuss the results of a two-year experiment to evaluate the effectiveness of targeted lionfish removals as a means to control lionfish densities, as well as to evaluate the effectiveness of lionfish removal for native reef fish community recovery.

Fish Community Structure and Resilience to Large-Scale Perturbations: Comparisons of Gulf Ecosystems

**S. A. Murawski**[1], E. Peebles[1], A. Gracia[2]
[1]University of South Florida, St. Petersburg, FL, [2]Universidad Nacional Autonoma de Mexico, Mexico City, Mexico

The abundance, diversity and size structure of fish communities are key attributes that determine the resiliency of fish communities to large-scale perturbations. Natural and anthropogenic perturbations occur over differing time and space scales, altering the dynamics and recovery potential of affected species. In this presentation, we analyze continental shelf fish communities throughout the Gulf of Mexico (United States and Mexico) using data from demersal longline sampling conducted during 2011-2016. A total of 296 stations were sampled, deploying over 130,000 baited hooks and catching more than 13,000 fishes, along shallow-to-deep transects. Results indicate important differences in the species composition, abundance, size, and diversity spectra among Gulf demersal fish communities. These differences indicate which Gulf regions are more or less resilient to large-scale spills, climate change, fishery effects hurricanes and other drivers of ecosystem change. Measures of resilience and resistance to such perturbations are discussed.

Association between Habitat Quantity and Quality and Exploited Reef Fishes: Implications for Retrospective Analyses and Future Survey Improvements



*Student presenter

**T. S. Switzer**, K. Thompson, S. F. Keenan, A. J. Tyler-Jedlund
Florida Fish and Wildlife Conservation Commission – Fish and Wildlife Research Institute, St. Petersburg, FL

Since the Deepwater Horizon (DWH) oil spill, significant resources have been devoted to improving our understanding of ecosystem structure and function. These recent research efforts not only serve to assess disturbance and recovery associated with DWH but also provide baseline data for quantifying the impacts of future environmental perturbations. In the eastern Gulf of Mexico, the state of Florida recently expanded the spatial extent of monitoring efforts that integrate a combination of side-scan sonar and underwater stereo video imagery to characterize reef-fish assemblages and associated benthic habitats. Results from the first two years of this survey have identified notable regional differences in habitat quantity and quality as well as the relative abundance of several exploited reef fishes. On the West Florida Shelf, natural reef habitat is both common and widely-distributed. In contrast, artificial reef habitat is much more prevalent in the Florida Panhandle, whereas natural reef habitat is less common and concentrated along specific isobaths. Concomitantly, several exploited reef fishes, including Gray Triggerfish, Red Snapper, Red Porgy, and Greater Amberjack were more abundant in the Florida Panhandle; all but Red Porgy also exhibited highest abundances in association with artificial reef habitats. Of the species examined, only Red Grouper, Gray Snapper, and Lane Snapper were more abundant on the West Florida Shelf. Our results indicate that the relative quality of different reef habitat types varies markedly among exploited reef fishes. Accordingly, careful consideration needs to be given to accounting for the relative quantity and quality of habitat sampled when combining data across similar surveys (e.g., state of Florida, NMFS - Panama City, NMFS - Pascagoula reef fish survey).

Could We Resolve the Effect of a Future Oil Spill Event on Primary Production in the Mississippi Bight Ecosystem?

**J. W. Krause**[1], L. K. Cole[2], A. K. Mojzis[3], A. D. Boyette[3]
[1]Dauphin Island Sea Lab, Dauphin Island, AL, [2]University of South Alabama, Mobile, AL, [3]University of Southern Mississippi, Stennis Space Center, MS

The Mississippi Bight Ecosystem supports highly productive fisheries (e.g. Gulf Menhaden). It is affected by the Mississippi River outflow in the southeast domain, and discharge in the northern domain mainly from the Pascagoula River and the Mobile Bay, the latter being the fourth largest freshwater source in North America (Mississippi River is the highest). Given this region's proximity to two of the top four freshwater point sources on the continent, and its high fisheries productivity, the magnitude for primary production is expected to be high. If so, then interpreting how low-frequency events (e.g. oil spill) affect system processes would be difficult. Here we report preliminary results from three system-wide cruises during Fall 2015, Spring 2016 and Summer 2016, and a higher temporal resolution data set at one site in the northern domain. Early results demonstrate that the degree of temporal variability among seasons is similar to the spatial variability observed within the entire system during one season. The contribution of large phytoplankton to total primary production is highest in the western domain during spring. The biomass-normalized primary production rates in larger phytoplankton were not significantly different from normalized rates in smaller phytoplankton, suggesting that the main reason for the increased proportional contribution to primary production from larger phytoplankton is due to food-web processes (e.g. lack of grazing pressure). These results underscore that this system is highly dynamic and resolving effects due to low-frequency events (e.g. oil spill) will require significant shifts in magnitude given such high natural variability.



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Deep-Sea Ecosystem Services: Out of Sight but Still Invaluable

**T. W. Washburn***, D. Yoskowitz, P. Montagna
Texas A&M University - Corpus Christi, Corpus Christi, TX

The deep sea is far removed from direct human contact and easily overlooked when evaluating benefits humans derive from the environment. Monetary valuation is often not possible for many supporting and regulating services, yet they can often be considered as invaluable. Many processes which occur in the deep sea are necessary for life on Earth as we know it. The Deepwater Horizon oil spill provided a unique opportunity to examine not only how human activities can affect the deep sea but also how services provided by the deep sea can assist in the recovery of the environment after man-made disasters. Waste regulation is one such service which is defined as the removal of non-nutrients from the environment. Hydrocarbon-consuming bacteria in the deep GoM were responsible for breaking down much of the material released by the DWH spill while other components were removed from the ecosystem via burial. This presentation begins to explore the value of deep-sea services in the GoM and what these services saved in humans in money, time, and effort during the DWH spill and clean up efforts.



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## Session 009: Deepwater Horizon Natural Resource Damage Assessment: What Have We Learned?

Nearshore Overview of the Deepwater Horizon Natural Resource Damage Assessment
**M. Steinhoff**, M. Baker
National Oceanic and Atmospheric Administration, Seattle, WA

Marla Steinhoff, NOAA lead for the Shoreline Technical Working Group for the Deepwater Horizon Natural Resource Damage Assessment, will provide an overview of the nearshore injury assessment including the conceptual models, approach, methods, injury and quantification results with a focus on assessments of coastal wetland vegetation and associated fauna, as well as nearshore oysters and erosion.

Nearshore Injury Assessment Panel
**M. Baker**[1], **S. Zengel**[2], **S. P. Powers**[3], **M. W. Hester**[4], **R. Turner**[5], **J. Short**[6]
[1]NOAA, Seattle, WA, [2]RPI, Tallahassee, FL, [3]University of South Alabama/Dauphin Island Sea Lab, Mobile, AL, [4]University of Louisiana at Lafayette, Lafayette, LA, [5]Louisiana State University, Baton Rouge, LA, [6]Independent Consultant, Juneau, AK

Overview of the Approach and Quantification of Injuries to Water Column Resources through NRDA
**D. R. Hahn**[1], J. A. Quinlan[2], J. Kunzelman[1]
[1]NOAA, Assessment and Restoration Division, St. Petersburg, FL, [2]NOAA, South East Fisheries Science Center, Miami, FL

The Deepwater Horizon (DWH) discharged oil into the Gulf of Mexico continuously for 87 days before the well was capped. Deep plumes, rising oil, surface slicks and sinking oil exposed the highly diverse biological resources in the water column to contaminants from the spill. In conducting the Natural Resource Damage Assessment (NRDA) the Trustees implemented a large field program to determine where oil was in the water column and on the ocean surface, and used the data collected from ships, ROVs, aircraft and satellites. The Trustees also conducted net, imaging, and acoustic sampling to describe the distributions of biota in the offshore areas, some of which had not previously been well studied. Combining the field data and historical information with a laboratory toxicity program, the Trustees quantified volumes of impacted water, and impacts to biota in the Gulf of Mexico.

The surface slick that covered a cumulative area of 112,100 square km and the associated oil mixed below it accounted for the majority of the injuries that the Trustees quantified in the water column. In addition to the toxicity of the slicks themselves, the Trustees used concentrations of polycyclic aromatic hydrocarbons (PAHs) that were measured below the slick to describe impacted waters and, on a daily basis, an average of 57 billion cubic meters of water under the slicks were impacted. UV enhanced toxicity to early life stages of fish and invertebrates were a driver of the epipelagic injury. Slicks also impacted *Sargassum*, resulting in thousands of square km of lost *Sargassum* production. In the deep waters and plume of rising oil, the Trustees used a modeling approach to estimate impacts to fish larvae and planktonic invertebrates. For a subset of the impacted species, the Trustees investigated the forgone production of the killed biota.



*****Student presenter

Overview of Deepwater Horizon Oil Spill Benthic Resource NRDA Injuries

**C. G. Lewis**
Industrial Economics, Incorporated, Cambridge, MA

As an introduction to our panel discussion, an overview of benthic injury included in the Trustees' NRDA claim will be provided. With the 2016 settlement of claims between the State and Federal Trustees and BP, the Trustees submitted a Programmatic Damage Assessment and Restoration Plan, describing injuries to natural resources from the Deepwater Horizon Oil Spill and the Trustees' plan for pursing environmental restoration. One area of focus of the Plan was injuries to benthic resources, including resources along the rock- and sediment-covered ocean floor stretching from the shallow shelf to the deep ocean, where the spill occurred. The Trustees focused their assessment on resources representative of ecosystem components, including deep sea hardground corals, mesphotic reef, sediment infauna, and red crabs. Relying on both NRDA-sponsored and independent academic research, the Trustees determined that the sea floor within ~2,000 sq. km. of the wellhead, and ~10 sq. km. of mesophotic reef along the shelf edge were injured as a result of the spill. Benthic injuries within the zone around the wellhead decreased in severity with increasing distance from the wellhead. The innermost ~28 sq. km. zone included injuries of smothering and a reduction by half in macrofauna diversity. The second and third concentric zones (~195 and ~793 sq. km., respectively) exhibited impacts ranging from coral mortality to less dramatic reductions in macrofauna diversity. In the outermost zone of ~1,275 sq. km., the chemical quality of benthic habitat was injured, the food web fouled, and sediment PAH concentrations in some locations exceeded LC20 and LC50 toxicity values. The ~10 sq. km. of ecologically important mesophotic reef habitat on the shelf edge experienced coral and fish losses. The Trustees also determined that a larger area of ~9,200 sq. km. of potential exposure and uncertain impacts extended beyond and between these quantified areas. Natural recovery time without restoration will vary based on sensitivities, growth rates, reproduction, and recruitment of individual component resources.

Water Column and Benthic Injury Assessment Panel

**S. A. Murawski**[1], **S. Joye**[2], **P. A. Montagna**[3], **J. A. Quinlan**[4]
[1]University of South Florida, St. Petersburg, FL, [2]University of Georgia, Athens, GA, [3]Texas A&M University-Corpus Christi, Corpus Christi, TX, [4]NOAA-Fisheries, Miami, FL

Overview of DWH NRDA Exposure and Injury Assessment for Marine Mammals

**L. Sullivan**[1], L. Schwacke[2], T. Rowles[3], T. Brosnan[4]
[1]NOAA ORR ARD, Santa Rosa, CA, [2]NOAA, NCCOS, Charleston, SC, [3]NOAA NMFS OPR, Silver Spring, MD, [4]NOAA ORR ARD, Silver Spring, MD

For the approach to assess exposure and injury to marine mammals, the DWH Marine Mammal Technical Working group used a combination of live and dead animal studies. Live animal assessment included health assessment, aerial surveys, satellite tagging, remote biopsy collection and longitudinal photo ID surveys, primarily targeting bottlenose dolphins (*Tursiops truncatus*) as surrogates for other Gulf of Mexico cetaceans. Dead animal investigations included investigating spatial and temporal patterns in stranding during the investigation, histopathology findings to investigate known potential causes of mortality, including oil. Animals from oiled areas suffered adverse health and reproductive failure leading to decreased survivorship compared to reference populations.



*****Student presenter

Injury Assessment and Sea Turtles following the Deepwater Horizon Oil Spill
**B. A. Stacy**
Office of Protected Resources, NOAA, Gainesville, FL

As the lead veterinarian for response operations involving sea turtles during the Deepwater Horizon oil spill, Stacy was directly engaged in the documentation, rescue, and recovery of oiled threated and endangered sea turtles. In addition, as one of the principal investigators for the sea turtle injury assessment, he was involved with assessing exposure, injury determination, and injury quantification for all species and life phases of sea turtles that were affected by the spill. This role included postmortem examinations of oiled and stranded sea turtles, evaluation of clinical data collected from oiled turtles, collaboration in laboratory studies of petroleum exposure and effects of oil, and application of response data to metrics of total exposure and injury estimates. He will be prepared to answer questions related to the types of data and scientific approaches that were used in the sea turtle injury assessment for DWH and potential applicability to future spills and other wildlife.

Marine Mammal and Sea Turtle Injury Assessment Panel
**M. J. Hooper**[1], P. L. Tuttle[2], **L. H. Schwacke**[3], **D. Tillitt**[4], **T. K. Collier**[5], **M. Ziccardi**[6]
[1]U.S. Geological Survey, Columbia, MO, [2]U.S. Fish & Wildlife Service, Fairhope, AL, [3]National Marine Mammal Foundation, Charleston, SC, [4]U.S. Geological Survey, Columbia, MO, [5]Independent Consultant, Bainbridge Island, WA, [6]University of California, Davis, Davis, CA

Economic Valuation of the DWH Natural Resource Injury
**A. Domanski**
NOAA, Silver Spring, MD

Environmental economists have multiple tools at their disposal to quantify the value of an injury to public goods and resources. This introductory session will set the stage by covering basic concepts of private/public goods, non-market valuation, and an overview of their historical use in policy and NRDA applications.

Deepwater Horizon Total Value Losses
**N. F. Meade**
National Oceanic and Atmospheric Administration, Silver Spring, MD

In May 2010 state and federal agencies (natural resource trustees) assembled a team of experts to estimate the value of total economic loss incurred by U.S. households as a result of injuries to natural resources from the release of oil into the Gulf of Mexico from the Macondo well. The expert team was instructed by the trustees to choose and implement a reliable measurement technique capable of estimating the total economic loss. The contingent valuation method was chosen. The presentation will summarize the study conducted by an inter-disciplinary team of economists, psychologists, sociologists, and survey research experts. Topics covered will include: the underlying economic theory, study design and execution, results, measure of reliability and lessons learned.

Socioeconomic Impact Assessment Panel
**W. D. Shaw**[1], **C. G. Lewis**[2], **R. Kopp**[3], **M. Baker**[4], **R. Tourangeau**[5]
[1]Texas A&M University, College Station, TX, [2]Industrial Economics, Incorporated, Cambridge, MA, [3]Resources for the Future, Washington, DC, [4]NOAA, Seattle, WA, [5]Westat, Rockville, MD



*****Student presenter

## Session 010: Impacts and Recovery of Benthic Marine Environments in the Aftermath of the DWH Event

MOS formation in contrasting Atlantic waters: what, where and why

**T. Gutierrez**
Heriot-Watt University, Edinburgh, United Kingdom

The Deepwater Horizon (DWH) oil spill brought to light the importance of marine oil snow (MOS) in the fate of oil that entered the Gulf of Mexico. Whilst much interest was directed towards the study of the water column microbial community response, especially of the deepwater oil plume, the formation of MOS was another distinctive feature of the spill that progressively received increased attention. Although conjecture still surrounds its genesis, MOS formation appears to have been directly associated with the influx of the Macondo oil into the Gulf of Mexico, its interaction with planktonic microorganisms, dissolved organic polymers such as exopolymeric substances (EPS), and with nutrient and suspended mineral discharges into the Gulf from the Mississippi River. Furthermore, despite the interest in MOS formation as a product of spilled oil into the Gulf and its significance to the fate of oil, such as its transportation to the seafloor, the diversity and function of microorganisms associated with MOS particles remains largely unexplored. This talk will present work on the role of EPS produced by hydrocarbon-degrading bacteria enriched during the DWH spill in MOS formation, and the factors influencing this process. Experiments performed in a contrasting Atlantic water mass, the Faroe-Shetland Channel, show that seasonality, the presence of dispersants, and associated water properties can play a major role in MOS formation.

Effects of Water-Accommodated Fraction of Macondo Oil and Corexit on Sinking Marine Snow Formation and Oil Transport in Three Mesocosm Experiments

**P. H. Santschi**[1], C. Xu[1], S. Zhang[1], K. A. Schwehr[1], P. Lin[1], L. Sun[1], P. G. Hatcher[2], A. Wozniak[2], T. Wade[3], A. Quigg[1]
[1]Texas A&M University at Galveston, Galveston, TX, [2]Old Dominion University, Norfolk, VA, [3]Texas A&M University, College Station, TX

Up to one-third of the spilled oil during the Macondo blowout associated with the Deepwater Horizon (DWH) drilling platform was unaccounted for, partially being ascribed to its deposition on the seafloor, through a possible pathway, in which large (cm sized) and mucous-rich marine snow formed near the surface water in the close vicinity of the DWH wellhead, and rapidly sedimented carrying with the associated oil down to the seafloor. The application of chemical dispersants (i.e., Corexit) added additional complexity to this process due to their counteracting effects. With the purpose of testing the effects of oil and Corexit on marine snow formation and the associated petroleum compounds sedimentation, we carried out experiments in mesocosms with contrasting conditions: 1) coastal water seeded with natural coastal algae concentrate yet without nutrient addition; 2) coastal water with nutrient addition (f/8); 3) open ocean water with nutrient addition (f/8). In each mesocosm experiment, there were four treatments of 1) control; seawater amended with 2) water accommodated fraction (WAF), 3) chemically-enhanced WAF (CEWAF) and 4) diluted CEWAF. The objectives of this study were to 1) determine how the presence of WAF and Corexit affect the carbon biogeochemical cycling. More specifically, using a combination of radiocarbon and NMR techniques, one can assess the distributions of bulk carbon and petroleum carbon between water column including suspended particulate, colloidal, truly-dissolved fractions and sedimented marine oil snow; 2) evaluate



*****Student presenter

how oil sedimentation efficiency (the sedimented oil amount over the initial amount) changes with and without corexit; 3) oil sedimentation efficiency in nutrient-replete and nutrient-deplete coastal conditions, as well as 4) in coastal and open ocean environments. Results obtained from the three distinct mesocosm experiments provide essential information for oil spill response and remediation planning, and long-term prediction of petroleum contaminants in the ocean.

Formation of Microbial Exopolymers in Mesocosm Experiments using Coastal and Open Ocean Waters Dosed with BP Surrogate Oil and Corexit 9500A

**M. E. Morales-McDevitt***[1], A. Knap[1], T. L. Wade[1], G. Gold-Bouchot[1], D. Shi[1], G. Bera[1], A. Quigg[2]
[1]Texas A&M University, College Station, TX, [2]Texas A&M University, Galveston, TX

Among the questions that emerged from the Deepwater Horizon (DWH) oil spill, was the role that microbial communities had on the fate of the oil. MODIS imagery showed that during and near the location of the spill, the Fluorescent Line Height (FLH, a proxy for phytoplankton biomass) values were high. In addition, within the same area, marine snow was observed shortly after the incident. This research proposes that an unrelated nutrient enrichment of the water close to the explosion site triggered a planktonic bloom, which produced profuse marine snow. This marine snow and its associated microbes may have removed oil from the water column and degraded it. Marine snow includes all organic and inorganic particles, and aggregates &gt0.5mm. These aggregates consist of “sticky” exopolymeric substances (EPS) secreted by diatoms and bacteria naturally or when exposed to stressful conditions. From August 2015 to July 2016, the ADDOMEx consortium conducted four mesocosm experiments with water collected from the coastal Gulf of Mexico, the Flower Garden Banks and buoy R. Water accommodated fraction (WAF) chemically enhanced water accommodated fraction (CEWAF) and diluted CEWAF (~1/10) were generated in 130 L baffled recirculation tanks, and 81 L transferred into mesocosm tanks. The estimated oil equivalents (EOE), polycyclic aromatic hydrocarbons (PAHs), and nutrients were determined at the start, during and at the end of each experiment. There was EPS formation within 24 h of the addition of plankton and/or nutrient concentrate in all treatments. The decrease in the EOE in all treatments occurred within the first 10 hours. PAH data show weathering (e.g. degradation, evaporation and sedimentation), formation of surface slicks and/or adhering to the walls of the mesocosms. Dissolved inorganic nitrogen (DIN) decreased rapidly in CEWAF treatments indicating microbial activity. Ongoing analyses will provide information on relative importance of EPS aiding the sedimentation of oil.

Microbially-mediated exopolymeric substances production, composition and regulation of Macondo oil transport in two contrasting environments

C. Xu, S. Zhang, M. Beaver, **P. Lin**, L. Sun, K. A. Schwehr, A. Quigg, P. G. Hatcher, A. Wozniak, P. H. Santschi
Texas A&M University at Galveston, Galveston, TX

After the Deepwater Horizon oil spill accident, large-scale exopolymeric substance (EPS) formation observed in the surface waters of the Gulf of Mexico played a key role in the fate of oil through bacterial activity, oil interaction with particles and coagulation, followed by formation of aggregates and marine oil snow (MOS) sedimentation. Both bacteria and phytoplankton release EPS into the water that enhance this aggregation process. Although EPS and marine snow are ubiquitous in the ocean, the conditions under which they are produced cause variations in their physico-chemical properties. To resolve the influence of oil-water accommodated fraction (WAF) and Corexit on EPS production and



*Student presenter

composition, and subsequent formation of sinking MOS, three mesocosm experiments were carried out using 1) coastal water seeded with natural algae concentrate yet without nutrient addition; 2) coastal water with nutrient addition (f/8); 3) open ocean water with nutrient addition (f/8). We hypothesize that the content and make-up of polysaccharides and proteins regulate the properties of EPS. EPS produced in four treatments (Control; WAF; chemically-enhanced WAF, or CEWAF; diluted CEWAF, or DCEWAF) and its partitioning into different size fractions: suspended particulate matter (SPM), colloidal fraction and MOS, displayed distinct characteristics. Overall, phytoplankton and bacteria produced more EPS in the presence of WAF and/or Corexit, yet with different yields of protein vs. carbohydrates: the presence of WAF appeared to stimulate the microbes to produce more carbohydrates, whereas Corexit promoted protein production. More importantly, the presence of Corexit stabilized more hydrophobic EPS in the water column, and removed MOS with higher content of carbohydrates out of the water column. The interactions between Corexit and EPS, to a large extent, regulate the partitioning of petroleum hydrocarbons between water column vs. sinking MOS and determine the ultimate removal of oil to the bottom.

Surface Tension and Chemical Composition of Exopolymeric Substances, EPS: Insights into Mechanisms of Aggregate Formation and Carbon Removal

**K. A. Schwehr**[1], C. Xu[1], S. Zhang[1], O. Agueda[1], M. Beaver[1], C. Jackson[1], L. Sun[1], P. Lin[1], A. Quigg[2, 3], P. H. Santschi[1, 3]

[1]Dept. of Marine Science, Texas A&M University, Galveston, TX, [2]Dept. of Marine Biology, Texas A&M University, Galveston, TX, [3]Dept. of Oceanography, Texas A&M University, College Station, TX

Microbes produce varying amounts of exopolymeric substances (EPS), colloidal macromolecules, with varying chemical composition and physico-chemical properties in response to changes in their environment. The EPS, have a significant proportion of proteins (which tend to be more hydrophobic) and polysaccharides (which are nonionic or anionic and thus more hydrophilic). These properties result in bio-surfactant characteristics that may be parallel to the surfactant properties of Corexit, a commercial dispersant used in the DWH oil spill. Interestingly, surfactants cause a decrease in interfacial or surface tension as they embed themselves between the hydrophobic and hydrophilic phases of oil and water, or of air and water, respectively. Here we evaluated the surface tension of water column colloids containing microbial EPS derived from mesocosm experiments conducted using seawater collected from coastal and open ocean regions of GoM, respectively, under four experimental conditions, including control, water accommodated fraction (WAF), chemically-enhanced WAF (CEWAF) and diluted CEWAF (DCEWAF). Each condition is sampled along a time series of days. We explored the complexities of these systems by comparing the difference in surface tension between the colloidal phases containing EPS in the different treatments and their chemical protein to polysaccharide ratio. Also, compared are other factors, i.e., organic carbon, salinity, molecular weight, and their effect on surface tension. Here we relate the implications of the EPS to disperse WAF versus form a sticky network of gel-like aggregates that entrain oil droplets and assemble large enough to form marine oil snow (MOS) that can export carbon and oil to the benthos.



*****Student presenter

Identifying oil/marine snow associations and oil transformations in mesocosm simulations of the Deep Water Horizon Oil Spill event

**A. S. Wozniak**[1], W. Obeid[1], C. Xu[2], S. Zhang[2], P. Santschi[2], A. Quigg[2], P. Prem[1], P. G. Hatcher[1]
[1]Old Dominion University, Norfolk, VA, [2]Texas A&M University, Galveston, TX

The Deep Water Horizon oil spill in the Gulf of Mexico stimulated the release of significant amounts of marine snow made up of dead/living plankton/bacteria and their exopolymeric polysaccharide substances (EPS). This conglomerate of organic materials interacted with both oil and the dispersant Corexit to form an association that promoted rapid removal from the water column and the resulting mixture became incorporated into sediments in and around the well site. Mesocosm simulations of this process demonstrated that Macondo-like oil has a tendency to become associated with the marine snow via either physisorption or chemisorption. Solid-state $^{13}C$ NMR performed by a new low-volume sample container and a quantitative pulse sequence readily distinguishes this oil from marine snow that forms naturally. Moreover with this approach, one can evaluate quantitatively the amount of oil associated with the marine snow and compare this with independent estimates made by other approaches. The polar fraction of the EPS, which presumably contains any oil oxidation products that form during the mesocosm simulations, was further isolated via extraction with dichloromethane and silica column chromatography. These extracts were then analyzed by Fourier transform ion cyclotron resonance mass spectrometry in order to evaluate at the molecular level any potential oxidation effects on oil compounds that associate with the EPS. This approach enables the identification of potential oil degradation marker compounds and provides insight into oil transformation mechanisms that result from the oil/marine snow/dispersant interactions.

Effect of Oil Spill on Marine Microbe Exopolymeric Substances Release

**M. Chiu**[1], Z. Khan[1], S. S. Garcia[1], A. W. Kagiri[1], A. Sibal[1], J. L. Yang[1], P. H. Santschi[2], A. Quigg[2], W. Chin[1]
[1]UC MERCED, Merced, CA, [2]Texas A&M University, Galveston, TX

Marine microbial communities play critical roles in the marine environment forming the base of the food chain. They are able to respond rapidly to environmental changes. Oil spills have been frequently reported to impact marine ecosystems also causing changes in exopolymeric substances (EPS) release by microbes that can lead to coagulation of oil in sinking aggregates. However, until now cellular level responses of marine microbes to oil spills have not been thoroughly investigated. Here we show evidence that the EPS release from four different diatom species isolated from Gulf of Mexico (*Odontella mobiliensis*, *Skeletonema grethae*, *Phaeodactylum tricornutum*, *Thalassiosira pseudonana*) and one green alga (*Dunaliella tertiolecta*) following oil and Corexit treatments. We prepared a water accommodated fraction (WAF) of oil, a Corexit (or chemically) enhanced water accommodated fraction (CEWAF) of oil and Corexit only treatment in addition to a control. We found that cell survival rates for all diatoms dropped to 50% in 10 ppm Corexit samples, implying significant toxicity. However, *Dunaliella tertiolecta* was able to tolerate conditions with up to 1% Corexit. Corexit alone exhibited noticeable toxicity to the marine phytoplankton species that were investigated that led to overall EPS release. The WAF treatment showed relatively minor effects (5%-10%) on individual cell survival rate of all phytoplankton that were tested. CEWAF stimulated EPS release from *Dunaliella tertiolecta*, *Odontella mobiliensis* and *Skeletonema grethae* but reduced EPS release from *Thalassiosira pseudonana* and *Phaeodactylum tricornutum* per unit cell. Our preliminary results indicate that generally CEWAF is more likely to trigger an increase in EPS release than Corexit or WAF alone; however, the response of individual phytoplankton species to WAF, CEWAF and Corexit varied significantly.



*****Student presenter

The Influence of Pressure on Hydrocarbon Biodegradation in Shallow and Deep Gulf of Mexico Sediments

**U. T. Nguyen***[1], S. A. Lincoln[1], A. G. Valladares Juárez[2], M. Schedler[2], J. L. Macalady[1], R. Muller[2], K. H. Freeman[1]

[1]Pennsylvania State University, State College, PA, [2]Institute of Technical Biocatalysis, Hamburg University of Technology, Hamburg, Germany

A significant portion of oil released during the Deepwater Horizon disaster reached the Gulf of Mexico (GOM) seafloor (1,2). Predicting the long-term fate of this oil is hindered by a lack of data about the combined influences of pressure, temperature, and sediment composition on microbial hydrocarbon remineralization in deep-sea sediments. To date, studies regarding the influence of high pressure on hydrocarbon biodegradation have focused on the fates of model compounds or soluble fractions of crude oil in the water column. In this study, we investigated crude oil biodegradation by native GOM microbial communities under simulated seafloor conditions, with particular focus on the role of pressure. Oxic core-top sediments collected from 13 GOM sites at water depths from 60-1500 m were incubated aerobically with crude oil at temperatures (4, 10, 20$^{o}$C) and pressures (0.1-15 MPa) that approximated *in situ* conditions. After 18 days, 45-90% of total n-alkanes and 3-60% of total polycyclic aromatic hydrocarbons were depleted. At ≤ 6 MPa, more than 80% of n-alkanes were lost. We observed a modest inhibitory effect of pressure. In reactors incubated at 4$^{o}$C and pressures of 6-15 MPa, the ratio of total n-alkanes to the biomarker 17α(H),21ß(H)-hopane was negatively correlated with pressure ($R^2$ = 0.85), equivalent to a 4% decrease in total n-alkane depletion for every 1MPa increase. These results extend the findings of Prince *et al*. (3), who found that pressure had a slight inhibitory effect on crude oil biodegradation by planktonic microbes, to deep sediment communities. Although pressure alone is not a major inhibitor of biodegradation in our experimental range, the expansion of oil exploration to deeper waters (e.g., 5000m) opens the risk of spills at conditions at which pressure might have a more significant effect. (1) Valentine *et al*., 2014. *PNAS, Vol. 111, No. 45*. (2) Romero *et al*., 2015. *PLoS One 10(5)*. (3) Prince *et al*., 2016. *Marine Pollution Bulletin (2016)*.

Multi-parameter assessment of fast repetition rate (FRR) fluorescence signals in natural phytoplankton communities exposed to the water accommodated fraction of oil and the chemical dispersant Corexit

**L. Bretherton**, M. Kamalanathan, J. Genzer, J. Hillhouse, S. Setta, B. Couffer, A. Quigg
Texas A&M University at Galveston, Galveston, TX

Fast repetition rate (FRR) fluorescence offers rapid measurement of photosynthesis *in vivo*, and is an effective tool for assessing stress responses in phytoplankton exposed to crude oil. The most commonly used fluorescence parameter, Fv/Fm, a measure of photosynthetic efficiency, is often sensitive to stressors but does not offer much insight into which photosynthetic processes are disrupted. Phytoplankton are important not only in their role as primary producers, but also as producers of extracellular polymeric substances (EPS), which are thought to facilitate the export of oil from surface waters to the deep ocean. Thus, identifying how oil and dispersants are toxic is critical to understanding how marine systems as a whole can respond to these events. Using natural phytoplankton communities collected from the Gulf of Mexico exposed to oil using the water accommodated fraction (WAF) and a chemically enhanced WAF (CEWAF) by adding the dispersant Corexit, we measured fluorescence signals every 12 hours over 3 days using a Fluorescence Induction and Relaxation (FIRe) system. The FIRe allows for multi-parameter characterization of phytoplankton photophysiology by using both single and multiple turnover flashlets. Fv/Fm values were similar



*Student presenter

between control and WAF tanks over the course of the experiment, but were significantly lower in CEWAF tanks. Further analysis of different aspects of the fluorescence signals, such as PSII connectivity (p) and electron turnover (tau), showed different sub-lethal effects depending upon the concentration of the CEWAF. The data from these preliminary mesocosm findings highlight the value in considering all aspects of physiology as a stress signal, rather than solely reporting Fv/Fm, and may translate to alterations in key microbial processes that govern the fate of oil in the Gulf of Mexico.

Marine Snow Enhances the Adverse Effects of Oil on Benthic Invertebrates

**J. S. van Eenennaam***[1], S. Rahsepar[1], J. R. Radović[2], T. B. O. Oldenburg[2], A. A. M. Langenhoff[1], A. J. Murk[1], E. M. Foekema[3]

[1]Wageningen University & Research, Wageningen, Netherlands, [2]University of Calgary, Calgary, AB, Canada, [3]Wageningen Marine Research, Wageningen, Netherlands

This study describes the behavioral response of several benthic invertebrate species to oil-contaminated marine snow. Unusually large amounts of marine snow were formed during the Deepwater Horizon oil spill. During this MOSSFA (Marine Oil Snow Sedimentation & Flocculent Accumulation) event, as much as 14% of the total oil released ended up on the sediment. This concentrated oil can have negative impacts on the benthic community. The invertebrates were exposed to clean and oil-contaminated artificial marine snow, and oil-only, on natural sediment in glass aquaria. After 16 days, the surviving organisms were counted. Sediment and water samples for oil biodegradation and in vitro toxicity testing were taken at several time points. Survival of the amphipod *Corophium volutator* was 80% lower than control in oil-contaminated snow, and 91% lower in oil-only treatment. Clean snow reduced survival by 31%. The gastropod *Hydrobia ulvae* was able to climb up the glass walls, and survival was only reduced in oil-contaminated snow, by 40%, possibly due to consumption of oiled snow. Survival of the bivalve *Macoma balthica* was reduced in clean and oil-contaminated snow (by 68% and 79%, respectively), but not in oil-only, possibly due to smothering and low oxygen concentration. The relative % of living foraminifera was most reduced in sediments with oil-contaminated snow. Presence of marine snow inhibited biodegradation of oil, while the presence of bioturbating invertebrates affected biodegradation compared to no-invertebrates aquaria (see abstract of Rahsepar et al.). This study showed that benthic invertebrates are negatively impacted by the presence of both marine snow and oil, and the combination of both enhances the negative effect. Application of oil spill dispersants can facilitate the formation of MOSSFA. The extra route of oil exposure via the sediment and potential enhanced adverse effects on the marine benthic community should be taken into account when deciding on oil response actions.

New insights in the fate of oil could lead to reconsidering alternative response strategies during algal blooms

**A. J. Murk**[1], E. M. Foekema[2]

[1]Wageningen University, Wageningen, Netherlands, [2]Wageningen Marine Research, Wageningen, Netherlands

One of the important lessons learned from the Deep Water Horizon oil spill is that the use of dispersants in conditions with algae blooms and particulate matter may cause large scale formation of marine snow-clay aggregates resulting in concentration of the oil on the sea bed (referred to as the MOSSFA event). As the presence of excessive amounts of marine snow depletes the oxygen supply, this hampers oil biodegradation and enhances the negative impact of the settled oil on the benthic



*Student presenter

ecosystem. Now that it is known that oil does not always dilute and disappear through dispersant application, but may be transported to the sea floor, oil spill responders have to weigh the impact of floating oil on the ecological/economic functions versus that connected to the benthic system. In case the benthic impacts are considered relatively low compared to organisms/areas that would potentially be threatened if the oil was still present as a floating slick, or was dispersed in the water column in situations without algal bloom, actively promoting oil settlement could be the best choice to reduce the overall impact of a spill. To prevent a MOSSFA event with the associated presence of marine snow increasing the ecological impact of the oil and hampering its biodegradation, application of clay particles could form an alternative response tool. The clay particles will form aggregates with oil and bring it down to the sea floor, but without the extra organic matter load in the form of marine snow that can develop due to dispersant application during algal blooms. With this presentation we want to open discussion about the pros and cons of such an alternative oil spill response. Results from indicative experiments on lab scale about the effectiveness of clay and the consequences for a number of benthic model species will be presented.

Post DWH sedimentation in the Northeastern Gulf of Mexico: a 6-year Overview

**R. A. Larson***[1], G. Brooks[2], P. Schwing[3], C. Holmes[4]
[1]Eckerd College/USF, Saint Petersburg, FL, [2]Eckerd College, Saint Petersburg, FL, [3]USF, Saint Petersburg, FL, [4]Environchron, Tallahassee, FL

Multi-cores were collected annually in the Desoto Canyon region of the NE Gulf of Mexico (GoM) over the ~6 years following the DWH event. Sediment analyses include grain size and composition, as well as short-lived radioisotope ($^{210}$Pb and $^{234}$Th) geochronology at 2-5 mm resolution. Results show a rapid, but short-lived increase in sedimentation within ~5 months following the event, which has been linked to marine snow formation (MOSSFA). The depositional pulse resulted in ~1 cm of sediment accumulation on the seafloor that exhibited sea surface characteristics, as well as a distinct change in grain size, signifying a different sedimentological response in different sedimentary regimes on either side of the Desoto Canyon. Four time series sites occupied annually over the past ~6 years exhibited excellent reproducibility in grain size and composition below the surficial 2-3 cm, representing little spatial heterogeneity of the sedimentary system at the scale of core sampling. The surficial 2-3 cm of cores exhibit a high range of variability in grain size compared to the down-core mean, and the greatest excursion from the mean occurred in the 1st cores collected after the DWH event. This pattern is consistent with $^{234}$Th inventories and mass accumulation rates, both of which exhibited extremely rapid increases during the pulse, followed by significant decreases within one year. This suggests that the sedimentary system experienced an abrupt shift in 2010, followed by a rapid recovery to near pre-event conditions. However, indications of the return of bioturbation have only been observed at some sites. The high variability of sediment parameters in the surficial 2-3 cm suggests the sedimentological signature of the depositional pulse has thus far been preserved. Continued time series sampling, as well as comparison with sediments impacted by the 1979/80 IXTOC-I spill in the SW GoM, will help to determine the longer term preservation of the depositional pulse.



*Student presenter

Multiproxy approach to reconstruct the response of marine environment to major oil spills using the geochemical stratigraphy of deep-water sediments

**J. Radovic**[1], P. Schwing[2], I. Romero[2], R. Silva[1], A. Jaggi[1], R. Larson[3], G. Brooks[3], S. Larter[1], T. Oldenburg[1]
[1]University of Calgary, Calgary, AB, Canada, [2]USF, St. Petersburg, FL, [3]Eckerd College, St. Petersburg, FL

Complex dynamics of marine systems is reflected in equally intricate geochemical composition of deep-water sediments. They are the records of ecosystem responses to major anthropogenic and/or natural perturbations. These complex geochemical archives are difficult to interpret in environments such as the Gulf of Mexico (GoM), affected by numerous confounding events, including Mississippi River discharge, coastal erosion and runoff, hurricanes, natural oil seeps, and spills from oil exploitation, such as the two largest submarine oil spills in history - Ixtoc-I and the Deepwater Horizon (DWH). In the past decade, methods and tools of (bio)geochemistry converged to enable much more comprehensive understanding of ocean system and its responses to major impacts. Using a multiproxy approach, which integrates the results of several deep-water sediment studies, we will demonstrate its potential to elucidate post-spill mechanisms in the GoM. To this end, annual stratigraphy of a core from the DeSoto canyon collected in 2014 was obtained by short-lived radionuclide geochronology. The presence and composition of petroleum hydrocarbons in strata corresponding to post-DWH period confirms that at least some portion of released oil ended up on the seafloor. In addition, ultrahigh resolution FTICR-MS revealed an elevated abundance of phytoplankton and archaeal biomarkers which seems to corroborate the hypotheses of increased planktonic productivity induced by the presence of post-DWH hydrocarbons in the water-column and in submerged plumes, which ultimately led to a rapid sedimentation event, so called MOSSFA (Marine Oil Snow Sedimentation and Flocculent Accumulation). Finally, these samples also exhibit a depleted stable carbon isotope signature of foraminiferal carbonate, indicating that spilled oil entered the benthic food web. We will compare these findings to some preliminary observations in the sediments from the Bay of Campeche, in order to assess whether similar post-spill events occurred in the aftermath of Ixtoc-I spill.

Trace elements fluxes in sediment cores from the Gulf of Mexico and their relationship with the IXTOC Oil Spill

**A. Ruiz Fernandez**[1], L. Perez-Bernal[1], P. Lopez Mendoza[1], J. Sanchez Cabeza[2], M. Machain Castillo[2], P. Schwing[3], D. Hastings[4], A. Gracia-Gasca[5], D. Hollander[3]
[1]UNAM, ICMyL- UA Mazatlan, Mazatlan, Mexico, [2]UNAM, ICMyL- UAPOC, Mexico City, Mexico, [3]University of South Florida, St. Petersburg, FL, [4]Eckerd College, St. Petersburg, FL, [5]UNAM, ICMyL, Mexico City, Mexico

The Ixtoc-1 blowout, occurred in the Bay of Campeche in June 1979, produced a surface oil spill which dispersed northwards, over the coastal areas of the Gulf of Mexico, during several months after the accident. Six sediment cores collected in areas within the spill path, during the C-IMAGE 2015 oceanographic expedition, were analyzed to evaluate trace element enrichment and fluxes in connection with the accident occurred ~36 years ago. The $^{210}$Pb dating method was used to determine the mass accumulation rates through the constant flux (CF) model; trace elements were analyzed by X-ray fluorescence spectrometry (XRF) and the trace element enrichment was evaluated by using an aluminum normalized enrichment factor. The terrigenous (K/(Fe + Mg), weathering (Al/(Al+Fe+Mn), redox (Mo/Al, U/Th) and crude oil contamination (Ni/V) index were used to evaluate the influences of these factors on the spatial and temporal variations of the metal concentrations within the study sites. In spite of the differences in fluvial input, sediment supply, as well as land and marine based pollution sources, all sediment records showed remarkably similar temporal trends of trace metal enrichment,



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which indicated a complete recovery from the Ixtoc-1 oil spill, and highlighted the long-term resilience of the Gulf of Mexico to the impacts of global change.

Changing Sedimentary Redox Conditions Following Deepwater Horizon Blowout and IXTOC-I events: Geochemical and Ecological Implications

**D. Hastings**[1], T. Bartlett[1], G. Brooks[1], B. Carr[1], R. Larson[1], K. Quinn[2], D. Razionale[1], I. Romero[2], P. Schwing[2], D. Hollander[2]
[1]Eckerd College, St. Petersburg, FL, [2]College of Marine Science, USF, St. Petersburg, FL

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 in the sediments. 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, then decreased, indicating a return to pre-impact conditions. A dramatic reduction of foraminiferal abundance is coincident with reducing conditions, demonstrating the important consequences of changing redox conditions on benthic ecosystems.

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 event.

System Recovery and Organic Source Variability: Sinking Particulate Organic Carbon Stable and Radioisotope Time Series at 3 Sites in the Northern Gulf 2010-2014

**J. Chanton**[1], U. Passow[2], V. Asper[3], S. Bosman[1], J. Sweet[4], K. Rogers[1], A. Diercks[3], B. Yan[5]
[1]Florida State University, Tallahassee, FL, [2]University of California Santa Barbara, Santa Barbara, CA, [3]University of Southern Mississippi, Stennis, MS, [4]University of California, Santa Barbara, CA, [5]Columbia University, Palisades, NY

We report isotopic time series for particles collected from funnel-shaped sediment traps deployed at three stations in the northern Gulf, OC-26 (28.7N, 88.4W), GC-600 (27.4N, 90.5W) and AT-357 (27.5N, 42.7W). OC-26 is about 5 km from DWH site, while GC-600 represents a site heavily influenced by sea-floor seepage of oil and gas, and AT-357 represents a low intensity seep site and ultimately, background conditions. At OC-26, particle radiocarbon $\Delta^{14}C$ values increased following the spill from a low of -140‰ to reaching values above 0‰ in December 2012. From 2013 to 2104, values continued to trend upwards reflecting the time series of recovery in the Gulf. At GC-600, values varied from +43‰ to -150‰ suggesting that the trap captured the deposition of oiled particles entrained upward from the seafloor with advecting fluids which were then subsequently sank. These results suggest a localized MOSFFA-event in the vicinity of this strong hydrocarbon spring. At site AT357 particles varied between $\Delta^{14}C$ of +50 and -50‰ but mostly reflected the deposition of surface derived carbon. The $\delta^{13}C$ values of sinking particles were consistent with the radiocarbon trends, becoming $^{13}C$ enriched over time at OC-26, following $^{14}C$ depletion patterns at GC-600, and showing the most enriched values at AT-357. Sulfur



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$^{34}S$ values also reflected these trends, particularly at OC-26, where values reached a minimum of +3‰ in early 2011, and later rebounded to values varying between +14 to +20‰ in late 2012 to 2013.

Microbial Oil Degradation in Gulf Of Mexico Sediment Measured *in situ* Using Long-Term Benthic Lander Enrichment Experiments

**B. N. Orcutt**[1], L. L. Lapham[2], J. Delaney[3], N. Sarode[3], K. S. Marshall[2], K. J. Whaley Martin[4], G. Slater[4], C. G. Wheat[5], P. R. Girguis[3]
[1]Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, [2]University of Maryland Center for Environmental Science, Solomons, MD, [3]Harvard University, Cambridge, MA, [4]McMaster University, Hamilton, ON, Canada, [5]University of Alaska Fairbanks, Monterey, CA

Weathered crude oil sank to the seafloor following the Deepwater Horizon disaster, removing this oil from further physical and photo-chemical degradation processes and leaving benthic processes as the mechanisms for altering and remediating this hydrocarbon source. To quantify microbial oil degradation rates and associated changes in sediment microbial community structure at the seafloor, we deployed sediment flow-through chambers using a novel *in situ* benthic lander at a natural hydrocarbon seep in the Gulf of Mexico (GC600) at roughly the same water depth as the Deepwater Horizon wellhead. Sediment amended with 20% unweathered crude oil had elevated rates of sulfate reduction over the course of the 5-month long *in situ* experiment as compared to an unamended control, yielding some of the highest rates of sulfate reduction ever measured in hydrocarbon-influenced deep-sea sediment. Oil amendment also stimulated methane production towards the end of the experiment, and led to slightly higher cell densities without significant changes in microbial community structure, based on 16S rRNA gene sequence libraries and fatty acid profiles. Notably, these data suggest that electron acceptor availability may become limiting in heavily oiled deep-sea environments, resulting in reduced rates of degradation. This study provides some of the first data on seafloor sediment responses to oil deposition, and reveals the value of using *in situ* observatories to fill the gap in understanding deep-sea microbial processes, especially for ephemeral and stochastic events such as oil spills.

Assessing the Role of Benthic Foraminifera as Indicators of the Benthic Ecosystem Health and Evolution after the IXTOC-I Oil Spill

**M. L. Machain-Castillo**[1], A. Gracia[1], A. C. Ruiz-Fernández[2], J. A. Sanchez-Cabeza[1], A. Rodríguez-Ramírez[1], H. M. Alexander-Valdés[1], X. A. Nava-Fernández[1], L. E. Gómez-Lizárraga[1], P. T. Schwing[3], D. Hollander[3]
[1]University of Mexico -UNAM, Mexico city, Mexico, [2]University of Mexico -UNAM, Mazatlán, México, Mexico, [3]University of South Florida, St. Petersburg, FL

Benthic foraminifera have been widely used as indicators of environmental health. The impacts of the DWH in the sediments of the northern Gulf of Mexico include benthic foraminiferal shell morphological and geochemical modifications and density and accumulation rate decrease. Foraminiferal populations show recovery in some of the impacted sites, but this is not spatially nor temporally homogeneous. To have a better understanding of the benthic foraminiferal populations recovery after an oil spill (IXTOC - I, 1979-80) we explored the responses of this group over a larger spatial scale, covering the entire southern Gulf of Mexico (south of 22°N), and a time period of 37 years in sediment superficial samples and box cores. We looked at three time-windows: 1) a present time (2015), 2) in 2010 (30 years after the spill), and 3) the closest time after the spill (1979-80). At time slice 3, benthic foraminiferal diversity and density were lowest compared to present-day, although not directly correlated with well distance,



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nor to the main plume pathway. Time 2 showed that taxonomical composition of benthic foraminifera followed a bathymetric distribution, not affected by the proximity to the oil platforms area. However, foraminiferal density showed a low correlation with sediment organic matter, presumably derived from hydrocarbon input, as suggested by their C-13 signature. Recent (2015) foraminiferal fauna is diverse and abundant, with values similar to other non-polluted areas of the gulf. In spite of this, some specimens do show morphological deformations and some of them have a $\delta^{13}C$ signature indicative of hydrocarbon incorporation into their shells, possibly due to intermittent long-tern exposure to oil in the southern gulf, both of natural and anthropogenic origin. A closer look has to be paid to individual areas, sources and individual foraminiferal responses to refine the potential use of foraminifera as indicators of oil pollution.

Benthic Foraminiferal Community Structure is a Sensitive Indicator of Benthic Impacts and Recovery Following the Deepwater Horizon Oil Spill

**P. T. Schwing**, B. J. O'Malley, D. J. Hollander
University of South Florida, Saint Petersburg, FL

During and directly following the Deepwater Horizon (DWH) oil spill, a marine oil snow, sedimentation and flocculent accumulation (MOSSFA) event occurred in the northern Gulf of Mexico (NGOM). Relative to background (pre-DWH), the MOSSFA event caused a 4-10 fold increase in bulk sediment accumulation rates and a 3-fold increase in the concentrations of sedimentary hydrocarbons. These changes in sediment inputs and related variations in post-depositional environmental conditions (i.e., intensification of anaerobic redox conditions) are the primary causes for the region-wide decreases in benthic foraminiferal density, species richness, and heterogeneity observed during (2010) and after (2011) the DWH event. Sediment cores from seven time series sites have been collected annually in the NGOM in order to assess benthic community health and determine the rates of benthic foraminiferal recovery. Standard ecological indices of species richness (Fishers Alpha, S), heterogeneity (Shannon, H) and density were used as primary indicators of benthic foraminiferal community health from eight subsamples of each core top (<5 cm). These three measures of benthic community health increased over time from 2010-2015. We observed the highest increase coefficient in species richness (23% ±2.1) and heterogeneity (S: 15% ±0.1) between cores collected from 2010-2012 and those collected from 2013-2015. These changes in benthic foraminiferal condition suggest a benthic recovery on the order of three years. In the NGOM, benthic foraminiferal density, and diversity indices have proven to be robust bioindicators of benthic system health and for establishing a benthic recovery rate following submarine oil release. These measures of benthic health are essential for establishing current baselines (new normal) and providing a template in which to interpret the severity of benthic impact and recovery from future submarine petrochemical releases.

Persistent Impacts to the Deep Soft Bottom Benthos and Potential for Recovery after the Deepwater Horizon Event

**P. A. Montagna**[1], J. G. Baguley[2], J. L. Hyland[3], C. Cooksey[3], D. Hollander[4]
[1]Texas A&M University - Corpus Christi, Corpus Christi, TX, [2]University of Nevada-Reno, Reno, NV, [3]NOAA, NOS, Charleston, SC, [4]University of South Florida, St. Petersburg, FL

In September-October 2010, three to four months after the Deepwater Horizon blowout was capped, a zone of moderate and severe impacts to deep-sea soft-bottom benthos was identified that extended over an area of 172 km2. The impact was a loss of -53.7% of macrofauna family diversity and -38.3% of



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meiofauna major taxa diversity in the most severely impacted zone. The area was resampled in May-June 2011 and May-June 2014 to determine if the identified effects were persisting. The sampling design compared 20 stations in the impact zone to 14 stations in the reference zone that were sampled in all years. There is evidence of persistent, statistically significant impacts to both macrobenthic and meiobenthic diversity because the relative losses of biodiversity are largely the same in 2011 and 2014 as it was in 2010. The persistence of significant biodiversity losses four years after the wellhead was capped indicates that no recovery has occurred. Recent work at the Ixtoc oil spill site identified oil at about 5-7 cm below the surface after 35 years. If this trend holds for the DWH site, then recovery will take about 70 years because the bioreactive zone for benthos is 10 cm deep.

Forming a Gulf-wide dataset of PAH exposure and accumulation in benthic-dependent teleosts

**S. M. Snyder***, E. L. Pulster, S. A. Murawski
University of South Florida, St Petersburg, FL

Since 2011, scientific longline surveys have sampled teleosts on the continental shelf in the northeastern Gulf of Mexico in response to the Deepwater Horizon blowout. In 2015 and 2016, surveys were extended to the southern Gulf of Mexico to create a Gulf-wide dataset of polycyclic aromatic hydrocarbon (PAH) exposure, accumulation and associated health effects. Target species include benthic-dependent fishes, such as golden tilefish (*Lopholatilus chamaeleonticeps*), king snake eel (*Ophichthus rex*) and red snapper (*Lutjanus campechanus*). To date, a time series of 700 bile samples collected from 2011 to 2016, has been analyzed using high performance liquid chromatography with fluorescence detection (HPLC-F) to semi-quantitatively measure naphthalene and benzo[*a*]pyrene metabolites as a short term biomarker of exposure to PAHs. Results indicate species-specific differences in exposure, possibly due to level of benthic dependency, and decreases in naphthalene metabolite concentration in the years following the Deepwater Horizon event. Biliary PAH metabolite concentrations are higher in golden tilefish and red snapper sampled in the northeastern Gulf of Mexico, compared to those sampled in Mexican waters. Analysis of parent PAHs and alkylated homologs, via QuEChERS extraction and GC-MS/MS detection, is ongoing in liver samples. Preliminary results show a dominance of the low molecular weight PAHs in liver tissue, with low concentrations of high molecular weight and carcinogenic PAHs. These PAH measurements will be correlated with ongoing studies of additional biomarkers of exposure, such as ethoxyresorufin-O-deethylase (EROD) activity, active immune response, genotoxicity, oxidative stress and liver damage. Creating this gulf-wide dataset of PAH exposure and accumulation will provide baseline data on contamination and associated health effects as oil and gas activity continues to expand in the Gulf of Mexico.



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## Session 011: Human Dimensions and Activity of Oil Spill Response, Restoration, and Future Preparedness: Interdisciplinary Communications and Community Resilience from a Social Ecological and Systems Approach

Decision Science and Environmental Stressors
**B. Fischhoff**
Carnegie Mellon University, Pittsburgh, PA

Decision science studies how people make judgments and decisions in terms that can be contrasted with analyses of how they could, or should, make them, if well-informed about the world and themselves. As such, it can provide a platform for integrating knowledge about the world and about people who must make their way within it. The talk will offer an overview of the field and what it might learn from and contribute to the diverse decisions addressed by scientists and practitioners at the conference.

Mental and Behavioral Health in the Gulf States 5 Years after the Deepwater Horizon Oil Spill
**R. Ramchand**[1], V. A. Parks[2], R. Seelam[1], M. L. Finucane[1]
[1]RAND Gulf States Policy Institute, New Orleans, LA, [2]Louisiana State University, Baton Rouge, LA

A challenge of research on the health effects of disasters like oil spills is the lack of pre-event health information of affected communities. This is especially true for estimating mental health effects of oil spills on community residents: individuals with mental health symptoms may distort perceptions about the extent and degree of exposure to the spill when asked to recall the event which can, in turn, bias estimates of effects. The Survey of Trauma, Resilience, and Opportunity among Neighborhoods in the Gulf (STRONG) is a cross-sectional, telephone survey designed with two purposes: to estimate how past exposure to the Deepwater Horizon Oil Spill affects residents' health, and to provide representative estimates of key health conditions among coastal communities between Florida and Texas, should another spill or natural disaster occur in the region. In the current study, we present estimates of depression, anxiety, alcohol misuse, and health care utilization among residents in the Gulf of Mexico's coastal communities, including state-specific estimates. A little under half of the residents in the region screened positive for each of the three mental and behavioral health care conditions with 4 out of 5 of those screening positive not accessing any mental health care in the past 12 months; preliminary results suggest no differences across states. We did find differences both across the region and within states by sociodemographic characteristics (gender, age, race/ethnicity, and industry and education). These results provide a baseline for future planning in the Gulf region to potentially minimize the behavioral and mental health effects of a future oil spill. Services should be targeted toward communities with existing mental health conditions, since untreated pre-existing mental health conditions may be exacerbated after a disaster.

Persistent perceived vulnerability as a function of exposure to the Deepwater Horizon oil spill
**A. M. Parker**[1], M. L. Finucane[1], L. Ayer[1], R. Ramchand[1], V. A. Parks[2], N. Clancy[1]
[1]RAND Gulf States Policy Institute, New Orleans, LA, [2]Louisiana State University, Baton Rouge, LA

To better understand and promote communities' resilience to adverse future events, in 2016 the Consortium for Resilient Gulf Communities conducted the Study of Trauma, Resilience, and



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Opportunity among Neighborhoods in the Gulf (STRONG), a representative telephone survey of 2520 Gulf Coast residents from Texas through Florida, designed to assess long-term health, economic, and social impacts of the Deepwater Horizon oil spill. Here we examine how past exposure to the oil spill is associated with persistent perceptions of vulnerability. Self-report assessments of exposure to and impacts from the oil spill include multiple questions on working in affected industries, economic and job loss, and effects on lifestyle patterns. Persistent perceived vulnerability includes current worry about ongoing health, economic, and social impacts. Overall, reports of past exposure strongly predict higher current worries about ongoing impacts, controlling for socio-economic status and other demographic information. These results are largely robust to the form of perceived vulnerability (health, economic, social), and appears to be largely driven by (a) working in an affected industry, such as oil and gas or fishing and seafood, (b) reported impacts on hunting and fishing, as well as dietary impacts, and (c) reports of monetary or property loss. Relative to those who did not live in the region at the time of the oil spill (but currently living in the region and hence surveyed), those in the region who reported exposure and impact had modestly higher perceived vulnerability, but those in the region reporting no exposure or impact had much lower perceived vulnerability. These findings suggest that those reporting impacts from the Deepwater Horizon oil spill continue to deal with lingering concerns. These findings highlight the long-term impact of disaster exposure on ongoing psychological well-being and could help guide efforts to protect well-being of affected populations.

Local Ties, Natural Resource Employment, and Oil Spill Exposure: Effects on Mental Health Outcomes in Gulf Coast Communities

**V. Parks***[1], L. Drakeford[1], R. Ramchand[2], T. Slack[1], M. Finucane[3], M. R. Lee[1]
[1]Louisiana State University, Baton Rouge, LA, [2]RAND Corporation, Washington, DC, [3]RAND Corporation, Pittsburgh, PA

The Consortium for Resilient Gulf Communities disseminated the Survey of Trauma, Resilience, and Opportunity among Neighborhoods in the Gulf (STRONG) to assess the health and wellbeing of Gulf Coast residents, five years after the Deepwater Horizon oil spill (DHOS). Existing literature on community resilience has found that in the months following disasters, such as oil spills, residents with high amounts of social capital experience adverse mental health outcomes. However, in the medium and long term, social capital can serve as a protective force against mental health symptoms. Furthermore, involvement with natural resource-based employment has been found to negatively impact residents' mental health. Six years after the DHOS, the present study examines the effects of social capital, as operationalized by close local ties, on mental health symptoms, while controlling for ties to natural resource-based livelihoods, as well as perceived economic loss and social disruption related to the DHOS. Preliminary analyses indicate that respondents with a greater number of local, close ties report better mental health outcomes. When controlling for perceived economic losses and social disruption, ties to natural resource-based employment have little to no effect on mental health. These findings suggest that social capital, in the form of local networks, is associated with better mental health in the medium and long term, and that natural resource-based employment may not predict worse mental health above and beyond economic and social exposures. Additional results and potential implications are discussed.



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Addressing the need for expanding knowledge of occupational & environmental human health issues in the gulf coast region

**K. H. Kirkland**
Association of Occupational and Environmental Clinics, Washington, DC

In the aftermath of the Deepwater Horizon oil spill, the Association of Occupational and Environmental Clinics (AOEC), along with the Center for Gulf Coast Environmental Health Research at Tulane University's School of Public Health and Tropical Medicine (Tulane), has been working with a number of Federally Qualified Health Centers (FQHCs) in the Gulf Coast region to try to address the health occupational & environmental health (OEH) concerns of community members & to help primary care clinicians better understand the impact of OEH factors on their patients' health. Since 2013, AOEC staff & members have participated in outreach efforts to engage the FQHCs in the region. These efforts have included personal visits by AOEC staff, participation in community & regional meetings, free online continuing education, & establishing a referral network for patients to be evaluated by OEH specialists. AOEC staff & members have interacted with over 600 community members & 300 clinical staff since the program began. A key component to this outreach has been the development of Case Studies in Environmental Medicine (CSEM). These CSEM have been available (with CME/CE credit available) for self-instruction on the Tulane website as well as presented by AOEC staff at clinics involved in the project, professional meetings & in classrooms. They address the most frequently mentioned environmental issues raised during community interactions that are potentially related to health concerns, such as possible reproductive effects from the Deepwater Horizon oil spill, dispersants used during the oil spill clean-up, seafood consumption, & an overview of OEH. The work is funded by the Gulf Region Health Outreach Program.

Estimating the Effects of the Deepwater Horizon Oil Spill on Fisheries Landings and Revenues

**J. Fiore***[1], C. Bond[2], S. Nataraj[3]
[1]Tulane University, New Orleans, LA, [2]RAND Corporation, Arlington, VA, [3]RAND Corporation, Santa Monica, CA

What were the direct impacts of the 2010 Deepwater Horizon (DH) oil spill on the Gulf fisheries industry? We perform an ex-post analysis of the spill using publicly available, routinely collected data on landings, revenues, and fishing effort for select fish species in the Gulf. Our methods examine the overall impact of the oil spill as well as changes that occurred over time. A key contribution of our work is that it goes beyond simple pre-post analysis and applies various identification strategies that have been developed in the econometric literature, in order to attempt to identify the causal effects of the spill. Investigation of the short and longer term dynamics of the Gulf fisheries has important implications for understanding the resilience of Gulf communities in the face of large-scale environmental events like DH. The dynamic path of certain indicators, such as fisheries landings and revenues, can provide information about the abilities of fisheries to withstand and recover from oil spill events at the sectoral level, aggregating the various physical, policy, and behavioral responses that combine to form the latent resilience construct. Our findings may help stakeholders, policy-makers, and researchers define the true impacts, including potential costs, of environmental disasters over time, understand the dynamics of response, and plan for future uncertain events.



*Student presenter

Assessing the Effects of Religion and Disruption on Mental Health in Vulnerable Gulf Communities
**L. Drakeford***[1], V. Parks[1], R. Ramchand[2], M. Finucane[2], M. Lee[1]
[1]Louisiana State University, Baton Rouge, LA, [2]RAND Corporation, Washington, DC

Numerous studies have illustrated the effects of religion in coping with the effects of experiencing disasters. However, most of these studies have focused on religion at the individual level, with little insight provided into the religious ecological effects associated with the contextual factors of religious adherence and composition. We address this gap in the literature using multilevel modeling of data provided by the Study of Trauma, Resilience, and Opportunity among Neighborhoods in the Gulf in order to assess the effect of county-level religious adherence and composition on the long term mental health impacts of exposure to the Deepwater Horizon oil spill. Preliminary results suggest that higher levels of county-level religious adherence have deleterious mental effects on those that experienced social disruption from the oil spill. Additionally, individuals in counties with higher concentrations of conservative Protestants experienced magnified negative effects on mental health relative to their perceptions of economic loss and social disruption following the Deepwater Horizon oil spill. Results and their implications are discussed.

An Interdisciplinary Framework for Analysis of Multiple Gulf and Deep South Disasters: Synthesizing Ecological Systems & Social Network Perspectives
C. F. Bright[1], R. Hanks[2], E. Sayre[1], **B. Bagley***[1]
[1]The University of Southern Mississippi, Hattiesburg, MS, [2]The University of South Alabama, Mobile, AL

In the world of social science research, the work of Urie Brofenbrenner has been the dominant influence on sociobehavioral investigations over the last half-century. The five-dimension conceptualization of how individuals interact with their environment is both intuitively appealing and evidence based. Briefly, Bronfenbrenner and various colleagues have proposed that individuals are socialized within levels of linkages that influence them directly and indirectly, including: (1) Microsystem - the most direct linkage of individual to family, friends and close regular contacts; (2) Mesosystem - the system of microsystems or connections between two or more microsystems; (3) Exosystem - systems in which the individual is not situated but is influenced by; (4) Macrosystem - culture, belief systems, social organization; and (5) Chronosystem - time as environment; changes over time; influences of situation in time. Neal & Neal (2013) offer an expansion of Bronfenbrenner's theory proposing that linkages may need to be redefined within a social network framework to capture methodological advantages such as use of social network analysis to gain precision in measuring linkages. Similarly, we draw on the historical analysis by Rosa & Tudge (2013) tracing the evolution of Bronfenbrenner's theory of human development from ecological to bioecological, with relevant cautionary considerations for synthesizing social and bioecological concepts among colleagues engaging in interdisciplinary research. Drawing data from 84 interviews with individuals impacted by one of three Gulf region disasters—the Mississippi River flooding in the Delta communities, the Tuscaloosa tornadoes, or the Deepwater Horizon oil spill—we assess the role of social network factors in the context of Bronfenbrenner's ecological systems theory. In doing so, we actualize Neal and Neal's (2013) call for the incorporation of social network analysis for understanding the influence of linkages in human development.



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US Coast Guard Incident Management and Preparedness - Community Interactions during Recent Crises in the Gulf of Mexico

**W. Carter**
Commanding Officer, USCG National Strike Force, Elizabeth City, NC

The US Coast Guard has a variety of responsibilities during crises and disasters that impact Gulf of Mexico communities. As the Nation's maritime first responder, crisis leadership, management, and command and control are Coast Guard core competencies. During Hurricane Katrina and Deepwater Horizon (DWH), US Coast Guard personnel established large scale command and control organizations to aggressively mitigate the negative environmental impacts from these events. For a coastal oil spill, such as the one that resulted from DWH tragedy in 2010, the USCG provides the Federal official to lead the response in the regulatory role of Federal On-scene Coordinator, or FOSC. Most local Coast Guard leaders have a baseline understanding of the Coast Guard's approach to incident management, such as a units' ability to successfully organize and coordinate response actions for most locally managed incidents. Crises which are high-impact and/or complex incidents require an extensive, well-coordinated multi-agency, whole community response to save lives, minimize damage and protect the environment. As the incident grows, so does the need for open and transparent communication between the Coast Guard and the communities we serve. The crises of Hurricane Katrina and the DWH oil spill highlighted the continuing need for enhancing incident management to address concerns of, and engage, a broader set of stakeholders. This presentation will highlight some Hurricane Katrina and DWH oil spill situations that Coast Guard personnel encountered with communities who were largely dependent on the environment and a marine-based economy. I'll describe a few examples of challenges and lessons we encountered which were beyond our typical incident management training and preparedness. While some lessons have found resolution, others might benefit from consideration by the researchers in this session.

Supporting Child and Adolescent Resilience Following Disasters

**J. D. Osofsky**, T. C. Hansel
Louisiana State University Health Sciences Center, New Orleans, LA

Disasters, both natural and technological, touch the lives of millions of children each year. Following disasters, many children suffer from displacement and separation from families and friends, loss of resources and family income, loss of homes, possessions, and pets, and almost always, loss of community. How children and adults respond after such catastrophic events depends on many factors including their direct exposure and experience with the disaster, previous trauma and loss history, developmental level of the child, and, perhaps most important, amount of support that is available from family, school and community. More is being learned about additional factors that influence outcomes including children's exposure to earlier traumatic experiences, concurrent ongoing traumas that accompany disasters, and increased vulnerability related to temperament and personality. While researchers and clinicians frequently focus on problems following disasters such as behavioral health symptoms, less attention is addressed to potential positive outcomes. Resilience, that is, the ability to adapt and cope following adversity and self-efficacy, a person's belief in her or his ability to succeed in a particular situation may be important, but overlooked, factors influencing outcomes. This presentation will focus on research following the Gulf Oil Spill on over 5,000 children and adolescents ages 12-18. Results suggest that perceived self-efficacy serves as a protective factor that influences the association among disaster exposure and trauma symptoms. Findings support the need for resilience-based programming before and after disasters to support child and adolescent recovery.



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Correlation of Biomarkers and Self-Reported Seafood Consumption among Pregnant and Non-Pregnant Women in Southeastern Louisiana, the GROWH Study

**L. Zilversmit***, J. Wickliffe, A. Shankar, E. W. Harville
Tulane University School of Public Health and Tropical Medicine, New Orleans, LA

Background: Self-reported diet may be subject to inaccuracy. Pregnant women, in particular, may be hesitant to correctly report seafood consumption. Using self-reported seafood from pregnant and non-pregnant women in the GROWH study, self-reported seafood was compared to mercury (Hg) blood levels and Omega-3 and Omega-6 fatty acids. Differences in self-report between pregnant and non-pregnant women were also studied. Methods: 662 pregnant and non-pregnant women from oil spill affected areas were interviewed between 2012 and 2015 and provided blood samples. Women were asked their daily, weekly and monthly consumption of seafood. Logarithmic values were calculated for Hg, Omega-3 and Omega-6 fatty acids found in blood. Pearson's correlation coefficients were calculated comparing blood Hg and Omega-3 and Omega-6 fatty acids and compared the levels to the total seafood consumption. Pearson correlation coefficients for blood levels and total seafood consumption were also stratified by pregnancy status. Crude and adjusted linear regression predicting levels of Hg and Omega-3 and Omega-6 fatty acids adjusting for age and pregnancy status. Results: Significant correlations were found for between log Hg levels and total high Hg seafood level reported (0.094, P=0.02) and pregnancy status (-0.151, P<0.0001). Log omega-3 levels were correlated with reported seafood that were high in omega-3 seafood consumption (0.12, P=0.02). Omega-6 levels were only correlated with pregnancy status with pregnant women reporting lower Omega-6 containing seafood (-0.088, P=0.0003). When adjusted for age and pregnancy, this association was maintained between omega-3 and omega-6 fatty acids and seafood reported (β=0.01, P=0.02 and β=0.01, P=0.02 respectively). Seafood consumption was also associated with blood Hg levels in the adjusted model (β=0.03, P=0.05). When stratified by pregnancy, Hg levels were only correlated to seafood response in non-pregnant women (0.09, P=0.048). Conclusions: Self-reported seafood consumption was correlated with biomarkers of both dietary fatty acids and metals contamination in the way that would be expected, but this association was stronger in non-pregnant women. Pregnant women may be more likely to mis-report seafood consumption, or pregnancy might affect metals and fatty acid levels.

In Media we trust? Reaching special populations in the Gulf of Mexico

**E. L. Petrun Sayers**
RAND Corporation, Arlington, VA

Crisis communication research explores how to effectively reach audiences during an emergency to minimize harm to persons and communities. A key barrier is that communication tends to be tailored for dominant groups, leaving minority or special populations at a disadvantage. Failing to reach minority groups with essential messages positions them to be unable to respond to emergency messages, or to provide unnecessarily confusing or unclear communication. This is concerning, considering minority groups could already be at a disadvantage and less likely to be prepared for disasters due to prolonged and consistent social inequality. Distrust is also commonly cited as a contributor to racial disparities in domains spanning health and media. For example, minorities may possess greater levels of distrust toward healthcare practitioners and the health care industry, which can interfere with care seeking and adherence to treatment. Distrust of media can similarly impede the ability of persons to take action in the wake of an emergency. This distrust can be traced back to concerns stemming from a history of media that is censored by "gatekeepers" who decide what information should be shared and how information is presented. Thus, minorities may see centralized



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and traditional sources as less trustworthy when compared to local, web, or interpersonal sources of information. This paper will examine how demographic characteristics affect communication source preferences and trust in media in the Gulf of Mexico. Research questions addressed include: **RQ1**: How do demographic characteristics (i.e. sex, race/ethnicity, age, education, and income) affect source preferences? **RQ2**: How do demographic characteristics (i.e. sex, race/ethnicity, age, education, and income) affect trust in media sources? **RQ3**: Is higher distrust correlated with more negative outcomes from the BP Oil Spill? As trust remains a key issue in disaster response, additional research will provide important insight to response organizations tasked with mitigating the short and long-term consequences of disasters. We expect the findings to contribute to capacity building allowing responders to create more equitable communication strategies during disasters.

Coalitions and Conversations: Translating Lessons Learned from Past Disaster Recovery for Preparedness and Response Efforts

**A. Speier**, J. Osofsky, H. Osofsky, N. Savage, T. Hansel
Louisiana State University Health Sciences Center, New Orleans, LA

Research concerning survivors' behavioral health, temporary displacement and social connectedness is well-grounded, however the methods of addressing these needs are often lost in history. Lessons learned are worthy of discussion to improve preparedness or recovery models for areas prone to disasters. The purposes of this presentation are three fold 1) report qualitative findings of reflections from providers that worked immediately following Hurricane Katrina; 2) provide examples of how technical assistance from the coalition have been provided following community violence and the recent Louisiana flood and 3) present the Terrorism and Disaster Coalition for Child and Family Resilience as a method of translating lessons learned into practice. While the past decade has presented many challenges to residents of the Gulf Coast, there have also been a number of lessons learned that will prove beneficial to future disaster response and policy approaches with critical planning, capacity building, and community resilience.

Social Networking Sites as a Method for Disaster Relief, Public Communication and Health Advocacy

**T. K. Craft**, S. M. Tokarz, V. A. Sacco, T. Cross Hansel
LSU Health Sciences Center, New Orleans, LA

The benefits of social networking sites (SNS), such as Twitter and Facebook, for use following disastrous events are becoming increasingly popular methods of public communication and health advocacy. For example in 2010, global data from over 25 billion tweets revealed that two of the top ten trending topics related to disasters—the fourth was the Haiti Earthquake and the number one trend was the Gulf Oil Spill. The popularity of these topics, and Twitter's (approximately 300 million active users) points to a need for increased social media presence for disaster relief and behavioral health organizations. This presentation will discuss methods of using SNS following mass events and provide trend data regarding the use of Facebook in response to the Louisiana Flood of 2016. The Mental and Behavioral Health Capacity Project in Louisiana began a social media campaign to increase access and knowledge of community supportive services, educational outreach, and connectedness for the general population. Initial efforts of the social media campaign are conducted through Facebook and entitled Community Psychiatry Resilience Education and Strengths (CYPRESS). Following the recent floods, CYPRESS scheduled a small series of Facebook posts which both helped connect victims of the flooding to disaster relief and mental health services as well as informed on trauma, grief, and the importance



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of rebuilding in the aftermath of disaster. In less than one month our posts reached over 1300 persons. Opportunities for using SNS to promote understanding and assist with behavioral health following disasters are many and such efforts can increase community resilience, preparedness, and the well-being of disaster survivors.

Socio-Spatial and Experiential Variations in Perceptions of Risk and Resilience on the Mississippi Gulf Coast

**D. M. Cochran**, B. Kar, B. Blackmon, J. Lee, T. Rehner
University of Southern Mississippi, Hattiesburg, MS

Building community resilience requires an understanding of how residents of at-risk communities perceive their own risk and resilience, as well as how their perceptions vary according to socio-demographic and geographical characteristics and their experience with disasters. This research was conducted by an interdisciplinary team of geographers and social workers from the University of Southern Mississippi. In the spring of 2015, the research team administered a survey on the Mississippi Gulf Coast to residents who experienced Hurricane Katrina (2005) and the Deepwater Horizon oil spill (2010). A spatially-stratified, random sampling method was used to select participants living in communities south of Interstate 10 and near the coastline. The survey included the Communities Advancing Resilience Toolkit (CART) instrument and a series of socio-demographic questions that were developed by the team. All five domains of CART - Connection and Caring, Resources, Transformational Potential, Disaster Management, and Information and Sharing - were included in the survey to capture a multi-faceted view of how people perceive the resilience of the communities in which they live. Additional questions provided information about their socioeconomic, cultural, and behavioral characteristics, their perception of risk, and their experience with Hurricane Katrina and Deepwater Horizon. Analysis focused on the relationship between perceptions of risk and resilience and on the degree to which social and spatial characteristics varied among participants. These results demonstrate that using CART can help policy makers and community organizations understand how resilience varies among different segments of vulnerable populations so that effective actions can be taken to enhance resilience and disaster preparedness.

The Role of Community Resilience and Its Impact on Depression after Multiple Disasters: An Examination of the Mississippi Gulf Coast

**J. Lee**, B. J. Blackmon, D. M. Cochran Jr., B. Kar, T. A. Rehner
University of Southern Mississippi, Hattiesburg, MS

Community resilience is critical to helping residents overcome challenges in disaster preparation, response, and recovery efforts. However, little is known about the impact of community resilience on mental health outcomes of disaster survivors in the long-term recovery process. Previous studies that examined the impact of disasters on mental health have focused largely on the role of resilience at the personal level (e.g., psychological resilience), while limited attention has been paid to the community level. The current study examines how community resilience is related to psychological resilience and depressive symptoms among MS Gulf Coast residents. This survey research project was conducted by an interdisciplinary team of social work and geography researchers. The survey administration took place in the spring of 2015 to a spatially-stratified, random sample of households in the three coastal counties of Mississippi. A total of 294 participants who experienced both Hurricane Katrina and the Deepwater Horizon oil spill were included in the study. The survey contained validated instruments



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such as the Communities Advancing Resilience Toolkit scale, the Connor-Davidson Resilience Scale, and the Center for Epidemiologic Studies Depression Scale. Socio-demographic information and disaster-related damages were also measured. Results indicated that cumulative disaster-related damages were related to greater depressive symptoms. Results also indicated that community resilience was indirectly related to depressive symptoms through the mediating variable of psychological resilience, such that community resilience was positively related to psychological resilience, which, in turn, was inversely related to depressive symptoms. Findings from the current study demonstrated a significant link between personal and community resilience, highlighting the importance of enhancing community resilience in disaster prone areas.

Fostering a Resilient Community: Utilizing Community Training to Restore and Strengthen Disaster-Prone Areas

J. Langhinrichsen-Rohling, C. Wornell, **C. Selwyn**, H. Finnegan
University of South Alabama, Mobile, AL

The Gulf Coast Behavioral Health and Resiliency Center (GCBHRC) at the University of South Alabama engages laypersons and professionals from cross-boundary disciplines (public health, social work, education, nursing, psychology, law enforcement, non-profit, etc.) to promote mental/behavioral health resiliency in lower Alabama. According to the U.S. Department of Health and Human Services: "Resilient communities include healthy individuals and families…with the knowledge and resources to care for themselves and others in both routine and emergency situations." Consistent with emphasis on knowledge and access to resources in building a resilient community, the GCBHRC focuses significant efforts on providing training to members of the local community related to recognition of and response to mental health needs across the lifespan. Utilization of developmentally appropriate educational programs can restore and strengthen a disaster-prone community by cultivating positive changes in the micro-system (e.g., job-relevant skill building; awareness of and attitudes toward mental/behavioral health issues and interventions; willingness to respond to mental health needs for self and others), meso-system (i.e., networks promoting social connectedness between individuals, groups, and agencies), and macro-system (e.g., increased discussion of mental/behavioral health gaps and opportunities in the community; reduced stigma regarding mental health). This presentation will highlight training opportunities offered to the lower Alabama community including Youth Mental Health First Aid (*n* = 192), Adult Mental Health First Aid (*n* = 185), the annual Generational Resiliency Conference (*n* = 349), and targeted training sessions for medical staff and school personnel (*n* = 400). Relevant research data and future directions for promoting population well-being while fostering community resiliency, disaster preparedness, and response efforts will be discussed.

Utilizing Lay Health Workers to Increase Community Resilience by Expanding Social Networks and Building Social Capital

**B. Gilliam**, S. Picou, K. Nicholls, S. McCord, A. Wood
University of South Alabama, Mobile, AL

This paper deals with the role Lay Health Workers (LHWs) can play in increasing community resilience. Previous research has demonstrated that LHWs can lower healthcare costs while improving health outcomes. This comes not only from increasing patient understanding of health issues and encouraging patient compliance with health recommendations, but also through helping patients obtain needed health and social service resources. It is important to recognize that this process establishes trusting



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relationships between LHWs and community members, which in turn, builds social capital and contributes to community resilience. These relationships can be particularly advantageous in times of crisis because the LHWs will have the legitimacy and credibility to serve as effective mediators between disaster response and recovery officials and affected communities. This advantage can be enhanced through more effective training of LHWs in disaster mitigation, preparedness, response, and recovery. In this paper, we provide a conceptual review of the utility of LHWs in both healthcare and emergency management. We present evidence of the resilience-building potential of LHWs with data on the field activities of seven Community Health Workers currently working in areas affected by the BP Deepwater Horizon oil spill. We conclude with recommendations for more effectively utilizing LHWs in emergency management through targeted training activities and by formally involving them in disaster response and recovery teams.

Developing Community Resilience through Mental and Behavioral Health Service Delivery in Integrated Settings

**J. Friend**[1], J. Langhinrichsen-Rohling[1], M. Brazeal[2], T. Rehner[3], T. Hansel[4], A. Speier[4], H. Osofsky[4], J. Osofsky[4], G. Rohrer[5]

[1]University of South Alabama, Mobile, AL, [2]Social Work, University of Southern Mississippi, Long Beach, MS, [3]University of Southern Mississippi, Long Beach, MS, [4]Louisiana State University, New Orleans, LA, [5]University of West Florida, Pensacola, FL

Building community resilience increases the probability that individuals can endure and recover from a disaster. An important element of community resilience is population health. Population health includes not only physical health but also mental and behavioral health (MBH). One way to increase a community's MBH is to provide accessible MBH services. This presentation brings together a partners from the Gulf Region Health Outreach Program's MBH Capacity Project who represent four states (LA, MS, AL, FL) affected by the Deep Water Horizon Oil Spill. Authors will address how each state is building community resilience through the development of integrated care systems and the delivery of MBH health services through two avenues: Federally Qualified Health Centers and schools. The presentation will focus on three main topics: 1) Developing and building MBH networks within FQHC's and schools. Primary care and schools are unique environments with many competing priorities. It is imperative to develop a collaborative approach focusing on the specific needs of the population setting. The authors will discuss specific strategies used to increase buy-in and develop MBH programs. 2) Methods of delivering MBH interventions. Authors will discuss clinical efforts that focus on the delivery of MBH evidence-based interventions. They will also consider challenges that occur when delivering MBH services in these unique settings. 3) Examining how integrated care and the incorporation of MBH care into FQHC's and schools, can improve preparedness response and recovery to current and future disasters. Authors will examine how the development of integrated health care systems in FQHC's and schools can increase access to and services for vulnerable populations, thus, increasing resilience during disasters. Also, successful MBH outcomes and system change through integration will lead to a more resilient community which will be better prepared to react to and recover from a disaster.



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Resilience Research in the Real World: Building Community Resilience with an Integrated Approach

**M. L. Finucane**
RAND Gulf States Policy Institute, New Orleans, LA

Environmental health problems, like large oil spills, are often characterized as “wicked problems.” That is, there are conflicting interpretations of the causes, impacts, and solutions posed for these problems. These problems test community resilience because abrupt changes within the complex socio-ecological system affected can have unexpected, cascading impacts on public health, socio-economics, and social well-being. To understand and address the human dimensions of complex problems such as the Deepwater Horizon oil spill, the Consortium for Resilient Gulf Communities adopts an integrated approach that draws on diverse scientific and decision-maker perspectives. The Consortium’s activities support and connect stakeholders, respond to stakeholder needs, generate actionable information and tools, and critically evaluate human impacts and programs or strategies designed to address those impacts. We focus on the intersection of different sectors such as health, economics, and social well-being for innovative understandings and responses. This talk will describe how the Consortium draws on diverse methods to iteratively develop context-sensitive approaches to building community resilience. We will explain how we adopt a complex systems framework to guide and link research and outreach activities in multiple domains and at multiple levels. We will discuss lessons learned for developing effective risk communications and risk management strategies that facilitate community resilience.



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## Session 012: Deepwater Horizon Oil in Coastal Environments: Observations, Experiments and Predictive Modeling

Degradation of Deepwater Horizon Oil Buried in a Florida Sandy Beach
**M. Huettel**[1], W. A. Overholt[2], J. E. Kostka[2], C. Hagan[3], J. Kaba[1], W. Wells[1], S. Dudley[4]
[1]Florida State University, Tallahassee, FL, [2]Georgia Institute of Technology, Atlanta, GA, [3]East Tennessee State University, Johnson City, TN, [4]University of California, Riverside, CA

Crude oil that spilled from the damaged MC252 Macondo well polluted approximately 970 km of sandy Gulf of Mexico beaches. The prospect that buried oil may persist in the popular beaches for decades raised concerns regarding its influence on human and environmental health and potential impacts on the economy. We present the results of a one-year time-series study that focused on the fate of the buried oil and the mechanisms controlling its degradation. Within one month after the oil had reached the Florida panhandle, petroleum hydrocarbons contaminated the white sands at Pensacola Beach in an approximately 10 m wide zone along the water line. The sedimentary community responded with blooms of hydrocarbon degraders that led to reduced microbial diversity. Early responders were dominated by aerobic Gammaproteobacteria, Flavobacteria, and Alphaproteobacteria. The microbial degradation of the buried petroleum hydrocarbons caused a steady decline of the aliphatic and aromatic hydrocarbons detectable with standard gas chromatography methods. The measurements suggest that a combination of warm temperatures and air penetration into the permeable sand promoted the rapid degradation of the buried petroleum hydrocarbons. BP's Operation Deep Clean accelerated beach recovery through removal of buried oil-sand aggregates and grinding of such aggregates, which enhanced oil surface area exposed to microbial activities. Within a year, concentrations of these compounds had decreased to levels similar to those in the uncontaminated control beach, while oxygenated oil residues persist in Gulf beaches to the present day.

Assessing the increases in background oil contamination levels along Alabama beaches six years after the DWH oil spill
**T. Clement**, G. John
Auburn University, Auburn, AL

The Deepwater Horizon (DWH) oil spill resulted in widespread contamination of Alabama's white sandy beaches. These beaches continue to be impacted by the various forms of oil spill residues that originated from the DWH oil spill. This study will primarily focus on establishing past, present and future oil background levels in Alabama's beaches. As part of this effort, we have reviewed currently available field data and have used them to develop the following set of hypotheses that are broadly used for describing the DWH oil spill related contamination problems and their impacts on Alabama's beaches: 1) the Gulf of Mexico (GOM) has several oil seeps and oil exploration wells, therefore Alabama beaches always had visible levels of background oil deposited in various forms; 2) as of June 2013, Alabama's beaches have recovered and reached a minimal contamination level, which is close to the normal background level that existed prior to the DWH oil spill; and 3) the GOM system hosts highly efficient hydrocarbon degrading microbes which should have played a significant role in rapidly degrading all of the toxic compounds, including PAHs, contained in the DWH oil. We have tested the validity of these three hypotheses based on our own field data and other published data. Based on the results of our findings we make the following two key conclusions, which we believe can also serve as revised hypotheses that better describe the current state of Alabama's beaches, and also can predict



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the future fate of the sunken DWH oil trapped near Alabama's beaches. These alternate hypotheses are: 1) the current background oil contamination levels are much higher than the relatively low (in some cases, negligible) background levels that existed prior to the DWH oil spill; also, our chemical fingerprinting data show that virtually all visible oil residues found on Alabama beaches are from the DWH oil spill; and 2) several higher molecular weight PAHs, such as chrysene and its alkylated homologs, trapped in sunken DWH oil spill residues are weathering at a much slower rate compared to the rates they were weathering over the open ocean.

Biodegradation of Deepwater Horizon oil in the Gulf of Mexico beaches

**M. Boufadel**, X. Geng
New Jersey Institute of Technology, Newark, NJ

Oil from the Deepwater Horizon blowout occupied various portions of the Gulf of Mexico beaches, and was subsequently buried by sand accretion. Under these conditions, oil biodegradation is the main process affecting the persistence of oil. Using data from various beaches in the GOMEX and the numerical model BIOMARUN, which is multiple-Monod kinetic model (BIOB) coupled to a density-dependent variably saturated groundwater flow model 2-D (MARUN), we investigated various scenarios of oil biodegradation with a focus on best case and worst case scenarios. We also dedicated a particular effort to understand how beach hydrodynamics affect oil biodegradation. It was found that different limiting factors affect different portions of the beach. In the upper intertidal zone, where the inland incoming nutrient concentration was large (1.2 mg N/L), oil biodegradation occurred deeper in the beach (i.e., 0.3 m below the surface). In the midintertidal zone, a reversal was noted where the biodegradation was fast at shallow locations (i.e., 0.1 m below the surface), and it was due to the decrease of oxygen with depth due to consumption, which made oxygen the limiting factor for biodegradation. Oxygen concentration in the midintertidal zone exhibited two peaks as a function of time. One peak was associated with the high tide, when dissolved oxygen laden seawater filled the beach and a second oxygen peak was observed during low tides, and it was due to pore oxygen replenishment from the atmosphere. The effect of the capillary fringe (CF) height in the beach was also investigated, and it was found that there is an optimal CF for the maximum biodegradation of oil in the beach. Too large a CF (i.e., very fine material) would attenuate oxygen replenishment (either from seawater or the atmosphere), while too small a CF (i.e., very coarse material) would reduce the interaction between microorganisms and oil in the upper intertidal zone due to rapid reduction in the soil moisture at low tide.

Microbial Processes in Submerged Coastal Sands Impacted with Weathered Oil

**W. A. Overholt***[1], E. Mercando[1], X. Sun[1], I. C. Romero[2], D. J. Hollander[2], K. Konstantinidis[1], M. Huettel[3], J. E. Kostka[1]
[1]Georgia Institute of Technology, Atlanta, GA, [2]University of South Florida College of Marine Science, St. Petersburg, FL, [3]Florida State University, Tallahassee, FL

An estimated 22,000 tons of weathered crude oil from the Deepwater Horizon blowout contaminated Gulf coast beaches in 2010 and deposited an unknown amount into nearshore environments, which so far has received little attention. Although DWH oil contamination was shown to impact microbial communities in intertidal and supratidal coastal ecosystems, little information is available on biodegradation and the impacts of oiling on ecosystem function in submerged coastal sediments. In this study, we employ advective-flow chambers that simulate *in-situ* pressure gradients found in



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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, (2) directly link the metabolic pathways of biodegradation to specific microbial groups, and (3) examine the controls on biodegradation activity and community succession. Incubations were conducted over a 3-month period and oxygen consumption rates as well as nutrient concentrations were monitored. At regular intervals, oil chemistry, viable cell counts, microbial metabolisms, and specific metabolic rates were determined. Initial results indicate sustained and increasing rates of respiration in oiled chambers 2 times higher than observed in controls. Viable counts indicate a significant increase in bacterial abundances in oiled chambers relative to controls that increase with time. Nitrate concentrations remain depleted in oiled chambers while a large increase up to 60 µmol/L is observed in the control chambers. Thus far, results support field data to show elevated respiration and organic matter turnover in response to oiling. Overall, our results will contribute to a comprehensive prediction on the fate, impacts, and microbial community response to buried oil in sandy subtidal coastal sediments under a "no hydrocarbon transport" regime.

Spatial Biodegradation of MC252 Crude Oil across a Coastal Headland Beach Profile

**Z. Romaine***, L. Fitch, V. Elango, J. Pardue
Louisiana State University, Baton Rouge, LA

Beach response efforts deployed hard structures to deter oil migration into sensitive marsh areas behind Fourchon Beach, LA. These hard structures created conditions for accumulation and burial of oil across an 8-foot deep beach profile. Buried oil persists in these areas due to the anaerobic conditions of groundwater on these beaches. The objectives of this field study are to compare the rate and extent of biodegradation of 3-ring alkylated PAHs in crude oil deposits from the surface and subsurface. Field samples were removed from 2011-2016 from the area consisting of oil samples from depth using a Geoprobe, oil-sand aggregates distributed over the surface of the beach, free oil floating on the groundwater surface and oil recovered during excavations used as part of response in 2013 and 2014. Weathering of PAHs was estimated based on ratios of alkylated phenanthrenes and dibenzothiophenes to poorly biodegradable alkylated chrysenes. The ratio of total phenanthrenes and dibenzothiophenes to chrysenes ranged from 0.37 to 0.93 and 0.18 to 0.71 respectively, with lowest values were observed in SRBs from the surface where O2 limitations are absent. SRBs just below the surface are less weathered, although more so than samples below the groundwater surface. In the samples removed from depth, weathering ratios were significantly higher coincident with submergence in anaerobic groundwater. Beach groundwater samples collected from wells showed high levels of sulfate (400 to 1500 mg/L) and sulfide (0.1 to 4 mg/L) coupled with non-detectable dissolved oxygen (less than 0.02 mg/L). Groundwater pH is close to neutral, alkalinity ranged from 750 to 1400 mg/L, with ammonia and phosphate levels greater than 1.0 mg/L, suggests nutrient conditions favorable for biodegradation in the subsurface. Salinities are generally hypersaline, routinely exceeding 50 ppt. Taken together, data indicate that PAH weathering is highly dependent on the vertical position of the oil aggregate in the beach profile and submergence in highly reduced groundwater.



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Am I wrong or should more work be done on the formation of oxygenated hydrocarbons?
**C. Reddy**
Woods Hole Oceanographic Institution, Woods Hole, MA

One unpredicted finding on the fate of the spilled Macondo well oil was rapid oxidation, producing a complex pool of oxidized hydrocarbons in surface slicks, rock scrapings, and oiled sands. Several analytical approaches have supported this finding. The unprecedented nature of this weathering shed new light on the fate of spilled oil in the environment. I believe it is one the most significant advances in oil-spill science in decades. While excellent work has been done in laboratory studies, there is little or no published work on field samples post 2012. Being one of the few scientists studying the oxidized hydrocarbons, I will reflect on the limited work done, other observations, and provide suggestions on how to continue to learn about the oxidized hydrocarbons.

Identification of oxygenated transformation products in weathered Deepwater Horizon oil samples and assessment of their bioaccumulation and toxicity potential
**D. Nabi**, S. Katz, C. Aeppli
Bigelow Laboratory for Ocean Sciences, East Boothbay, ME

Recent work shows that oxygenated hydrocarbons (oxHCs) are predominately formed during the oil weathering. This oxHC fraction is complex and potentially contains thousands of compounds, which poses an analytical challenge using traditional techniques. In this study, we use multistep derivatization scheme to selectively derivatize different oxygenated functionalities of oxHCs. Carbonyl oxygen, carboxylic and alcoholic groups were converted to methyl oxime, methyl ester and silyl derivatives, respectively. This not only made oxHCs amenable for the analysis on comprehensive two-dimensional gas chromatography (GCxGC) but also generated characteristic ion fragments useful for their identifications. To confirm their identities, we produced simulated GCxGC chromatograms using quantum chemical tools and compared with the observed chromatograms of oxHCs. Using this technique, we were initially able to identify several ketones, aldehydes, carboxylic acids and alcohols in weathered oil samples from Deepwater Horizon disaster. Next, we are interested to understand if the oxHCs are bioaccumulative and toxic. To answer the question, we use approaches based on the Abraham solvation model and quantum-chemical computations to estimate bioaccumulation and toxicity related properties such as bioavailability, bioaccumulation factor, baseline and excess toxicity and partitioning between biomembrane-water, lipid-water, protein-water phases. The test set includes several model oxHCs, as well as the oxHCs analytes identified in the weathered oil samples. Very preliminary results show that straight chain terminal carboxylic acids, alcohols, aldehydes and ketones with carbon chain greater than $C_{10}$ are significantly bioaccumulative and membrane toxicants (narcotics). In short, the approaches we are developing in our laboratory can give a good insight about the molecular composition and the fate and effect of oxygenated fraction of weathered oil.



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Molecular-level Insights into the Increased Toxicity of Macondo Well Oil Transformation Products
**R. P. Rodgers**[1], S. M. Rowland[2], H. Chen[1], Y. E. Corilo[2], A. M. McKenna[1], D. C. Podgorski[2], M. A. Tarr[3], P. Zito[1]
[1]National High Magnetic Field Laboratory, Tallahassee, FL, [2]Future Fuels Institute - Florida State University, Tallahassee, FL, [3]Department of Chemistry, University of New Orleans, New Orleans, LA

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. However, these changes are difficult to track at the molecular level, as the qualitative understanding of the (predominately) oxidative weathering is hampered by the immense complexity of the unaltered oil and multiplicative increase in complexity post-oxidation. Furthermore, the oxidative transformation involves multiple mechanisms (i.e. photo-oxidation, microbial alteration) and the significance of each mechanism with regards to the amount / type of products detected in field samples is nonholonomic, and thus unknown. 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. Analysis by Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR MS) exposes the compositional differences between the unaltered and transformed oil samples at a molecular-level. 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. Combined with the molecular-level information provided by FT-ICR MS, an explanation for the increased toxicity is provided. Work supported by NSF Division of Materials Research through DMR-11-57490, The Gulf of Mexico Research Initiative, Future Fuels Institute, and the State of Florida.

Assessing the contribution of photochemical processes to the formation of oxidized hydrocarbons following the Deepwater Horizon oil spill: insights from preliminary laboratory experiments
**C. Ward**, C. Reddy
Woods Hole Oceanographic Institution, Woods Hole, MA

Less than a year after the Deepwater Horizon spill, approximately 50% of oil residues (by mass) collected in the environment were comprised of oxidized hydrocarbons. While the relative importance of different weathering processes for the production of these oxidized residues remains unknown, several studies have suggested that photochemical oxidation contributes to oxidized hydrocarbon formation. Using Fourier transform infrared spectroscopy, we show that exposure of surrogate MC252 oil provided by BP to 40 hours of simulated sunlight results in greater than two orders of magnitude increase in stretching of key O-containing functional groups compared to dark controls. The spectral shape of oil photo-oxidized in the laboratory was similar to oil residues collected in the field. The intensity of O-containing functional group stretching in the photo-oxidized oil accounts for 50 to 75% of O-containing functionality stretching in a naturally weathered surface slick oil collected from the skimming vessel Juniper approximately two months following the blowout. By exposing oil to sunlight in the presence and absence of molecular oxygen, we demonstrate that the majority (> 90%) of these sunlight-derived O-containing functionalities require molecular oxygen for production. This finding suggests that photochemically formed reactive oxygen species (ROS) dependent on the presence of molecular oxygen, such as singlet oxygen, were relatively more important for the formation of oxidized



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hydrocarbons compared to ROS that can be produced in the absence of molecular oxygen, such as hydroxyl radical. These results build upon the mounting evidence that sunlight-driven processes contributed substantially to the formation of oxidized hydrocarbons following the Deepwater Horizon spill, and provide first insights into the photochemical mechanisms governing the formation of oxidized oil residues.

Effects of tropical storms in distribution and redistribution of Deepwater Horizon oil residues in the coastal Louisiana marshes

**P. L. Adhikari**, E. B. Overton, M. S. Miles, B. M. Meyer
Louisiana State University, Baton Rouge, LA

The Deepwater Horizon oil spill in the summer of 2010 resulted in significant amounts of oiling in the coastal Louisiana marshes. The lighter constituents of the crude oil were removed fairly quickly via weathering in the time from its release well offshore until the time it reached the Louisiana coastal marshes. These weathered oil residues were then either stranded on or buried within the shoreline portion of the coastal marshes. After the initial oiling, several tropical weather events (including Tropical Storm Lee in 2011 and Hurricane Isaac in 2012) crossed this area and resulted in a re-mobilization of the DWH oil residues from the initially oiled marsh shorelines. These tropical weather events caused erosion and forced oil residues farther into the marshes, and buried a portion of the oil residues more deeply within the associated soil pore space and burrows. In an effort to understand the effects of tropical storm events on the redistribution of the DWH oil residues, more than 900 sediment samples collected in 2011-2016 from the various locations in the Louisiana marshes were analyzed for relatively persistent oil components; polycyclic aromatic hydrocarbons (PAHs) and biomarker compounds (hopanes, steranes, and triaromatic steranes). The results show a significantly higher total PAHs and relatively fresh biomarker patterns in the surface sediments (top 5 cm) collected after Hurricane Isaac, indicating that a significant amount of oil residues were re-mobilized during the tropical event. In 2016, even 6 years after the spill, a significant amount of weathered oil residues that came ashore in 2010 were found buried more than 15 cm below surface in several locations, which can be attributed to the effect of tropical events or seeping of oil in porous marsh soil, potentially through fiddler crab burrows. The results of this study and the implications associated with the patchy vertical and horizontal distribution of oil residues in coastal marshes will be discussed.

Presence of Marine Snow Hampers Oil Biodegradation and Prolongs the Presence of Toxic Compounds in Marine Sediment

S. Rahsepar[1], J. van Eenennaam[1], J. Radović[2], T. Oldenburg[2], T. Murk[3], E. Foekema[4], **A. Langenhoff**[1]
[1]Wageningen University, Wageningen, Netherlands, [2]PRG, Department of Geoscience, University of Calgary, Calgary, AB, Canada, [3]Marine Animal Ecology group, Wageningen University, Wageningen, Netherlands, [4]Wageningen Marine Research, Den Helder, Netherlands

We studied the influence of marine snow on fate of the oil components on marine sediment layer through laboratory experiment. The large marine snow formation event was observed following the dispersant application during the Deepwater Horizon oil spill in the Gulf of Mexico. This marine snow facilitated the MOSSFA (Marine Oil Snow Sedimentation and Flocculent Accumulation) mechanism and contributed to transferring of almost 14% of the total spilled oil to the ocean floor. Biodegradation of oil associated marine snow that is present at the ocean floor is expected to be hampered by oxygen limitation, since marine snow degrades itself and consumes oxygen. Therefore, oil has longer residence



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and half-life, due to the slower oil biodegradation. We performed aquaria experiments in triplicates with and without artificial marine snow to study the biodegradation and toxicity of oil that is associated with marine snow and deposited on the top of a sediment layer. Experiments lasted 42 days and every week sediment samples were taken for analyses of major oil constituents, such as *n*-alkanes, aromatic compounds and biomarkers. According to our results, 73% of the *n*-alkanes were degraded in the absence of marine snow, and only 49 % in the presence of it. Reduced oxygen concentrations in the sediment layer were observed when marine snow was present. This indicates that marine snow consumed dissolved oxygen and competed with oil for the available oxygen. Further experiments with invertebrates in similar aquaria demonstrate enhanced mortality and reduced oil biodegradation due to the presence of marine snow (van Eenennaam *et al*.). Based on our results, application of dispersants in presence of algae and suspended particles followed by formation of marine snow affects the oil transport pathways in the ocean and influences oil biodegradation. This experimental study improves our understanding of chemical dispersant treated oil spill behavior and the fate of spilled oil.

Succession of Microbial Populations Linked to Surface Residual Ball Degradation in Pensacola Beach Sands Impacted by the Deepwater Horizon Oil Spill

**B. Shin***[1], M. Huettel[2], J. E. Kostka[1]
[1]Georgia Institute of Technology, Atlanta, GA, [2]Florida State University, Tallahassee, FL

The Deepwater Horizon oil spill contaminated large areas of coastline from Louisiana to Florida and oil was buried as deep as 55cm in sandy beaches. Buried oil is protected from photodegradation and mechanical erosion and thus microbial decomposition may play a key role in its degradation. Although our group and others have examined biodegradation in oiled sands and surface residual balls (SRB), the rates and mechanisms of biodegradation of buried SRBs is less clear. Thus, the main objectives of this study are (i) to determine rate of SRB degradation *in situ* in dry beach sand, (ii) to investigate the succession of microbial communities in simulated SRBs, and (iii) to monitor gene expression during SRB degradation. Replicate standardized SRBs were buried from 5 to 55cm depth in Pensacola Beach sand and sampled from October 2010 to December 2013. Microbial communities were characterized using next generation sequencing of 16S rRNA gene amplicons from SRBs sampled early and late in the time series, in January 2011 and October 2012. Results indicate pronounced change in microbial composition with time but little change with depth. All SRB samples were predominated by members of *Alphaproteobacteria* and *Gammaproteobacteria*. *Alphaproteobacteria*, *Actinobacteria*, and *Planctomycetes* were enriched, while the relative abundance of *Gammaproteobacteria* was reduced with time. A number of known hydrocarbon-degrading populations were enriched in 2011 and then declined in 2012 including *Alcanivorax*, *Marinobacter*, *Oceanibaculum*, and *Halomonas*. In contrast, known oil-degrading genera *Parvibaculum* and *Rhodococcus* increased in relative abundance from 2011 to 2012. At least a two-fold increase of relative abundance of *Rhizobiales* was detected, which implicates an enrichment of nitrogen fixing taxa. Results thus support field data, which point to a succession from early responding taxa, mainly members of the *Gammaproteobacteria* capable of alkane degradation, to other groups capable of degradation of more recalcitrant compounds such as PAHs. Overall results will help better understand persistence and impact of buried oil in Gulf Coast beaches and point to methods that could improve bioremediation.



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## Session 013: Multi-year Signatures of the DWH Oil Spill in Coastal Systems

Shoreline Recession in Barataria Bay from the Deepwater Horizon Oil Spill
**C. Jones**[1], A. Rangoonwala[2], E. Ramsey[2]
[1]California Institute of Technology, Pasadena, CA, [2]U.S.G.S. Wetland and Aquatic Research Center, Lafayette, LA

Upper Barataria Bay, Louisiana, the site of the heaviest Deepwater Horizon (DWH) oiling, experienced widespread oiling along many of its marsh margins. Here we report the results of an analysis of shoreline recession in the area based on synthetic aperture radar (SAR) starting from a year before the spill and extending for 2.5 years following the spill. The study includes a comparison of shoreline recession linked to DWH oiling that occurred over the two year period following the spill relative to storm-induced erosion that occurred from Hurricane Isaac. The study is unique in evaluating loss across nearly the entire upper Barataria Bay area and in having a baseline of annual loss for the year immediately prior to the spill. The analysis showed that shoreline recession changed following the spill in the spatial pattern of shores affected, the length of shoreline impacted, and the amount of recession that occurred along the shorelines. We document a distinctly different pattern of shoreline loss in the two years following the spill, both from that observed in the year prior to the spill, during which there was no major cyclonic storm, and from change related to Hurricane Isaac, which made landfall in August 2012. Shoreline erosion following oiling was far more spatially extensive and was more prevalent along shores experiencing heavy or medium oiling, and therefore included loss in areas protected from wave-induced erosion. We conclude that petroleum exposure can substantially increase shoreline recession particularly in areas protected from storm-induced degradation, and disproportionally alters small oil-exposed barrier islands relative to natural erosion. This work was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

Six-Year Response and Recovery of Coastal Salt Marsh Vegetation to the Deepwater Horizon Oil Spill
**Q. Lin**[1], I. A. Mendelssohn[1], S. A. Graham[2], J. W. Fleeger[1], A. Hou[1], D. R. Deis[3]
[1]Louisiana State University, Baton Rouge, LA, [2]Nicholls State University, Thibodaux, LA, [3]Atkins, Jacksonville, FL

The Deepwater Horizon oil spill exposed Louisiana's coastal shoreline salt marshes to varying degrees of oiling. To assess the long-term oil impacts and post-spill recovery, we conducted a series of field studies for six years in salt marshes of northern Barataria Bay that received heavy, moderate, or no visible oiling as a reference. Nine months after the spill, surface soil total petroleum hydrocarbon concentrations were ~70 mg $g^{-1}$ in moderately oiled marshes and >500 mg $g^{-1}$ in heavily oiled marshes, where they remained >100 mg $g^{-1}$ six years after the spill. Though the initial impacts of moderate oiling were evident, *Spartina alterniflora* and *Juncus roemerianus* aboveground biomass and total live belowground biomass recovered within 24-30 months after the spill. In contrast, heavy oiling resulted in near complete plant mortality initially, and recovery of total live aboveground biomass was <50% of reference marshes six years after the spill. Although live *Spartina* aboveground biomass in heavily oiled marshes recovered within three years, *Juncus* showed no recovery six years after the spill. Therefore, heavy oiling changed the vegetation structure from a mixed *Spartina-Juncus* community to predominantly *Spartina*. Furthermore, live belowground biomass (0-6 cm) in heavily oiled marshes was significantly reduced compared to the reference marshes. Severe impacts of heavy oiling on marsh



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plants also resulted in weaker soil shear strength compared to reference marshes, thus potentially affecting the shoreline marsh stability.

Salt Marsh Resiliency Shifts After the Deepwater Horizon Oil Spill
**G. McClenachan**[1], R. Turner[2]
[1]Coalition to Restore Coastal Louisiana, New Orleans, LA, [2]Louisiana State University, Baton Rouge, LA

The ability of an ecosystem to absorb a disturbance is directly linked to its resiliency. Humans have eroded the resiliency of Louisiana coastal marshes for centuries through pollution, canals, levees, and impoundments, resulting in extraordinarily high land loss rates. The potential for a large disturbance to cause significant additional loss to Louisiana's coastal marshes is, therefore, even more likely than in a system with uncompromised resiliency. The Deepwater Horizon oil spill was the largest marine oil spill in history, oiling over 2,000 km of shoreline along the northern edge of the Gulf of Mexico, from Louisiana to Florida. The spill had the capability to not only directly accelerate land loss via marsh grass dieoffs, but also decrease the capacity of the ecosystem to absorb a natural disturbance (e.g. hurricane). We studied erosion after the oil spill on varying spatial and temporal scales to analyze the trajectory of impact and the potential for the oil spill to leave the marsh more susceptible to damages from natural disturbances. We chronicled the effects in a southeastern Louisiana salt marsh using multiple techniques of documentation including field data collection of the marsh edge for 5 years and GIS analysis spanning 15 years. Across all scales, land loss accelerated after the oil spill for at least 1.5 years. Edge land loss was greater in the two years following the oil spill than it was in the two years following the hurricane season of 2005. The edge damage caused by the synergistic effects of the Deepwater Horizon oil spill and Hurricane Isaac was greater than any hurricane since at least 1998. The oil depleted the resiliency of the marsh, making it more susceptible to erosion precipitated by natural disturbances and leaving a land loss legacy much greater than the initial impacts

Assessing the long-term effects of Macondo oil spill on salt marshes using spaceborne multispectral and airborne hyperspectral remote sensing
**Y. Mo***, M. Kearney, J. Riter
University of Maryland, College Park, MD

The 2010 April 20 Macondo oil spill is the largest marine oil spill in recorded history, and may pose serious threats on Louisiana salt marshes. This study assesses the effects of the oil spill on the marshes using spaceborne multispectral and airborne hyperspectral remote sensing. Landsat and AVIRIS data sets (collected between 2009 and 2014 and between 2010 and 2012 and with 30 $m^2$ and 3.5 $m^2$ spatial resolution, respectively) were used to monitor the marsh conditions before and after the oil spill for six years. The study area is located in the Barataria Basin of southeastern Louisiana, where the largest amount of oil was deposited on Louisiana coastal marshes. The heavily oiled site and non-oiled site were selected based on the Shoreline Cleanup and Assessment Technique (SCAT) ground surveys performed in 2010. ENVI 4.8 software was used for remote sensing data processing, and SAS 9.4 software was used for statistical analysis. The Landsat data show that NDVIs of the heavily oiled site were significant lower than those of the non-oiled site in 2010 and 2011 ($p=0.0006$ and 0.0023, respectively). The AVIRIS data document great impact on the NDVIs of marshes in the heavily oiled site in May 2011, and substantial recovery in 2011 October and 2012 October. The AVIRIS data also suggest that the largest and most persistent impacts, not surprisingly, happened at the shoreline. Our results suggest that the major above-ground impact of the Macondo oil spill on Louisiana salts marshes



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resolvable by Landsat (30 $m^2$) lasted for two years, but finer-scaled and below-ground impacts are likely to last longer and their longevity remains to be determined.

Sustained Impacts on Louisiana Salt Marsh Soil Greenhouse Gas Fluxes Following the Deepwater Horizon Oil Spill

**B. J. Roberts**
Louisiana Universities Marine Consortium, Chauvin, LA

We quantified the effects of the Deepwater Horizon oil spill on greenhouse gas (GHG) fluxes from Louisiana salt marsh soils. Temporal patterns were assessed along transects of increasing distance from marsh edges at 4 sites (2 unoiled, 2 oiled) in Terrebonne Bay (TB) from 2012-2016. GHG fluxes showed significant seasonal and inter-annual (both in magnitude and seasonal patterns) variability. Oiled sites consistently had lower carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$) and higher methane ($CH_4$) fluxes 2-5 years post-exposure. $CO_2$ was the major driver of soil radiative balance, but $CH_4$ accounted for 33-60% of forcing in oiled compared to only 3-5% in unoiled soils. $CO_2$ (unoiled soils only) & $N_2O$ fluxes were correlated with multiple soil properties, but $CH_4$ fluxes were not. $CO_2$ fluxes increased with distance into marsh (stronger patterns in unoiled sites) whereas $CH_4$ fluxes showed different patterns in oiled (-) and unoiled (+) sites and $N_2O$ fluxes did not show a consistent pattern. Laboratory incubations of Barataria Bay (BB) soils showed $CO_2$ production was greater in unoiled marshes and comparable between *Spartina alterniflora* and *Avicennia germinans* soils; $CH_4$ production was greater in oiled marshes and *Avicennia* soils; $N_2O$ was higher in unoiled marshes and *Avicennia* soils. $CO_2$ production increased and $CH_4$ decreased with incubation salinity in TB and BB soils; $CO_2$ production increased as the magnitude of salinity manipulation increased and the slope of the $CO_2$ response was positively related to soil C, N and water content. 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.

Greenhead Horse Fly Populations as Bioindicators of the Impact of the Deepwater Horizon Oil Spill on Marsh Health and Recovery

C. Husseneder[1], J. Park[1], **L. Foil**[2]
[1]Louisiana State University Agricultural Center, Baton Rouge, LA, [2]Louisiana State University, Baton Rouge, LA

The greenhead horse fly, *Tabanus nigrovittatus* Macquart, is an excellent entomological model for coastal ecology since this species is native and tightly bound to coastal marshes of the Eastern United States. The greenhead horse fly larvae develop for 3-9 months as top invertebrate predators in the *Spartina* marsh soil and are thus vulnerable to changes in their environment. The adults are highly mobile which makes their population levels an important indicator of the health of large areas of *Spartina* marshes. Furthermore, the adults potentially are attracted to polarized surfaces like oil. Therefore, horse fly populations can serve as bioindicators of marsh health and toxic effects of oil intrusion and other environmental insults. We describe the impact of the April 2010 Deep Water Horizon oil spill in the Gulf of Mexico on tabanid population abundance and genetics as well as mating structure. Horse fly populations were sampled biweekly from oiled and unaffected locations immediately after the oil spill in June 2010 until October 2011 and again in 2016. Horse fly abundance estimates showed severe crashes of tabanid populations in oiled areas in 2010 and 2011, but appear to have rebounded in 2016. Microsatellite genotyping detected genetic bottlenecks in the majority of the



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oiled populations in 2010 and 2011 in association with fewer breeding parents, reduced effective population size, lower number of family clusters and fewer migrants among populations. These results will be compared to currently ongoing population genetic studies of 2016 samples to test whether populations have fully recovered. This is the first study assessing the impact of oil contamination at the level of a top arthropod predator of the invertebrate community in salt marshes.

Meta-Analyses of Oil Spill Impacts to Marsh Periwinkles and Fiddler Crabs

**S. Zengel**[1], J. Weaver[2], S. C. Pennings[3], D. R. Deis[4], B. Silliman[5], N. Rutherford[6], C. L. Montague[7], Z. Nixon[2], M. O. Krasnec[8], A. R. Zimmerman[7]
[1]RPI, Tallahassee, FL, [2]RPI, Columbia, SC, [3]University of Houston, Houston, TX, [4]Atkins, Jacksonville, FL, [5]Duke University, Beaufort, NC, [6]NOAA, Seattle, WA, [7]University of Florida, Gainesville, FL, [8]Abt, Boulder, CO

In order to examine impacts of the Deepwater Horizon oil spill on two important groups of salt marsh consumers and prey species (marsh periwinkle snails and fiddler crabs), collaborative meta-analyses across multiple studies were conducted to examine a larger suite of study sites, greater variability in marsh and oiling conditions across the study area, and a more complete time sequence post-spill, allowing for greater synthesis and understanding of impacts and recovery for these species. Natural Resource Damage Assessment (NRDA) and Gulf of Mexico Research Initiative (GoMRI) data sets, as well as several other sources, were jointly analyzed. The combined data set included 90-100+ sites and 4-5 years of data post-spill (to date). The meta-analyses approach allowed us to answer key questions that could not be addressed (or could not be addressed as thoroughly) by individual studies. Multi-year impacts were identified for both marsh periwinkles and fiddler crabs, although the degree, duration, and types of impacts differed by species and metrics examined. In this talk we plan to compare and contrast findings from the meta-analyses and on-going studies among these two groups of marsh species, placing them in ecological context, including post-spill recovery and possible implications for other estuarine and salt marsh species and the coastal ecosystem.

The effects of oil on blue crab (*Callinectes sapidus*) and periwinkle snail (*Littoraria irrorata*) predator-prey interactions

**E. Robinson***[1], N. Rabalais[1, 2]
[1]Louisiana State University, Baton Rouge, LA, [2]Louisiana Universities Marine Consortium, Chauvin, LA

The sub-lethal impacts of the Deepwater Horizon oil spill on marsh organisms and the impacts on predator-prey interactions are relatively unknown. Laboratory and mesocosm experiments were conducted to look at behavioral changes in blue crabs and periwinkle snails exposed to oil and how these changes affect their predator-prey relationship. Flume studies were conducted to examine how oil impacted chemosensory behavior and foraging success of blue crabs. Crabs were exposed to varying concentrations of water accommodated fractions for 48 h and placed in a flume to measure foraging time and success. Crabs were kept after the experiment for 48 h in clean seawater then re-tested. Mesocosm studies were conducted to examine periwinkle snail behavior and predator-prey interactions in the presence of buried oil. Mesocosm tanks comprised of water, sand, and *Spartina alterniflora*, were divided between two, temperature control chambers. The two chambers divided the experimental treatments (oil vs. no oil). In each chamber, half of the tanks contained only snails, while the other half contained snails and (one) crab. Over 96 hours, the climbing behavior of snails and the survival of the snails from blue crab predation ere measured. Blue crabs exposed to oil took longer to



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detect prey and were less successful in foraging than control crabs in the flume study indicating chemosensory function was altered. Crabs regained their chemosensory behavior after exposure to clean seawater. Snails exposed to oil climbed less high on *Spartina* grasses than unexposed snails. This caused snails to become more susceptible to blue crab predation. Crabs in the mesocosm were able to forage upon oil exposed snails, but did so using visual cues instead of chemosensory cues.

Analysis of Long-term Datasets Indicates Heterogeneous Impacts Resulting from the Deepwater Horizon Accident on Nekton in the Northern Gulf of Mexico

**C. Martin**[1], J. Valentine[2], S. Alford[2], T. Spearman[3]
[1]University of Florida, Cedar Key, FL, [2]Dauphin Island Sea Lab, Dauphin Island, AL, [3]University of South Alabama, Mobile, AL

Among the greatest of the challenges scientists face is determining the relative effects of natural and anthropogenic disturbances on ecosystem structure even more so because of the paucity of long-term monitoring efforts that span the occurrences of both forms of disturbance. Here, we report on the results of such an effort to separate the relative impacts of the Deepwater Horizon (DWH) accident, and earlier natural disturbances, on nekton in the northcentral Gulf of Mexico. Specifically, we used two state and federal databases (1999-2014), and our intensive sampling efforts (2010-2012), to assess the impacts of the DWH accident on these consumers in the region's inshore and offshore waters. Results from these analyses detected significant changes in the relative abundances and biomasses of most of these organisms beginning in 2010 offshore, where oiling was heaviest, which persisted through 2014. Importantly, no such shifts were detected in the region's inshore waters where oiling was intermittent. We found no evidence of lasting impacts from natural disturbances (i.e., freshets or hurricanes) in the region. These results provide evidence that longer-term impacts of the DWH accident on higher order consumers were limited to offshore waters of the northcentral Gulf of Mexico.

Quantifying Trophic Interactions in Louisiana Salt Marshes by Combining Stomach Content, Stable Isotope, and Fatty Acid Approaches

**P. C. Lopez-Duarte**[1], K. W. Able[1], F. J. Fodrie[2], C. M. Martin[3], C. Noji[4], J. A. Olin[5], J. Pincin[4], M. J. Polito[6], B. J. Roberts[7], O. P. Jensen[4]
[1]Rutgers University Marine Field Station, Tuckerton, NJ, [2]University of North Carolina at Chapel Hill, Morehead City, NC, [3]University of Florida, Cedar Key, FL, [4]Rutgers University, New Brunswick, NJ, [5]Stony Brook University, Stony Brook, NY, [6]Louisiana State University, Baton Rouge, LA, [7]Louisiana Universities Marine Consortium, Chauvin, LA

Multiple studies conducted as a result of the 2010 Deepwater Horizon Oil Spill (DHOS) indicate that oil impacts on marsh species vary widely among taxonomic groups. While some groups have exhibited negative responses, no change, or positive responses have been reported for others. These findings have greatly informed our awareness of oil impacts, but have also highlighted the knowledge gaps in our understanding of the impacts of environmental stressors on salt marsh food webs and of the assessments of potential restoration efforts. To be better equipped to measure significant alterations in salt marshes, such as changes in energy flow pathways and reduced resilience that result from environmental stressors, our objective was to first quantify trophic interactions in these systems. Our sampling effort focused on a marsh site in Bay Batiste, near an area directly impacted by the 2010 DHOS, and one located in a more sheltered location near Bay Sansbois, LA. Tissue samples from terrestrial and aquatic primary producers and primary and higher-level consumers (e.g., mollusks,



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crustaceans, and piscivorous fishes) were collected during the spring and fall of 2015. Diets and food web connections were quantified through a combination of three approaches. Stomach contents provided snapshots of fish diets at a single point in time. In contrast, stable isotopes and fatty acids reflected consumer diets averaged over weeks to months. Stable isotopes were analyzed to identify carbon sources ($\delta^{13}C$), estimate consumer trophic level ($\delta^{15}N$), and determine the relative use of terrestrial, estuarine and marine resources ($\delta^{34}S$). Fatty acids provided a greater taxonomic resolution of diet items. The combination of these three techniques provides a more robust approach to quantifying trophic relationships than any of these methods alone. Therefore, predator diets were estimated using mixing models. These findings will eventually inform and parameterize an ecosystem model under development.

Reconciling the disconnect between individual- and population-level responses to contamination in Seaside Sparrows

**P. C. Stouffer**[1], S. Woltmann[2], C. Bergeon Burns[3], A. Bonisoli Alquati[4], M. E. Hart[2], S. S. Taylor[1]
[1]Louisiana State University AgCenter, Baton Rouge, LA, [2]Austin Peay State University, Clarksville, TN, [3]Indiana University, Bloomington, IN, [4]California State Polytechnic University, Pomona, CA

Seaside Sparrows provide a study system for examining how the Deepwater Horizon oil spill affected individuals and populations for a species that links marine and terrestrial systems in salt marshes. These common sparrows spend their entire lives in salt marshes, feeding on seeds, arthropods taken from foliage, and marine invertebrates gleaned from the marsh substrate. Seaside Sparrows were contaminated by oil, as revealed by isotopic evidence of oil in sparrow tissue. Birds in contaminated marshes showed elevated expression of CYP1A, a gene involved in response to PAHs. A more extensive analysis of gene expression revealed enhanced activity of genes involved in DNA repair and apoptosis (programmed cell death) in birds from contaminated marshes. Even so, these individual-level responses did not generate sustained demographic consequences on our study plots or broader population-level effects that could be attributed to contamination. Sparrow abundance on our study plots may have been related to plot oiling, but weather events also had a strong influence on both sparrow abundance and potential for contamination. Although nest success was consistently lower on oiled plots, the vast majority of nests failed on all plots. Oil likely had significant negative consequences for birds living and nesting on the edges of contaminated marsh, but we suggest two reasons that population-level effects were difficult to detect. First, storm events led to redistribution of sparrows on the marsh. Second, the large population of Seaside Sparrows in south Louisiana (over 500,000 birds) overwhelmed the local effects of contamination. Similar results might be expected for other ubiquitous, mobile species.

Multi-year Metagenomic Assessment of Coastal Marsh Microbial Communities Impacted by the Deepwater Horizon Oil Spill

**X. Jiang**, A. Paterson, A. S. Engel
University of Tennessee, Knoxville, TN

Coastal salt marshes are vulnerable ecosystems that can undergo long-term impacts from anthropogenic events, such as oil spills. Although previous research suggests that microbial communities in the Gulf of Mexico shifted in response to oil from the Deepwater Horizon spill within a short period of time (on the order of months), the potential functional effects of long-term environmental stressors due to oiling of marsh soils (on the order of years), such as vegetation die-off,



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vegetation species changes, and land loss due to erosion, on microbial communities remain understudied. In this study, microbial community assemblages and functional diversity were investigated from a salt marsh near Port Sulphur, Louisiana, from 2010-2015. 16S rRNA gene amplicon and metagenomic sequencing was done by using sediment samples collected from the marsh edge from 0-2 cm depth before oil reached the marsh (spring 2010), at peak oil contamination (fall 2011), and after oil contamination was no longer detected in the marsh (spring 2014 and spring 2015). Through time, microbial assemblages correlated to annual changes in hydrocarbon concentrations, including even ($nC_{14}$, $nC_{18}$) and odd *n*-alkanes ($nC_{13}$, $nC_{19}$ - $_nC_{23}$), and some PAHs (C2-Pyrene, Chrysene, and Benzopyrene). Relative abundances of previously described hydrocarbon-degrading bacteria (*e.g.*, Proteobacteria, Actinobacteria) and archaea (*e.g.*, Euryarchaeota) increased with higher hydrocarbon concentrations in 2011 and 2014, and still persisted in 2015, despite the decrease in their abundance as hydrocarbon concentrations returned to background (2010) levels. Five years after the oil spill, these results suggest the marsh microbial communities exhibit a discontinuous regime shift, such that community compositions and functions shifted to an alternative "stable" state rather than reverted to the original equilibrium. Evaluating the microbial community functional diversity in this way will aide in future food web analyses.

Multi-year Patterns in Community Composition of Ammonia-Oxidizers in Louisiana Salt Marshes Following the Deepwater Horizon Oil Spill

**A. Bernhard**[1], A. Giblin[2], B. Roberts[3]
[1]Connecticut College, New London, CT, [2]Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA, [3]Louisiana Universities Marine Consortium, Chauvin, LA

We analyzed community composition of ammonia-oxidizing archaea (AOA) and bacteria (AOB) in three regions of Louisiana salt marshes that were impacted by the Deepwater Horizon oil spill to determine potential impacts of the spill, and also provide baseline data on nitrifiers in the Gulf of Mexico. Sediment samples (0-5 cm) were collected from oiled and unoiled marshes in July over 4 years (2012-2015) in Terrebonne (TB), western Barataria (WB) and eastern Barataria (EB) Bays. AOA and AOB communities were assessed by DNA fingerprints (TRFLP) of ammonia monoxygenase (*amo*A) genes. Differences in AOA and AOB communities were related to region and year, but could not be attributed to oil. Both AOA and AOB communities showed annual and regional differences. In the AOA communities, regional differences decreased over the 4 years. Additionally, samples in 2013 and 2015 showed increased abundance of low-abundance AOA populations relative to 2012 and 2014, suggesting a potentially important role of non-dominant populations under certain conditions. AOB communities were more variable compared to AOA, and communities at WB were significantly different from TB and EB, and these differences increased over the 4 years. Increased Mississippi River flow or impacts from Hurricane Isaac in September 2012 may be partially responsible for community shifts. Differences among the regions and sampling years suggest that AOA and AOB communities in Louisiana salt marshes respond differently to environmental drivers, and show differences in their resilience after a disturbance, with AOA communities showing greater resilience compared to AOB communities.



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Specificity of bacterial communities to dominant standing vegetation in coastal salt marshes, Bay Sansbois and Bay Batiste, Louisiana

**A. S. Engel**[1], A. T. Paterson[1], K. Boling[1], B. Roberts[2]
[1]University of Tennessee-Knoxville, Knoxville, TN, [2]Louisiana Universities Marine Consortium (LUMCON), Chauvin, LA

Previous research reveals that soil bacterial communities in coastal salt marshes in southern Louisiana shifted as a consequence of contamination from the Deepwater Horizon oil spill. But, years after oiling and return to 2010 conditions, soil bacterial communities continue to change. Causes for these shifts, whether due to natural or anthropogenic stressors, remain unclear. One of the noticeable transformations in some of these marshes since 2010 has been to the relative proportions of dominant vegetation, and even the replacement of *Spartina alterniflora* by *Juncus roemerianus*, *Distichlis spicata*, and *Spartina patens*. For this study, we tested the hypothesis that temporal changes in soil bacterial community compositions are due to these vegetation shifts. We established three quadrats within each of the four vegetation types in two coastal salt marshes, one near Bay Sansbois and one in Bay Batiste. Above and belowground biomass was quantified within each quadrat, and surface soil cores were collected to assess bacterial communities and to determine soil bulk density, water and organic matter content, organic C, total N, and total P concentrations, as well as porewater and extractable nutrient concentrations. Unique and shared taxonomic groups from 16S rRNA gene sequences were compared using multivariate statistical approaches to evaluate inter-/intra- site and vegetation community compositions. Soil communities at each marsh location were distinct from each other. But, regardless of location, soil bacterial communities from *J. roemerianus* and *S. alterniflora* were more similar, and communities from *D. spicata* and *S. patens* were more similar. As such, vegetation shifts through time are likely detectable at the bacterial level. These results emphasize the importance of interpreting the entire marsh landscape from multi-year datasets when trying to understand changes in organic matter quality and quantity and rates and types of biogeochemical processes in coastal salt marshes.

Weathering of the Macondo Oil during six years in Louisiana's coastal Marshes

**E. Overton**, S. Miles, B. Meyer, G. Olson, P. Adhikari
Louisiana State University, Baton Rouge, LA

The Macondo well blowout spewed oil and natural gas into the Gulf of Mexico over a 87 day period during the late spring and summer of 2010. Significant quantities of this oil were dispersed in the deep Gulf waters, and oil that arose to the surface was subjected to a series of compositional changes associated with environmental weathering. Since the oil was classified as a “light sweet crude”, the most dominate initial weathering processes were dissolution and evaporation. Surface oil was further weathered offshore by wind and wave action and mixed with Gulf water to form an oil-in-water emulsion. Some of this emulsified weathered oil came ashore along the barrier islands and into coastal marsh areas of Barataria Bay. This emulsion was deposited along the first 10 to 30 meters of marshy shoreline during May through July of 2010. Subsequent storms and other weather events re-suspended some of the stranded oil and redistributed it into areas not initially oiled. The chemical composition of the stranded oil began to be further changed by weathering processes dominated by mostly microbial degradation. These weathering compositional changes initially removed the lower molecular weight components of the oil, which increases the viscosity of the stranded oil residues and consequently slowed further weathering. However, the stranded oil was also subjected to continual high tide washing with muddy coastal waters and agitation by storm events. Thus, oil residues on the surface of coastal marshes continued to weather while the composition of the oil buried in anaerobic zones below



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the marsh's surface changes very little with time. Thus, the routes of exposure for the coastal benthic and faunal communities to the oil residue's toxic substances changed with time and burial location within the marsh. Initial routes of exposure coastal marshes included dissolution of the lower molecular components while subsequent routes of exposure were through ingestion of particulate matter and or exposure to microbial degradation byproducts. We will discuss the chemical compositional changes of coastal oil residues, and discuss what these changes can imply about oil's impacts and its disposition in the marsh environments.

A Computationally-Efficient Spatially-Distributed Model for Wave-Driven Marsh Edge Retreat

**G. Mariotti**
Louisiana State University, Baton Rouge, LA

Retreat of the marsh edge by wave attack has been recently recognized as a major driver for permanent marsh loss. Developing a robust modeling framework for marsh edge retreat would help understanding how disturbances such as reduced sediment supply, relative sea level rise, and oiling affect this process of marsh loss. Compared to marsh vertical dynamics, modeling marsh edge retreat remains a computational challenge. Here I propose a probabilistic method for marsh edge erosion that does not require sub-grid processes. The model uses a rectangular grid, with a cell size equal to 30 m to allow for direct comparison with existing maps of marsh loss. Cells are distinguished between marsh and mudflats based on their elevation. The wave field is computed with a simplified model that accounts for the mudflat geometry and bathymetry, as well as the wind speed and direction distribution. The elevation of each marsh and mudflat cell is evolved by simulating the inorganic sedimentation, organic sedimentation, wave resuspension and relative sea level rise. In addition, marsh boundary cells are converted to open water with a probability that is related to the retreat rate, which is set function of the wave power at the marsh edge. This method converges toward a continuous retreat process for time windows such that the cumulative retreat is larger than the cell size, which for the study case is about 50 years. The model is applied to Terrebonne Bay and Barataria Bay (LA), and it is used to investigate the asymmetry in wave erosion between north- and south-facing marshes. The simplicity of the model makes it suitable for coupling with other existing models of marsh hydrology and ecology.

Effects of Mississippi River Diversions on Hydrodynamics and Surface Oil Transport in the Northcentral Gulf of Mexico

**D. Justic**, L. Wang, H. Huang
Louisiana State University, Baton Rouge, LA

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 current Davis Pond and Carnarvon 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



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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 and estuarine-shelf exchanges, which in turn could profoundly influence surface oil transport pathways in the Northcentral Gulf of Mexico.



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## Session 014: Circulation, Mixing, and Ecosystem Responses to River Discharge Patterns

Observed surface circulation and pathways over the Mississippi Bight with High Frequency Radars compared with *in situ* measurements, model output and remote sensing

**S. D. Howden**[1], M. K. Cambazoglu[1], J. W. Book[1], I. M. Soto[1], S. M. Parra[2], R. Arnone[1], G. Jacobs[3], T. Miles[4], L. Hode[1]

[1]University of Southern Mississippi, Stennis Space Center, MS, [2]3American Society of Engineering Education Research Associate at Naval Research Laboratory, Stennis Space Center, MS, [3]The Naval Research Laboratory at Stennis, Stennis Space Center, MS, [4]Rutgers University, New Brunswick, NJ

The Central Gulf of Mexico Ocean Observing System (CenGOOS) operates three long-range CODAR High Frequency Radar (HFR) stations that measure surface currents over much of the Mississippi Bight, and a met-ocean and ocean acidification buoy at 30.0423 °N 88.6473 °W. These data have been utilized for addressing the science questions posed by the CONsortium for oil spill exposure pathways in COastal River-Dominated Ecosystems (CONCORDE). The radar covers the CONCORDE study region offshore of the 20 m isobath, and the buoy is moored within the study region. A prior climatology of the CODAR data showed surface current variability and seasonal surface circulation changes that vary onshore/offshore flow pathways, which would cause associated changes in surface oil transport pathways on a seasonal basis. A four-year surface current climatology will be presented and compared with that from the Navy Coastal Ocean Model at 1 km resolution. Surface currents and anomalies from climatology during the CONCORDE field campaigns will be presented and analyzed in the context of the *in-situ* measurements, model output, and remote sensing products.

Observed cross-shelf transport and flow structure to the east of the Mississippi River Delta

**J. W. Book**[1], S. M. Parra[2], S. D. Howden[3], M. K. Cambazoglu[3], T. Miles[4]

[1]U.S. Naval Research Laboratory, Stennis Space Center, MS, [2]American Society of Engineering Education Research Associate at the U.S. Naval Research Laboratory, Stennis Space Center, MS, [3]The University of Southern Mississippi, Stennis Space Center, MS, [4]Rutgers University, New Brunswick, NJ

As part of the CONsortium for oil spill exposure pathways in COastal River-Dominated Ecosystems (CONCORDE), five bottom-mounted acoustic Doppler current profilers (ADCPs) were deployed to the east of the Mississippi River Delta for six months from November 2015 through April 2016. One of the purposes of this observation array was to observe cross-shelf transport and flow patterns to gain a better understanding of potential oil pathways to the coast near a major river outflow. During much of the deployment period the Mississippi River was at historically high levels, especially for winter, because of heavy rainfall throughout the drainage basin. At the mooring sites, the semi-major axis values of the standard deviation ellipses of the flow were 4 to 13 times stronger than the mean flow values. The flow variances followed the local bathymetry at the two moorings farthest from the Delta, but the other three moorings had flow variance directions tilted towards the coast by as much as 32 degrees from local isobath directions. These three mooring sites also had weak mean depth-averaged flows toward the coast (northeastward or northwestward) with a maximum average speed of only 4 cm/s. The average flow toward the coast was nearly unidirectional with depth, ranging from near zero at the bottom to a peak average flow of 6 cm/s at 20 m below the sea surface. However, the upper 5 m of the water column cannot be observed by these ADCPs due to the surface acoustic interference zone. Along-slope mean flows were typically towards the northeast in the upper water column (peak of 8



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cm/s at 20 m below the surface) and towards the southwest near the bottom. Several stations suggest that along-slope flow is turning towards the southwest in the uppermost layer above the level of the ADCP observations. These observations will be examined within the scope of particular river flood discharge peaks and wind storms to further quantify cross-shelf transport and potential pathways of oil toward the Louisiana and Mississippi coasts.

Cross-Shelf Exchange and Transport in Northern Gulf of Mexico studied with Navy Coastal Ocean Model, NCOM

**M. K. Cambazoglu**[1], C. Pan[1], S. M. Parra[2], I. M. Soto[1], S. D. Howden[1], J. D. Wiggert[1], R. A. Arnone[1], J. W. Book[3], G. A. Jacobs[3], S. O'Brien[1]
[1]University of Southern Mississippi, Stennis Space Center, MS, [2]American Society of Engineering Education Research Associate at Naval Research Laboratory, Stennis Space Center, MS, [3]Naval Research Laboratory, Stennis Space Center, MS

Knowledge of circulation and dynamic patterns on the northern Gulf of Mexico shelf during possible future oil spill events is critical for management and protection of our coastal ecosystems. For this purpose, this study investigates the spatial patterns and seasonal variability of cross-shelf transport in the Mississippi Bight region. It is important to know the multi-layer flow dynamics, onshore/offshore advective influences and transport pathways of not only the surface waters but also the mid-layer and bottom waters across the shelf. The three dimensional model fields of a 1-km resolution Gulf of Mexico application of the Navy Coastal Ocean Model are being analyzed and used to improve the understanding of cross-shelf interactions, warm-water and cold-water intrusions at the surface, mid-layers, and the bottom, respectively. These physical mechanisms play an important role in biogeochemical connectivity of the coastal ecosystem. The modeled current fields will be coupled with satellite ocean color data to assess the surface transport pathways of biomass fluxes. At depth, the vertical variation of model fields along selected isobaths is studied to understand the multi-layer transport and exchange across the shelf. The extent of the freshwater plume transport from the Mississippi River as well as from Mobile Bay and Mississippi Sound onto the shelf was observed as part of the field work program of CONsortium for oil spill exposure pathways in COastal River-Dominated Ecosystems (CONCORDE). Data from five bottom-mounted acoustic Doppler current profilers (ADCPs), deployed to the east of the Mississippi River birdfoot delta, is being used as a validation for the model.

Circulation, Transport, and Exchange Variability in the Northern Gulf of Mexico Continental Shelf

**J. D. Wiggert**[1], M. S. Dinniman[2], P. J. Fitzpatrick[3], Y. Lau[3], C. Pan[1], E. E. Hofmann[2]
[1]The University of Southern Mississippi, Stennis Space Center, MS, [2]Old Dominion University, Norfolk, VA, [3]Mississippi State University, Stennis Space Center, MS

As part of CONCORDE, a circulation model based on the Regional Ocean Modeling System/Coupled-Ocean-Atmosphere-Wave-Sediment Transport Modeling System has been implemented for Mississippi Sound and the adjacent continental shelf region. The model uses 400-m horizontal resolution, 24 vertical layers, and includes wetting/drying capability to resolve shallow inshore regions. The circulation model was spun-up using oceanographic initial and lateral boundary conditions provided by the Navy Coastal Ocean Model 1-km Gulf of Mexico model and atmospheric forcing provided by North American Regional Renalysis products. The resultant circulation fields were used as initial conditions for simulations done with high-resolution atmospheric forcing fields, which are focused on particular time periods. These simulated circulation distributions show exchange between Mississippi Sound and the



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adjacent continental shelf. To quantify this exchange, Lagrangian drifters were embedded in the circulation fields and tracked. The simulated drifters provide estimates of primary transport pathways, residence times and their variability. Additional simulations that include a tracer provide quantitative estimates of exchange between the Sound, inner shelf and shelf waters. The exchange patterns have implications for potential oil spill pathways, biophysical interactions and biogeochemical variability.

Remote estimation of surface $pCO_2$ on the West Florida Shelf

**S. Chen***[1], C. Hu[1], R. Byrne[1], L. Robbins[2], B. Yang[3]
[1]University of South Florida, St. Petersburg, FL, [2]U.S. Geological Survey, St. Petersburg, FL, [3]University of Washington, Seattle, WA

Surface $pCO_2$ data from the West Florida Shelf (WFS) have been collected during 25 cruise surveys between 2003 and 2012. The data were scaled up using remote sensing measurements of surface water properties in order to provide a more nearly synoptic map of $pCO_2$ spatial distributions and describe their temporal variations. This investigation involved extensive tests of various model forms through parsimony and Principal Component Analysis, which led to the development of a multi-variable empirical surface $pCO_2$ model based on concurrent MODIS (Moderate Resolution Imaging Spectroradiometer) estimates of surface chlorophyll *a* concentrations (CHL, mg $m^{-3}$), diffuse light attenuation at 490 nm (Kd_Lee, $m^{-1}$), and sea surface temperature (SST, °C). Validation using an independent dataset showed a $pCO_2$ Root Mean Square Error (RMSE) of < 12 µatm and a 0.88 coefficient of determination ($R^2$) for measured and model-predicted $pCO_2$ ranging from 300 to 550 µatm. The model was more sensitive to SST than to CHL and Kd_Lee, with a 1 °C change in SST leading to a ~16 µatm change in the predicted $pCO_2$. Application of the model to the entire WFS MODIS time series between 2002 and 2014 showed clear seasonality, with maxima (~450 µatm) in summer and minima (~350 µatm) in winter. The seasonality was positively correlated to SST (high in summer and low in winter) and negatively correlated to CHL and Kd_Lee (high in winter and low in summer). Inter-annual variations of $pCO_2$ were consistent with inter-annual variations of SST, CHL, and Kd_Lee. These results suggest that surface water $pCO_2$ of the WFS can be estimated, with known uncertainties, from remote sensing. However, while the general approach of empirical regression may work for waters from other areas of the Gulf of Mexico, model coefficients need to be empirically determined in a similar fashion.

Bio-optical Water Mass Classification of the Mississippi Bight Region: Coupling High Resolution Satellite Data, Circulation Models and in situ Optics

**I. M. Soto**[1], R. Arnone[1], A. Weidemann[2], M. K. Cambazoglu[1], S. Howden[1], A. Boyette[1], D. Joung[1]
[1]University of Southern Mississippi, Stennis Space Center, MS, [2]Naval Research Laboratory, Stennis Space Center, MS

The Mississippi Bight is a convergence zone from multiple rivers, submarine groundwater discharge (SGD) and offshore Gulf of Mexico waters. Although both the freshwater outflow and offshore water intrusions play an important role in determining the circulation, as well as the transport and fate of pollutants such as an oil spill, they are not well understood in this system. To better characterize the transport pathways and freshwater sources across the Mississippi Shelf, we determined inherent and apparent optical properties among water masses by coupling *in situ* optical data, ocean color satellite data and circulation model outputs. For this analysis, we used a comprehensive data set of *in situ* optics, CTD sensors, and conservative chemical tracers collected during a series of CONCORDE



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(Consortium for oil spill exposure pathways in Coastal River Dominated Ecosystems) cruises between October 2015 and April 2016, including a cruise to address the Bonnet Carré Spillway opening in February 2016. The *in situ* optics and CTD data were collected using ship flow-through systems and the ScanFish Remotely Operated Towed Vehicle (ROTV). Satellite Ocean Color Data from the VIIRS sensor and model outputs from the 1km NRL NCOM Model were coupled with the field data to validate and extend our spatial coverage. The results show how the light properties change between the major freshwater sources (Mobile Bay, SGD, and Mississippi River Discharge) and offshore waters, and within the water column. The goal is to develop an optical water mass classification scheme using field measurements with several satellite and model products to define the freshwater plumes outflow in the Mississippi Bight region.

Boundary Mixing along the Northern Deep Water Gulf

**K. Polzin**[1], Z. Wang[2], A. Ruiz Angulo[3], J. Toole[1], S. DiMarco[4]
[1]Woods Hole Oceanographic Institution, Woods Hole, MA, [2]NOAA, Silver Spring, MD, [3]Universidad Nacional Autonoma de Mexico, Mexico City, Mexico, [4]Texas A&M, College Station, TX

An anthropogenic tracer reported in Ledwell et al. (J. Geophys. Res. Oceans, 2016) was released in 2012 above the continental slope of the Northern Deepwater Gulf of Mexico. Sampling after 4 months returned an average interior diapycnal diffusivity estimate of $1.3 \times 10^{-4}$ $m^2$ $s^{-1}$. Sampling at one year returned a background interior mixing rate an order of magnitude smaller, $1.5(+- 0.5) \times 10^{-5}$ $m^2$ $s^{-1}$, and an inference that the 4 month estimate is dominated by a boundary process. Ancillary data taken during the 1-year sampling cruise did not reveal mixing sufficient to explain the tracer dispersion (Polzin et al., JGR submitted). Polzin et al. hypothesized that the inferred boundary mixing could result from form drag connected with large amplitude but relatively infrequent low-frequency flows over rough topography situated on the continental slope of the Northern Gulf. This resulted in GoMRI funding of a three year long field program referred to as GoMIX to provide direct estimates of mixing. GoMIX is a collaborative project between Texas A&M and Woods Hole Oceanographic Institution. The A&M provided a microstructure equiped glider and two moorings, WHOI's contribution is the development and use of a third-generation free-fall fine- and microstructure profiler, the High Resolution Profiler (HRP3).

In this talk we will present results from the first year's effort obtained in September 2016. These efforts were centered just east of Mississippi Canyon. Near-bottom flow speeds where typically 0.1-0.2 m $s^{-1}$ above topography having rms variability of *O*(40) m. An initial characterization of the data set suggests both propagating (lee waves) and non-propagating responses appear in the data set, with both states supporting enhanced near-boundary mixing. The talk will focus on quantifying this enhancement relative to that required to explain the tracer dispersion reported in Ledwell *et al*.

In terms of practical implications, the hypothesized linkage of a strong dependence of diapycnal mixing on near-bottom velocity, a direct connection of near-bottom velocity in response to extreme atmospheric events or large eddies and the propensity of extreme events to be correlated with the destruction of petroleum industry related infrastructure implies the fate of blow-out related hydrocarbons could be highly dependent on our results.



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Evaluating turbulence measurements around the Deepwater Horizon spill site from a microRider mounted on different platforms (glider, tethered VMP and CTD rosette)

**Z. Wang**[1, 2], S. DiMarco[3], K. Polzin[4]

[1]NOAA National Centers for Environmental Information, Silver Spring, MD, [2]UMD/ESSIC/CICS, College Park, MD, [3]Texas A&M University, College Station, TX, [4]Woods Hole Oceanic Institute, Woods Hole, MA

One of the fundamental and most difficult problems of oil spill research is quantifying the role of mixing and diffusion of constituent properties (e.g. oil/gas hydrate). On the continental shelf and slope, turbulence plays a critical role in determining overall water mass exchange through its frictional and mixing effects, particularly in the surface and bottom boundary layers. To quantify the intensity of turbulence and to future investigate the role of mixing and diffusion, we have conducted several observational efforts that making direct measurements of turbulence (micro-structure) and fine structure around the Deepwater Horizon spill site on the continental shelf and slope of the northern GoM in the past four years, which were all as part of GOMRI funded projects. These include three GISR cruises (2013, 2014, 2015) and one GoMix cruise (2016). The instrument we used to make direct turbulence measurements is a microRider, which equipped with two shear probes, two fast-response thermistors, one micro-conductivity sensor and one two-dimensional accelerometer. The microRider has been utilized in different ways. It was first mounted on a CTD rosette in 2013 and then was converted to a tethered self-contained vertical microstructure profiler (2014 and 2015). Most recently, it was integrated with a 1000m-rated Slocum glider and tested during the Sep 2016 GoMix Cruise. In this presentation, we will overview these turbulence measurements conducted in the past four years and discuss advantages and disadvantages of these approaches. Specific focuses will be on the results from the glider turbulence measurements collected during the 2016 Sep Cruise. Finally we will use the data collected to characterize the turbulent field in the northern GoM and examine the relationship of turbulence to the diffusion and entrainment of active contaminant constituents (e.g. oil/gas hydrate) that have their own motions (e.g. terminal rise velocity).

Influence of Estuarine-exchange on the Coupled Bio-physical Water Column Structure during the Fall Season on the Alabama Shelf

**B. Dzwonkowski**[1], C. Briseño-Avena[2], A. L. Deary[3], A. T. Greer[4], I. Soto Ramos[4], M. K. Cambazoglu[4], F. J. Hernandez[3], J. D. Wiggert[4], P. J. Fitzpatrick[5], S. Dykstra[1]

[1]University of South Alabama, Dauphin Island, AL, [2]Oregon State University, Corvallis, OR, [3]University of Southern Mississippi, Ocean Springs, MS, [4]University of Southern Mississippi, Stennis Space Center, MS, [5]Mississippi State University, Mississippi State, MS

The coastal zone is characterized by having strong horizontal and vertical gradients in physical and geochemical properties that can exert a significant influence on the associated biological patterns. These gradients can be particularly strong around regions of estuarine-shelf exchange and can potentially lead to enhanced interactions between oil and organism aggregations in the event of a spill. Physical and biological data from an across-shelf transect due south of Main Pass, Mobile Bay, Alabama, in conjunction with regional time series data were used to determine the relative importance of estuarine-shelf interactions on the physical-biological structuring of the shelf environment during fall conditions (i.e. well-mixed, low discharge period). The period was characterized by a relatively unique weather-event associated with the remnants of Tropical Storm Patricia. The system response to the resulting physical forcing characteristics were similar to that of a cold-front passage, providing a good representation of typical fall/winter/spring regional atmospheric forcing. Despite the strong atmospheric forcing, the offshore extent of the estuarine-shelf exchange was highly localized. The



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limited impacts on shelf hydrographic structure were a result of the seasonal conditions with low river discharge and high winds that constrained the estuarine signal on the shelf. Estuarine discharge was linked to the horizontal and vertical structuring of the biological patterns on the inner shelf. The highest zooplankton counts and marine snow levels were collocated within regions of low density across the entire survey period. Additionally, an usually large bloom event of trichodesmium was concentrated in a shallow lens of fresher water 10's of km offshore of the barrier islands. While the survey was preceded by a severe weather-event, the temporal patterns in the biology data were consistent with an advection event and a potential community shift in freshwater plumes advected offshore.

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

**S. J. Warner**[1], S. M. Parra[2], J. W. Book[2], C. Briseno-Avena[3], J. N. Moum[1]
[1]Oregon State University, Corvallis, OR, [2]US Naval Research Laboratory, Stennis Space Center, MS, [3]Hatfield Marine Science Center, Oregon State University, Newport, OR

River plumes in the coastal ocean can affect the underlying and surrounding shelf waters by introducing nutrients, insulating deep water from the wind, subducting surface water, and creating shear forces that lead to increased subsurface turbulence. In this study, a week-long 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-funded research consortium that focuses on the impact that oil spills can have on coastal river-dominated ecosystems. Surface-to-bottom temperature, salinity, velocity, optical backscatter, fluorescence, and turbulent microstructure were all measured along a repeated 26 km, arc-shaped transect. In addition, 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 forcing. We not only quantify the propagation characteristics of the plume fronts, but we also look at how plume fronts and winds affect turbulence on subsurface pycnoclines in order to understand vertical and horizontal transport pathways for nutrients, plankton, and oil. Here, we describe the physical state of the system. The biological response to these changing physical conditions is examined in a companion study also submitted to this session.

Turbulence Microstructure in Coastal River Plumes: Measuring the *in situ* Effects on Plankton

**C. Briseño-Avena**[1], S. J. Warner[2], A. T. Greer[3], I. Soto-Ramos[3], S. M. Parrra[4], A. L. Deary[5], F. J. Hernandez[5], W. Graham[3], J. N. Moum[6], R. K. Cowen[1]
[1]Oregon State University, Hatfield Marine Science Center, NEWPORT, OR, [2]Oregon State University, Corvallis, OR, [3]University of Southern Mississippi, Stennis Space Center, MS, [4]Naval Research Laboratory, Oceanographic Division, Stennis Space Center, MS, [5]University of Southern Mississippi, Gulfcoast Research Laboratory, Ocean Springs, MS, [6]Oregon State University, Corvallis, OR

Zooplankton in coastal areas near intense river discharge experience high turbulence that affects their fitness and overall productivity. River plumes are important nutrient sources for plankton production. However, they are also sources of turbulence that directly affect nutrient fluxes (for primary producers), predator-prey encounter rates (e.g., grazers, ichthyoplankton), and can lead to individual metabolic rate increases resulting from elevated swimming activity. We achieved a highly resolved spatiotemporal sampling scheme of a rapidly changing river plume using two, fast-towed in situ platforms along two parallel arch-shaped transects (36 km long) south of the Mobile Bay inlet during a



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high river discharge season. The *in situ* Ichthyoplankton Imaging System (ISIIS) was towed behind the R/V *Point Sur* and the Chameleon Turbulence Profiler was deployed from the R/V *Pelican*. Both platforms were equipped with several physical sensors such as conductivity-temperature-depth profilers, fluorometers (Chl-*a* fluorescence), and, in addition, ISIIS had dissolved oxygen and photosynthetic active radiation (PAR) sensors. Here we combine fine-scale (centimeters-to-meters) abundance and distribution information of phytoplankton, zooplankton, and ichthyoplankton from ISIIS data along with turbulence microstructure from the Chameleon in order to evaluate the physical-biological relationships of turbulence on plankton. Stratified net samples (BIONESS) taken at both ends of the ISIIS transect will help corroborate *in situ* imagery identification and abundance estimates. Grazing rates estimated from net samples will help evaluate the effect of turbulence on mesozooplankton grazers. This study will help identify the relationship between turbulence and plankton production in regions dominated by river plumes. Furthermore, the results of this work can be used in physical-biological models exploring plankton exposure pathways of oil and dispersants in river-dominated ecosystems.

Films of Bacteria at Interfaces (FBI) as Protective Layers against Interfacial Stress.
**T. H. R. Niepa**[1], L. Vaccari[1], R. L. Leheny[2], M. Goulian[1], D. Lee[1], K. J. Stebe[1]
[1]University of Pennsylvania, Philadelphia, PA, [2]Johns Hopkins University, Baltimore, MD

Bacteria become trapped at fluid interfaces in a manner similar to colloidal particles. By adsorbing to the interface, the microbes eliminate a patch of interface, lowering the free energy of the system. While bacteria are indeed self-propelled, they are not simply active colloids. When trapped at an interface, they can sense their local environment, colonize the interface, consume or emulsify surrounding phases, or modify their local environment by other means. However, very little is known about the effects of surface tension and associated stresses at fluid interfaces on cell physiology, nor about how microbes restructure interfaces to cope with this challenging environment.

In this study, we compare the responses to confinement at hexadecane-water interface of *Pseudomonas aeruginosa* PAO1 and a more virulent strain, PA14. The *P. aeruginosa* PAO1 cells remodel the interface to form Films of Bacteria at Interfaces (FBI), i.e. elastic, solid films of bacteria, excreted olysaccharides and proteins, whereas the PA14 cells remained highly motile at the oil-water interface. To understand the biological implications of these features, transcriptional profiles were established for both strains. The PAO1 cells exposed to interfaces display little metabolic change in comparison to their planktonic counterparts. In contrast, the PA14 cells exposed to interfaces display significant metabolic changes, specifically, via the induction of genes associated with physiological stress, and cell death. These results suggest that the formation of FBI at fluid interfaces provides protection, in a manner akin to biofilms, enabling cells to cope with the detrimental effects of the interfacial environment.

Seasonal Variability in Ebb Tidal Plumes
**S. L. Dykstra***[1, 2], B. Dzwonkowski[1, 2], S. O'Brien[3], G. Lockridge[1]
[1]Dauphin Island Sea Lab, Dauphin Island, AL, [2]University of South Alabama, Mobile, AL, [3]University of Southern Mississippi, Kiln, MS

Coastal regions of fresh water influence (ROFI) are often associated with intense relatively freshwater discharge plumes that give way to buoyancy driven flows. The transition between these flow phases can be complex with the fate of all materials being transported, especially oil and oil-derived



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substances, difficult to accurately predict. A series of CODE style drifter releases and CTD transects during the fall season of 2016 and 2017 and the spring of 2016 at Main Pass of Mobile Bay were used to examine the seasonal differences in the flow structure of the freshwater discharge plume as it enters the shelf environment. Seasonal differences in the river discharge and the associated ebb tidal prism sizes were compared with kinematic characteristics of the nearfield and midfield regions of ebb tidal plumes. Observed differences in the ebb prisms ranged a half order of magnitude (1E8 m^3), while discharge ranged over one order of magnitude. Initial findings of plume velocity, dispersion, and tidal excursion show the variability in the nearfield characteristics to be more closely linked to ebb prisms than to river discharge. While patterns in the plume fairfield regions have been shown to be dependent on the river discharge, the near-field and mid-field characteristics may be more closely related to the tidal prism and the fortnight cycle. Understanding the factors that influence exchange at tidal inlets is critical for appropriate oil spill response and improved model forecasts in these complex regions.

Assessing the Effects of River Diversions on Oil Transport in Barataria Bay

**H. Huang**, L. Cui, D. Justi
Louisiana State University, Baton Rouge, LA

Freshwater diversions on the lower Mississippi River are considered an important component of wetland restoration efforts in coastal Louisiana. Diversions are used primarily for salinity control but increasingly proposed also as a major way to reduce the coastal wetland loss. Two large-scale sediment diversion projects are currently being considered for Barataria Bay that would convey an order of magnitude more water than the existing operational diversion Davis Pond. The impacts of current and proposed diversions on surface oil transport in Barataria Bay were investigated using a prognostic, three-dimensional, Finite-Volume Coastal Ocean Model (FVCOM). The numerical model domain covers central part of northern Gulf of Mexico with very high horizontal resolution (on the order of 20 meters) in the waterways, bayous, small lakes and adjacent wetlands of Barataria Bay. The model was driven by tidal and subtidal forcing at the open Gulf of Mexico boundary, freshwater discharge from the diversions, surface wind stress, and precipitation and evaporation at ocean surface. A number of different diversion scenarios were assessed, including concurrent operation of Davis Pond and mid-Barataria diversions with a combined flow of about 135,000 cfs. Numerical modeling results indicate that river diversions have the potential to strongly influence estuarine residence times and alter oil transport pathways, albeit with significant tradeoffs associated with estuarine freshening.

Seasonal dynamics of trace elements and Ra isotopes in Mississippi coastal waters

**D. Joung**[1], H. Box[1], P. Ho[1], L. Whitmore[1], W. Moore[2], A. M. Shiller[1]
[1]Division of Marine Science/USM, Stennis Space Center, MS, [2]University of South Carolina, Columbia, SC

The Mississippi Bight is a complex river-dominated coastal region with freshwater inputs from the Mississippi River Delta, Mobile Bay, and other smaller coastal systems. Understanding the interplay of Gulf waters with river input is critical both for understanding how oil from offshore spills is transported and interacts with the biota as well as for understanding how the various material inputs affect the biogeochemistry and productivity of the region. In this work, selected trace elements such as Ba, oxygen and Ra-isotopes, along with nutrients, chlorophyll, and dissolved oxygen were investigated during a series of CONCORDE consortium cruises from fall 2015 to summer 2016 including a period of Bonnet Carré Spillway (BCS) opening in February 2016. Despite the Mississippi River Delta bounding the western side of the Bight, the $\delta^{18}O$ of the water suggests a more dominant influence of Mobile Bay and



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other local freshwater sources. Indeed, even during the BCS opening, two trends, reflecting local and Mississippi River sources are evident in the data. Elevated levels of dissolved Ba and short-lived Ra isotopes suggest that submarine groundwater discharge (SGD) contributes measurably to the chemical mass balance in this region. This SGD input also contributes to scatter in the property-salinity plots within this region. High ratios of Ra-224/-223 at some sites indicate recent introduction of SGD and we also observed elevated Ra in saline groundwaters sampled on the barrier islands. Interestingly, in fall 2015, sampling after the passage of Tropical Storm Patricia showed the region was largely flushed by waters pushed out from Mississippi Sound. We speculate that seasonal and event-driven variability in flushing, stratification, and SGD input play important roles in biological production and bottom water hypoxia in the Mississippi Bight.

Characterization of Stratified Coastal Waters in Response to a Winter Mississippi River Flood and the Opening of the Bonnet Carré Spillway, LA

**A. D. Boyette***[1], S. M. Parra[2], A. M. Shiller[1], I. M. Soto[1], A. D. Weidemann[3], S. B. Joye[4], M. K. Cambazoglu[1], A. L. Deary[5], T. N. Miles[6], W. M. Graham[1, 5]

[1]University of Southern Mississippi, Stennis Space Center, MS, [2]American Society for Engineering Education Postdoctoral Fellow at the U.S. Naval Research Laboratory, Stennis Space Center, MS, [3]U.S. Naval Research Laboratory, Stennis Space Center, MS, [4]University of Georgia, Athens, GA, [5]University of Southern Mississippi, Ocean Springs, MS, [6]Rutgers School of Environmental and Biological Sciences Department of Marine and Coastal Sciences, New Brunswick, NJ

Large freshwater pulses to coastal waters change local hydrologic regimes and alter biogeochemical processes, which can significantly impact coastal ecosystems. In 2015, mild wintertime temperatures and heavy rainfall throughout the Mississippi River (MSR) drainage basin led to elevated river stages and significant flooding of its tributaries. Under normal flow conditions, the MSR empties into the northern Gulf of Mexico via the Birdfoot Delta Complex (BDC) and Atchafalaya River. But, historically high discharge prompted the Army Corps of Engineers to open the Bonnet Carré Spillway (BCS) on January 10, 2016 to relieve pressure on levees, thus marking the 11th time the BCS had been opened since 1931 and the earliest opening of the spillway in its 85-year history. To address the physical and ecological impacts of a large freshwater diversion on regional coastal ecosystems, CONCORDE organized a highly collaborative investigation with other GoMRI consortia ECOGIG, ACER, DEEPEND, and CARTHE along the western portion of the Mississippi Bight one month after BCS opening. Here we describe the physical, optical, and biogeochemical structure of a stratified water column resulting from exceptional flooding and subsequent BCS opening. Physical data suggest the region is comprised of a complex system of separate water masses and are identified as the Chandeleur Sound, Inner Shelf, Mobile Bay, and BDC waters. Oxygen isotopic signatures (δ18O) identified distinct end members indicative of MSR and local riverine sources, which were also at elevated discharge rates during the study period. Optical signatures also show that changes in the complex light regime result from the different water types. While the freshet produced an unusually large wintertime freshwater plume emerging from the BDC, despite the BCS opening, this extraordinary event provided a unique opportunity to examine effects freshwater diversions have on local circulation and potential contaminant transport pathways.



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Spatial variation in zooplankton and ichthyoplankton dynamics during an atypical freshwater discharge event in the northern Gulf of Mexico

**A. M. Hoover***, A. L. Deary, F. J. Hernandez
University of Southern Mississippi, Ocean Springs, MS

Variability in the recruitment of marine fishes to adult populations is largely related to environmental variability encountered during the early life stages, including biological and physical factors that affect feeding success, predation risks, or some combination of both. Mesozooplankton (the dominate prey for larval fishes) are highly responsive to physical, chemical, and biological changes in the water column, and environmentally mediated changes in zooplankton abundance or community composition can impact larval fish survival. In January 2016, historic rainfall levels within the Mississippi River drainage system prompted the earliest opening of the Bonnet Carré Spillway, a water control structure that diverts excess Mississippi River flow through Lake Pontchartrain on its way to the Gulf of Mexico. CONCORDE (Consortium for Coastal River Dominated Ecosystems) led a collaborative investigation with other GoMRI consortia (ECOGIG, ACER, DEEPEND, and CARTHE) to collect physical and biological data aboard the *RV Point Sur* from February 10-12, 2016 and assess the biophysical impacts of this atypical discharge event. Distinct water masses originating from multiple sources (e.g., Mississippi River, Mobile Bay) were identified using physical (temperature, salinity) and chemical ($\delta^{18}O$, Ba) observations. Zooplankton and ichthyoplankton samples were collected in each water mass using a 60-cm bongo net fitted with 202-µm and 333-µm mesh nets towed under the sea surface. In this study, we will compare mesozooplankton abundance and community composition among the different water masses in relation to larval fish diet (gut content analysis) and condition (size-adjusted dry weight and morphometrics) to examine the potential impacts of this 'pulse' winter discharge event in the northern Gulf of Mexico.

Highly-Resolved Temporal *in situ* Variability of Zooplankton Diel Vertical Migrations in the Mississippi Bight

**S. M. Parra**[1], A. L. Deary[2], J. W. Book[1], A. Greer[3], C. Briseño-Avena[4], A. Boyette[3], T. Miles[5], F. J. Hernandez[2]
[1]Naval Research Laboratory, Stennis Space Center, MS, [2]University of Southern Mississippi, Ocean Springs, MS, [3]University of Southern Mississippi, Stennis Space Center, MS, [4]Oregon State University, Corvallis, OR, [5]Rutgers University, New Brunswick, NJ

Zooplankton play an important ecological role in the northern Gulf of Mexico (nGoM) as the first link in the heterotrophic food web. Zooplankton's behavioral response to various environmental cues greatly influences their vulnerability to pollutants, such as oil, that can be transported onto the shelf. However, variations in abundance at high spatiotemporal resolution is poorly understood. The dominant structure of vertical zooplankton migrations and the influence of river plumes were studied using time series of acoustic backscatter and vertical velocity profiles obtained at two separate areas in the nGoM shelf. Five bottom mounted acoustic Doppler current profilers (ADCPs) were deployed east of the Mississippi River Delta from November 2015 to April 2016. Six other bottom mounted ADCPs were deployed south of the Mobile Bay inlet in April 2016. The deployments involved ADCPs of 300, 600, and 1200 kHz frequencies that detect particles greater than 5, 2.5, and 1.25 mm, respectively. The taxonomic composition and abundance of the zooplankton were determined by an array of measurements including depth-discrete net samples, conductivity-temperature-depth casts equipped with a fluorometer and collecting water samples, tow-yo of both In Situ Ichthyoplankton Imaging System and Scanfish, and shipboard LIDAR. Diurnal backscatter anomalies and vertical velocities could



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point to vertical diel migrations of increased concentrations at nighttime and lowest concentrations at daytime. This may indicate that at daytime the scatterers were near-bottom unable to be detected by the upward facing ADCP, and at sunset they migrated to shallower depths. The maximum concentrations appear to swim downward in the water column a few hours before sunrise. Diel migrations varied throughout the time series, and thus these observations contribute valuable new information on seasonal variations of diel behavior and the biological and physical influences on zooplankton abundance in the nGoM shelf.

Characterizing Spatial and Temporal Changes of the Suspended Particulate Matter in the Mississippi Sound and Mississippi Bight

**S. J. O'Brien***[1], S. L. Dykstra[2], L. Quas[1], B. Dzwonkowski[2], S. Howden[1], D. J. Wallace[1], I. Church[3], O. Schofield[4], T. Miles[4], J. D. Wiggert[1]

[1]University of Southern Mississippi, Stennis Space Center, MS, [2]Dauphin Island Sea Laboratory, University of South Alabama, Dauphin Island, AL, [3]University of New Brunswick, Fredericton, NB, Canada, [4]Rutgers University, New Brunswick, NJ

Mississippi Sound is a low lying coastline composed of marsh and wetland areas. It is characterized by turbid waters as a result of high suspended sediment input from several sources (Biloxi River, Mobile Bay, Pascagoula River, Pearl River, Wolf River, and Lake Pontchartrain through the Rigolets) and the resuspension of silt-sized bottom sediments. The passes present in the Sound act as pathways for the exchange of estuarine discharge and suspended particulate matter (SPM) with the Mississippi Bight. Particle size distribution, water samples, CTD, acoustic and optical backscatter measurements were obtained in the Sound and Bight from August 2015 to August 2016, in support of the CONsortium for oil spill exposure pathways in COastal River-Dominated Ecosystems (CONCORDE) research effort to characterize the physical fields influenced by pulsed river discharge. SPM concentration was determined from in situ water samples from a number of sites within Mississippi Sound. To support the field measurements and provide spatio-temporal variability context at 500 m resoltuion, a remote sensing algorithm was applied to Moderate Resolution Imaging Spectroradiometer measurements of 645 nm remote sensing reflectance. Bottom velocity predictions provided by the 1 km Navy Coastal Ocean Model (NCOM) were used to estimate the bed shear stress threshold values in the Sound and Bight. The in situ data, remote sensing observations and NCOM simulations are used to assess the grain size distribution, sediment resuspension and sediment transport on the timescale of hours to days. This study provides an overview of the spatiotemporal variations in the SPM located in Mississippi Sound and Bight.

Impact of High Resolution Atmospheric Forcing on Circulation Variability within a Regional Model of the Mississippi Sound and Bight

**C. Pan**[1], M. S. Dinniman[2], P. J. Fitzpatrick[3], Y. Lau[3], E. E. Hofmann[2], J. D. Wiggert[1]

[1]University of Southern Mississippi, Stennis Space Center, MS, [2]Old Dominion University, Norfolk, VA, [3]Mississippi State University, Stennis Space Center, MS

A high resolution (400 m) regional ocean model has been developed for the Mississippi Sound and Bight as part of the GOMRI-funded CONCORDE consortium. The model is based on the Regional Ocean Modeling System (ROMS), with initial and lateral boundary conditions drawn from accumulated 3-day forecasts of the 1km-resolution Gulf of Mexico Navy Coastal Ocean Model. Vertically, the model has a terrain-following coordinate system with 24 layers. Surface forcing of the Mississippi Sound and Bight



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ROMS implementation (MSB-ROMS) is drawn from the North America Regional Reanalysis (NARR). A 2-year simulation (2014-2015) provides a baseline solution. Freshwater plumes of the Mississippi River, Mississippi Sound and Mobile Bay all influence the shelf waters of the Mississippi Bight. The model results are compared with available remote sensing data and with CONCORDE's moored and ship-based in-situ observations. Another aspect of CONCORDE's activities has been the development of a high resolution atmospheric reanalysis that covers the time frame of the consortium's field campaigns (2015- ). The model responses to the low resolution forcing from NARR and to the high resolution atmospheric reanalysis are compared in detail for the CONCORDE Fall campaign time frame when contemporaneous in situ date are available, with a focus on how simulated exchanges between MS Sound and MS Bight are impacted.

Differential Responses of Soil Greenhouse Gas Production and Denitrification to Salinity Alterations along a Wetland Salinity Gradient in Barataria Bay

**N. A. Ceresnak***[1, 2], A. Chelsky[2], T. Hill[2], B. J. Roberts[2]
[1]Louisiana State University, Baton Rouge, LA, [2]Louisiana Universities Marine Consortium, Chauvin, LA

Coastal wetlands provide several important ecosystem services including carbon sequestration and nutrient retention and cycling. However, wetlands experience numerous stressors including changes in salinity regimes due to increases from salt water intrusion and decreases from river diversions. The Barataria Bay (LA) estuarine system provides an ideal setting to examine the influence of current (Davis Pond) and future (2012 Coastal Master Plan calls for 2 large sediment diversions in the system) river diversions in a system that has well-documented increases in salinity. We examined greenhouse gas production (GHG; $CO_2$, $CH_4$, $N_2O$) and denitrification enzyme activity (DEA) rates from 4 wetland sites along the salinity gradient in Barataria Bay: freshwater, intermediate, brackish, and salt marsh in May, July and October 2016 to consider temporal (i.e. seasonal) differences. We evaluated GHG production and DEA rates at ambient salinities along the wetland salinity gradient, and how short term pulses of altered salinities (0, 10, 20, 30ppt) affect these rates. Ambient $CO_2$ and $CH_4$ rates tended to decrease along the salinity gradient from the freshwater to salt marsh, whereas, $N_2O$ production and DEA displayed either no pattern or a peak at intermediate and/or brackish marsh sites. The short term responses to increases in salinity consistently displayed strong patterns across sites and seasons but these patterns were sometimes consistent (decreases in $CH_4$ production and DEA) and sometimes opposite (increases in $CO_2$ and $N_2O$ production) the patterns of decreased rates observed along ambient gradients. This decoupling of patterns suggests that the drivers of short-term and long-term responses to salinity changes may differ. These results provide needed information on how future coastal restoration efforts (including river diversions) along the salinity gradient impact carbon balance and the cycling, retention, and removal of nutrients in coastal wetland ecosystems.

Long-term patterns in nitrification rates and ammonia oxidizer abundance in Louisiana salt marshes post-spill

**A. Chelsky**[1], J. Marton[2], A. Bernhard[3], A. Giblin[4], B. Roberts[1]
[1]Louisiana Universities Marine Consortium, Chauvin, LA, [2]CDM Smith Inc., Indianapolis, IN, [3]Connecticut College, New London, CT, [4]Marine Biological Laboratory, Woods Hole, MA

Salt marshes play an important role as transformers and sinks for reactive nitrogen, minimizing the delivery of nutrients to downstream ecosystems and reducing the extent of eutrophication those systems experience. One of the key N cycle components is nitrification, in which ammonium is



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converted to nitrite by ammonia-oxidizing archaea (AOA) and bacteria (AOB) and nitrite is subsequently converted to nitrate by nitrite-oxidizing bacteria. The aim of this study was to investigate long-term patterns and legacy effects of the Deepwater Horizon oil spill on nitrification rates and ammonia oxidizer abundances in Louisiana salt marshes. Sampling was conducted during peak growing season (July) at two unoiled/oiled marsh pairs in each of three regions across LA (12 total marshes), with plots along a gradient from the salt marsh edge to the interior. There was significant interannual variability in nitrification rates over the five years of the study, which was explained in part by soil properties, including porewater salinity and soil organic properties. AOA and AOB abundances were often correlated with nitrification rates. However, the strength of these relationships differed by region and year, and AOA and AOB often displayed different relationships with rates. No differences in nitrification rates were detected between unoiled and oiled marshes; however, more subtle changes in the link between ammonia oxidizer abundances and nitrification rates between unoiled and oiled sites were measured in some years and in some regions. These results are compared to two New England marshes where nitrification rates are much lower despite having similar ammonia oxidizer abundances to Louisiana salt marshes. This multi-year study elucidates the drivers behind spatial and temporal variability in salt marsh nitrification rates, as well as the abundance and efficiency of ammonia oxidizers responsible for carrying out this important process.

A Multi-Year Record of Biomass, Primary Production, and Allometry of Four Dominant Vegetation Types in Coastal Louisiana Salt Marshes

**A. J. Rietl**, T. D. Hill, B. J. Roberts
Louisiana Universities Marine Consortium, Chauvin, LA

Measurements of primary production are critical to understanding many ecosystem-level processes of salt marsh ecosystems. However, few long term datasets exist and most that do focus on a single dominant vegetation type. In many coastal marshes, including those that dominate coastal Louisiana regions impacted by the Deepwater Horizon oil spill, vegetation not only consists of *Spartina alterniflora* but also includes abundant patches of other species including *Spartina patens*, *Distichlis spicata*, and *Juncus roemerianus*. We present two years of above- and below ground biomass data for *Spartina alterniflora*, *Spartina patens*, *Distichlis spicata*, and *Juncus roemarianus* from two salt marshes in the Bay Batiste / Bay Sansbois region of Barataria Bay, Louisiana. Each vegetation type was destructively sampled from 3 quadrats at each site seasonally during 2015-2016 and above- and below-ground primary production rates calculated using multiple methods will be presented. In addition to reporting patterns of biomass and primary production, we use heights and masses of harvested stems to parameterize seasonal allometric equations for each species that can be later applied to non-destructively estimating aboveground biomass. Finally, by combining our areal estimates of above- and below-ground primary production with estimates of the percent coverage of each species over 75 m (shoreline) x 100-125m (deep) marsh sites, we will report landscape scale estimates of primary production by marsh vegetation. This research provides critical information on the productivity of common marsh vegetation types that have been shown to change in relative proportion following the oil spill and directly aids sampling efforts that are sensitive to repeated destructive harvests, such as post-disaster assessments or large-scale efforts to estimate marsh productivity.



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Leaf Tissues and Semi-permeable Membrane Devices as Passive Samplers for Dynamic Re-oiling Events in Marshes

**J. Pardue**, J. Kassenga, M. Decell, V. Elango
Louisiana State University, Baton Rouge, LA

Heavily-oiled marshes in Barataria Basin, LA continue to recover 6 years after the Macondo spill. While buried oil emulsions are a common feature of these oiled marshes, burial is not synonymous with recovery. Dynamic re-oiling events have been observed during field sampling that are initiated as wave action erodes the marsh edge. These dynamic events serve to re-initiate transfer of crude oil components into the food chain albeit on a different temporal and spatial scale to the original spill. This paper will present and summarize recent data from two salt marshes with different oiling histories. Data to be presented will compare direct measurements from cuticle fractions of *Spartina* (smooth cordgrass) and *Avicennia* (black mangrove) leaf tissue in oil-impacted marshes on Fourchon Beach and Bay Jimmy in upper Barataria Bay in 2016. These data will be contrasted with PAH concentrations measured in biomimetic semi-permeable membrane devices (SPMDs) deployed on the Bay Jimmy marsh surface and in the air 1-1.5 meters above the marsh surface. SPMDs consist of permeable tubing containing triolein, a triglyceride surrogate for environmental lipids such as the plant cuticle. SPMDs were deployed 4 times in summer and fall of 2016 at an oiled and a control location to compare the accumulation in plant cuticles co-located with the samplers. Data from SPMD and the plant cuticle of *Spartina* and *Avicennia* continue to show that the remobilization of PAHs is occurring in marshes with vegetation. SPMD and vegetation data will be used to elucidate the mechanism of continuing PAH release in marshes. The significance of this research is that vegetation can serve as highly sensitive passive samples for erosion-driven re-oiling events with the potential to continue to stress coastal marsh ecosystems.



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## Session 015: Monitoring and Modeling Responses to Oil Spill Injury and Restoration: Integrating Tools for Adaptive Management

### Conducting Restoration through the Lens of Adaptive Management

**G. D. Steyer**[1], M. Meyers[2], A. Hijuelos[3]
[1]U.S. Geological Survey, Baton Rouge, LA, [2]U.S. Geological Survey, New Orleans, LA, [3]Cherokee Nation Technologies, New Orleans, LA

Implementing restoration in complex and dynamic systems inherently includes scientific, technological, socio-economic, engineering, and institutional challenges. Because of intrinsic uncertainty and the inability to develop courses of actions optimal to all possible future scenarios, natural resource management agencies have increasingly committed to using Adaptive Management (AM) as a tool for ensuring success of restoration programs and projects. Although AM can be defined in many ways, it is essentially an iterative, science-based process that uses monitoring, modeling, and research to strategically reduce uncertainties and provide new information to support restoration decision making. AM is not a new idea, but addressing uncertainties that impede restoration decisions has rarely been effectively practiced. Although many restoration programs include a monitoring program, they lack formalized AM decision structures and often utilize a "trial and error" approach to implementing corrective actions. If the system response to restoration is not as predicted, the science of data integration, analysis, and modeling can be used under an AM framework to make transparent, efficient and coordinated decisions to inform restoration actions. Further, developing an AM framework prior to implementing restoration can help stakeholders think through the implications of the restoration action, thereby reducing ambiguity for when and what corrective actions will be taken. This presentation describes the role of monitoring and modeling under an AM framework as the building blocks to support Gulf of Mexico restoration. We illustrate how AM can help with decision making by providing a flexible framework that management can use to best direct restoration efforts while being responsive to changes in biological conditions, societal needs, political influences, funding availability, and restoration program goals.

### The National Academies Report, Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico

F. W. Davis[1], S. Johnson[2], S. Roberts[2], **P. Plotkin**[3]
[1]University of California, Santa Barbara, Santa Barbara, CA, [2]The National Academies, Washington, DC, [3]Texas A&M University, College Station, TX

In July 2016, The National Academies of Sciences, Engineering, and Medicine released the report *Effective Monitoring to Evaluate Ecological Restoration in the Gulf of Mexico*. The authoring committee undertook a review of best practices for monitoring and evaluating restoration activities to improve the performance of restoration programs and increase the effectiveness and longevity of restoration projects. An examination of past restoration efforts has shown that monitoring is often inadequate to evaluate restoration outcomes. The committee recommended that to provide assurance to funders and the public of the benefits derived from restoration investments, Gulf restoration programs should develop clear, quantitative objectives, against which progress would be evaluated at project and program levels. All restoration efforts should be accompanied by a plan that outlines a strategic, rigorous monitoring effort that enables an assessment of restoration progress relative to the goals and objectives. Gulf restoration programs should coordinate their efforts to ensure that monitoring data



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are as consistent and comparable as possible to enhance learning at larger scales and ensure that data are publicly available over the long-term by establishing and enforcing clear policies for archiving and sharing monitoring data. Synthesis activities will be necessary for observing restoration progress beyond individual projects and to evaluate restoration outcomes for wide-ranging species. Therefore, restoration programs should consider creating a specific dedicated enterprise for synthesis activities in support of Gulf restoration. The committee provides additional guidance on restoration monitoring and evaluation in Part I of the report and in Part II, provides more specific examples of how this general guidance could be applied for a few species and habitats, including oyster reefs, tidal wetlands, seagrass beds, birds, sea turtles, and marine mammals. The full report pdf is available for download at the National Academies Press.

Resource-level Monitoring and Analysis to Support Restoration for the Deepwater Horizon Programmatic Damage Assessment Restoration Plan (PDARP)

**M. Carle**[1], G. D. Steyer[2], J. Redding[1], M. B. Meyers[3], A. Hijuelos[4], P. Tuttle[5]
[1]ERT/ NOAA Restoration Center, Silver Spring, MD, [2]U.S. Geological Survey, Baton Rouge, LA, [3]U.S. Geological Survey, New Orleans, LA, [4]Cherokee Nation Technologies, U.S. Geological Survey, New Orleans, LA, [5]U.S. Fish and Wildlife Service, Fairhope, AL

While project monitoring is a critical component of the monitoring and adaptive management framework for the Deepwater Horizon Programmatic Damage Assessment Restoration Plan (PDARP), the unprecedented temporal, spatial, and funding scales of the restoration plan necessitate evaluation beyond the project scale. The PDARP allocates restoration funding to thirteen Restoration Types to support the restoration of coastal and nearshore habitats, improvement of water quality in priority watersheds, protection and restoration of living coastal and marine resources, and enhancement of recreational use opportunities across the 5 Gulf States, Open Ocean, and Regionwide Restoration Areas. Clearly defined goals for each Restoration Type provide criteria for evaluating broader restoration outcomes. The Trustees will develop monitoring standards, including core monitoring metrics for similar projects, to facilitate the aggregation and synthesis of monitoring data within each Restoration Type. Aggregation and synthesis of monitoring information across projects will allow evaluation of the effects of multiple restoration projects on the recovery of the targeted resources and facilitate comparison of the effectiveness and efficiency of restoration approaches. In addition, targeted resource-level monitoring may be needed to address critical information gaps that limit restoration planning, implementation, and/or evaluation of restoration outcomes for individual Restoration Types. Activities to address these uncertainties could include better characterization of the status, trends, and spatiotemporal distributions of injured resources and habitats to improve the Trustees' ability to target restoration activities and track resource recovery. Collectively, these monitoring and assessment activities for Restoration Types will help the Trustees evaluate collective progress toward meeting the ecosystem goals defined in the PDARP.

Evaluation of Population Biomass and Production Using Long-Term Monitoring Data from the Gulf of Mexico

**D. French-McCay**[1], J. Rowe[1], M. McManus[2], R. Balouskus[1], A. Morandi[1], M. Gearon[1]
[1]RPS ASA, South Kingstown, RI, [2]RI Department of Environmental Management, Jamestown, RI

Several long-term monitoring programs focused on fish and invertebrates are on-going in the Gulf of Mexico. The National Marine Fisheries Service (NMFS) Southeast Area Monitoring and Assessment



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Program (SEAMAP) Ichthyoplankton Survey has analyzed fish egg and larval abundances sampled over the past three decades. Trawl samples from the decades-long SEAMAP Shrimp/Groundfish Survey on the shelf have been counted and identified. These are valuable data sets for establishing baseline and long-term trends. However, the sampling gear and protocols used are selective of certain life history stages, size classes and portions of the environment due to logistical constraints and escapement of smaller, larger or faster organisms than the gears can capture. As part of the Deepwater Horizon Natural Resource Damage Assessment effort, vertical distributions of captured individuals, catchability analyses, and population modeling were used to determine the age classes and portions of the populations actually sampled, baseline biomass by age class present in various depth intervals of the Gulf of Mexico, and production rates integrated over age classes and the life time of the species. The results elucidate the important species groups in the ecosystem in terms of biomass and production, which informs ecosystem models designed to understand and quantify productivity of the Gulf of Mexico, as well as ecosystem services provided to stakeholders. In addition, population modeling based on the well-sampled early life history stages indicates a number of species groups may be important ecologically but are not evaluated by present programs and sampling protocols. Adaptive management can use the modeling results to focus monitoring to evaluate poorly sampled and understood populations and portions of the ecosystem.

GoMexSI: Its Role in Monitoring, Modeling, and Adaptive Management in the Gulf of Mexico

**J. Simons**
Texas A&M University - Corpus Christi, Corpus Christi, TX

The Gulf of Mexico Species Interaction database or GoMexSI was launched in September of 2013. GoMexSI was first conceived as a mechanism to provide fish diet data to fisheries modelers in the Gulf of Mexico, a large marine ecosystem that had no existing diet database, as exists in several US LMEs (i.e. Bering Sea, Gulf of Alaska, NW Atlantic). As you might have guessed, since there is no diet database in the Gulf of Mexico, there is no Gulf-wide diet monitoring program in the Gulf. The largest, continuous diet monitoring program in the Gulf is run by the state of Florida's Wildlife Research Institute in St. Petersburg. The continued development pf GoMexSI is now allowing us to begin to do gap analysis on available diet data, so as to help us target diet data collection efforts. Our recent MARFIN project is an example of how this was accomplished, allowing us to target some species that were either data poor, or had no diet data at all. The goal is for a completed GoMexSI database to provide a tool towards developing a Gulf-wide diet data monitoring program. Fisheries modelers, the original intended beneficiary of GoMexSI, have begun to use GoMexSI as evidenced by some recent publications. Unfortunately, sometimes the data they need are not in the database, but references that may contain useful data are posted on the GoMexSI webpage. Interactions with fisheries modelers have been fruitful and encouraging. As the Gulf of Mexico fishery managers move toward adaptive management and ecosystem based fisheries management, GoMexSI can continue to play a role. As management plans are implemented, data collected, and assessed, it will be apparent that new diet data are needed for certain species in certain locations. By referencing GoMexSI, a manager, scientist, or modeler can find out what data are already available, when and where it was collected. Thus, much needed data can be collected, new models run, and management plans adjusted or new ones conceived. Thus, a completed, maintained, and growing GoMexSI database can be a positive force for monitoring, modeling, and adaptive management of fisheries in the Gulf of Mexico.



*****Student presenter

Ecosystem impacts of the DWH oil spill

**C. Ainsworth**[1], C. Paris-Limouzy[2], N. Perlin[2], L. Dornberger[1], W. Patterson[3], E. Chancellor[1], S. Murawski[1], D. Hollander[1], F. Coleman[4], H. Perryman[2]

[1]University of South Florida, St. Petersburg, FL, [2]University of Miami, Miami, FL, [3]University of South Alabama, Dauphin Island, AL, [4]Florida State University, Tallahassee, FL

The Deepwater Horizon oil spill caused damages across a range of species and habitats in the Gulf of Mexico. Effects manifest at the population level as increased mortality or as sub-lethal impairment on the organisms' ability to forage, reproduce and avoid predators. We employ an end-to-end ecosystem model, Atlantis, to represent the cumulative impacts of the oil spill across taxa. We consider changes at the species and community level with emphasis on exploited species for estimating fisheries impacts. We simulate impacts of direct oil exposure on mortality and growth rates of fish as informed by a dose-response relationship, impacts on recruitment success due to ichthyoplankton contamination, and impacts of fishery closures on the food web. We validate predictions of the model by comparing population trends and age structure before and after the oil spill using fisheries-dependent and independent monitoring data. Synthetic ecological indicators such as biodiversity and mean trophic level reveal fundamental changes in ecosystem structure and function. The model predicts that DWHOS caused conspicuous changes in biomass, age structure and distribution in a variety of fish guilds. In areas most heavily affected, the forage base lost a majority of its biomass, which lead to starvation in some predators. Impacts on mobile populations translated trophic effects to areas far from the plume, including the western and southern Gulf.

Analyzing Changes in Ecosystem Structure and Function after Ixtoc Oil Spill with and Atlantis Model

**J. Ortega-Ortiz**, C. Ainsworth

University of South Florida, St Petersburg, FL

We developed an Atlantis biogeochemical marine ecosystem model for the southern Gulf of Mexico. The spatially explicit model represents bioregional features through an irregular polygon geometry with bathymetric, biogenic substrate and hydrodynamic characterization. We built upon a previous model developed to study the effects of the Deepwater Horizon oil spill (DWHOS) with a more detailed focus on the area potentially affected by the 1979 Ixtoc oil spill. We included fisheries statistics and bycatch estimations. Model simulations were used to analyze changes in ecosystem structure and function following the Ixtoc-I oil spill.

Simulating the Potential Impacts of Petroleum and Fisheries Activities in the Nursery Grounds of the Barents Sea Cod Fishery

**J. Carroll**[1], F. Vikebø[2], D. Howell[2], O. Broch[3], R. Nepstad[4], S. Augustine[1], G. Skeie[5], R. Bast[6], J. Juselius[6]

[1]Akvaplan-niva, Tromsø, Norway, [2]Institute of Marine Research, Bergen, Norway, [3]SINTEF Fisheries an Aquaculture, Trondheim, Norway, [4]SINTEF Materials and Chemistry, Trondheim, Norway, [5]Akvaplan-niva, Ski, Norway, [6]UiT-The Arctic University of Norway, Tromsø, Norway

Fisheries and petroleum resource development are concomitant in some of the world's most productive continental shelf seas. Much of our understanding of the impacts of oil spills to fisheries and the general health of ecosystems has been acquired from a few major events. It remains a significant challenge to link data on effects of oil on individual organisms, mainly gathered through controlled laboratory experiments, to impacts on the population as a whole. The advanced software tool,



*****Student presenter

SYMBIOSES, was developed to improve assessments of environmental impacts linked to oil spill scenarios, and in particular, effects of oil spills on fish stocks at the population level. The tool simulates the distribution and behavior of different life stages of important commercial fish species and their prey, effects of petroleum components on the eggs and larvae of fish and zooplankton, and multi-year changes in fish populations. It allows for impacts on larval survival to be traced through the population to observe the effect of oil spills on overall fish stocks. As a demonstration of the utility of such modeling tools, we will present simulation results for oil spill scenarios from a single location on the northern Norwegian continental shelf (75.2N 32.4E). We examine survival of early life stages of cod and the resulting impacts on the cod population. We will also demonstrate how SYMBIOSES may be used to assess two different oil spill mitigation strategies: reducing the fishing quota and applying dispersant. This study demonstrates the utility of predictive ecological models to explore and inform on a key impact factor of oil spills which, in turn, lends valuable support to science informed decision-making and stakeholder communication.

Applying Adaptive Management at a Programmatic Scale

**S. Romañach**[1], M. Eaton[2], F. Johnson[3], J. Lyons[4], C. Moore[5], M. Runge[4], A. Hijuelos[6], M. Meyers[7], G. Steyer[8]

[1]US Geological Survey, Fort Lauderdale, FL, [2]US Geological Survey, Raleigh, NC, [3]US Geological Survey, Gainesville, FL, [4]US Geological Survey, Laurel, MD, [5]US Geological Survey, Athens, GA, [6]Cherokee Nation Technologies, contracted to US Geological Survey, New Orleans, LA, [7]US Geological Survey, New Orleans, LA, [8]US Geological Survey, Baton Rouge, LA

Implementing adaptive management (AM) on a programmatic scale has the potential to provide a strong path toward meeting Gulf-wide restoration objectives, enhance shared learning, and promote wise use of restoration funding. Adaptive management includes consideration of alternative actions to meet natural resource management objectives, a formal mechanism to generate learning from outcomes, and adjusting future actions as a result. A body of literature and technical guidance exists on the application of AM at the project level. We explored the idea of implementing AM at a programmatic scale across a suite of Gulf restoration projects. Federal and state agencies jointly developed the Programmatic Damage Assessment and Restoration Plan (PDARP) to guide restoration of natural resources following the 2010 Deepwater Horizon oil spill. Restoration projects are mandated to use an AM framework under the 13 Restoration Types (i.e., damaged resources) identified in the PDARP. We used the Gulf sturgeon Restoration Type as a case study to explore the potential for applying AM at a programmatic scale. Initially, a suite of Gulf-wide sturgeon habitat restoration objectives would need to be determined (e.g., improve habitat quality, increase population size) to evaluate projects against. The result could be a portfolio of projects which together result in optimized performance toward established objectives. Monitoring can be used to reduce uncertainties in how individual projects perform, and can help guide the types of projects to select in subsequent funding decisions. Expanding further, sturgeon habitat restoration objectives could be extended so that a set of shared objectives could be developed regardless of funding sources (e.g., Natural Resource Damage Assessment, RESTORE Act). Application of AM principles to a broad scale, beyond a single project, should enable learning for more efficient use of resources at a programmatic level.



*****Student presenter

## Session 016: Fate and Transport of Oil in the Open Ocean: Water-Sediment Connectivity

### Numerical Modeling Study of the Deepwater Horizon Blowout under Different Scenarios: Major Findings on the Oil Plume Transport

**N. Perlin**, C. B. Paris
University of Miami, Miami, FL

Our study uses the oil application of the Lagrangian particle-tracking Connectivity Modeling System (CMS) to simulate oil droplets release and transport during the Deepwater Horizon blowout. The model uses additional assumptions about the biodegradation for the three different oil fractions comprising each particle. Oil concentrations are determined from CMS model output and interpolated into the 3-D grid and represented as isosurfaces of selected ppb, which allowed the analysis of the oil plume behavior and transport in the Gulf of Mexico interior and the extent of the water column contamination. Additionally, several different scenarios are considered in order to learn the effects of (1) added chemical dispersants, (2) different temporal onset of the blowout or different hypothetical location of the disaster, and (3) the surface wind on the surface oil slick transport. Major findings include the notable effect of the Earth's rotation on the vertical oil plume evolution, the bulk of the oil mass remaining submerged in the Gulf interior, as well as the ocean circulation and eddies playing a critical role in the oil spread into coastal regions.

### Evolution of the Chemical Signature of Macondo Oil in the Waters of the Northern Gulf of Mexico

**M. Trillo***[1], C. B. Paris[1], Z. Aman[2], M. J. Olascoaga[1]
[1]Rosenstiel School of Marine & Atmospheric Science, Miami, FL, [2]Western University of Australia, Perth, AUSTRALIA

On 20 April 2010, the BP-operated Deepwater Horizon (DWH) drilling platform exploded, and oil spilled in the Gulf of Mexico for 87 days. An unprecedented experiment, where powerful chemical dispersants were directly injected at the wellhead in various amounts, was carried out intending to test the efficacy of the new method. Widespread research in the past six years has revealed important characteristics of this unusual oil spill, including the formation of a prominent deep intrusion, the composition and mass fraction of Macondo oil, and sedimentation on the seafloor. BP made available the Gulf Science dataset of water chemistry oil samples collected during and after the blowout, which provides a unique opportunity to examine the temporal aspect of the partition of hydrocarbons in the water column and its potential relationship to the dispersant application. The objective of this research is to analyze the evolution of the chemical signature of Macondo oil in the water column up to December 2010. For this purpose, the dataset was classified in three pseudo-components based on their volatility, solubility and length of their carbon chain. The final numbers of samples analyzed were 11,042,15,035 and 11,675 for C1-C4,C5-C12 and C13+ ,respectively, and their concentrations were computed separately for four layers (0-20m, 20-400m,400-1000m and >1000m). Spatial analysis showed a clear vertical partition of heavier hydrocarbons higher in the water column, which is partly explained by the physical properties of the hydrocarbon chain length. Temporal analysis of pseudo-components in the water column was examined with variations in surface concentration and downstream oil surfacing. Despite inhomogeneous sampling, the Gulf Science data sheds some light on physical processes leading to the partition of hydrocarbons of different properties in the water column. Further tracking of the pseudo-components' mass flux is necessary to fully understand the nature of deep-sea blowouts.



*Student presenter

The Role of Corexit for the Formation of Sinking Marine Oil Snow

**U. Passow**[1], J. Sweet[1], M. Chiu[2], W. Chin[2], S. Zhang[3], C. Xu[3], P. Santschi[3], A. Quigg[3]
[1]UCSB, Santa Barbara, CA, [2]University of California, Merced, CA, [3]Texas A&M, Galveston, TX

The sedimentation of oil in association with marine snow (e.g. as marine oil snow) during and after the DWH spill in 2010 was an unexpected phenomenon and an important pathway for the distribution of oil within marine environments. A significant fraction of the spilled oil arrived on the seafloor, even at depths > 1200 m and impacted benthic ecosystems and organisms. Oil promotes the formation of both, aggregates and of microbial oil snow, which consists largely of mucus produced by microbes as a response to oil. However, the role of the dispersant Corexit for the formation of marine oil snow has been discussed controversially. Here we show experimental data on the effect of Corexit 9500A for the formation of marine oil snow, including diatom aggregates. The formation of Transparent Exopolymer Particles (TEP), which are an essential component of marine snow, is inhibited and retarded in the presence of Corexit, leading to a decrease in marine snow formation. These data strongly suggest that Corexit disperses TEP, which is in accordance with findings that microgel formation is inhibited by Corexit. Consequently, the amount of particulate organic carbon, TEP, particles, and diatom cells that sink as marine snow is reduced in the presence of Corexit. However, as the oil concentration in the water is greatly increased in the presence of Corexit, oil concentration within marine snow can nevertheless be elevated with the consequence that the absolute amount of oil that sediments may be increased in the presence of Corexit, even when overall sedimentation rate is decreased.

Stress Induced Variation in Transparent Exopolymer Particle Size Frequency Distribution

**L. K. Cole***[1, 2], J. W. Krause[1, 2], K. Thamatrakoln[3]
[1]Dauphin Island Sea Lab, Dauphin Island, AL, [2]University of South Alabama, Mobile, AL, [3]Rutgers University, New Brunswick, NJ

Transparent exopolymer particle (TEP) formation in marine systems depends on the quantity of dissolved organic carbon precursors released from phytoplankton communities and the abiotic factors that enable these precursors to coalesce. While bulk TEP measurements can document species dependent alterations in TEP production, it does not provide information on potential stress induced shifts in the particle size distribution that may not alter the bulk concentration. Such shifts may alter the timing of TEP aggregation into larger, potentially denser particles that would facilitate carbon export. To delineate the relationship between TEP size frequency distribution and a specific stressor, we conducted oil-exposure studies with water collected off the Alabama coast in the northern Gulf of Mexico. This region is highly dynamic due to the seasonal variation in freshwater influx from the Mobile Bay plume, and there is significant variation in the phytoplankton community structure across seasons. Multi-day grow out experiments were conducted with surface water amended with water accommodated fraction of crude oil (WAF), chemically enhanced WAF (CEWAF, crude + dispersant), or dispersant only. In each treatment (WAF, CEWAF, dispersant, control), the size and frequency distribution of TEP was quantified using FlowCAM and image analysis. Preliminary results indicate a higher frequency of small (20 - 40 µm) TEP and a lower frequency of large (200 - 400 µm) TEP in dispersant and CEWAF treatments relative to WAF and control treatments. As TEP abundance and reactivity are intricately linked with the biological pump, a shift to smaller and more abundant TEP may be an important mechanism affecting the timing of oil removal from the water column via particle aggregation and subsequent sedimentation.



*Student presenter

Variability in Sedimentation Dynamics in the Northern Gulf of Mexico Reflect Ecosystem and Foodweb Structure

**S. Giering**[1], J. Sweet[1], V. Asper[2], A. Diercks[2], J. Chanton[3], A. Alldredge[1], B. Yan[4], U. Passow[1]
[1]UCSB, Santa Barbara, CA, [2]University of Southern Mississippi, Stennis Space Center, MS, [3]Florida State University, Tallahassee, FL, [4]Columbia University, Palisades, NY

Multiyear time series data (2012-2015) of sedimentation rates below 1200 m at three different sites in the Northern Gulf of Mexico (NGoM) revealed large spatial and seasonal variability and the occurrence of episodic events. Differences in sedimentation dynamics between the stations highlight spatial variability in ecosystem and food web structure and differences in source particles. Sedimentation rates near the Deepwater Horizon site (OC26) were relatively high and strongly impacted by Mississippi flow dynamics, with peak sedimentation rates of diatoms and polycyclic aromatic hydrocarbons in spring following high Mississippi discharge. Later in the year elevated sedimentation of organic carbon, but not biogenic silica, indicated sinking of non-diatoms. A more off-shore site, GC 600, which is much more oligotrophic, experienced peak sedimentation rates in fall, when mixed layer depth increased. Overall, samples at GC 600 were characterized by different types of fecal pellets, and a high diversity, but low abundance of biominerals and hard parts, like tinntinid lorica, foraminifera tests, pteropod shells, and crustacean molts. The lower C: N ratio and the PO13C (always $\delta > -23.5‰$) values do not indicate significant terrestrial contribution to sinking material at GC 600. A large sedimentation event of radiolarians frustules was observed in 2013 only, e.g. on an event scale. An overall analysis of sedimentation rates of different biochemical parameters, identifies relevant drivers of flux; the good correlation between sedimentation rates of biogenic silica, particulate organic carbon and transparent exopolymer particles, for example, implies that peak sedimentation events at all three sites were frequently dominated by the sinking of diatom blooms. The outliers of such correlations point to episodic or unusual events. Seasonal flux patterns allow inferences about water column processes and seasonality.

Mechanisms and Models of Aggregation and Sinking of Oil and Marine Particles

**A. Burd**[1], K. Daly[2], S. Francis[3], U. Passow[3]
[1]University of Georgia, Athens, GA, [2]University of South Florida, St. Petersburg, FL, [3]University of California Santa Barbara, Santa Barbara, CA

Oil from spills or natural seeps can aggregate with particles already present in the water column thereby affecting the fate and distribution of oil. Physical aggregation of particles is an important process in the oceans that repackages small, slowly sinking particles into larger, rapidly settling particles called “marine snow”. Similar aggregation processes between oil droplets and marine particles result in the formation of Marine Oil Snow (MOS). The properties of these aggregates depend on the size distribution and properties (such as density, geometry etc.) of the both the marine particles and the oil droplets. The formation of these particles allows oil to be transported from surface to deep waters and will affect the length scales for horizontal advection of oil by changing the rate at which oil is transported vertically. The physical processes leading to particle aggregation are well known and can be represented in models of varying degrees of complexity. Brownian motion and fluid shear are important for bringing smaller particles together. Differential sedimentation is an important process for larger particles that can increase the interaction frequency between large and small particles; this may be important to aggregation of marine particles with oil droplets. Scavenging of oil by sinking aggregates is likely to be an important loss process for oil contained in deep and intermediate layers such as those that formed after the Deepwater Horizon oil spill.



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Where Does All the Oil Go - Transformation and Fate of Spilled Oil in Marine Environments
**T. B. Oldenburg**, A. Jaggi, J. Radovic, R. W. Snowdon, R. C. Silva, S. R. Larter
University of Calgary, Calgary, AB, Canada

The understanding of processes involved in the transport and fate of petroleum constituents spilled in aquatic media has improved substantially since the Deepwater Horizon oil spill, occurred six years ago, yet assessing the long term impact of fossil fuel components on the environment and ecosystem remains challenging. Many petroleum constituents undergo multiple transformations during degradation, other weathering and sedimentation processes. Such transformations, driven by both biotic and abiotic factors, control the partitioning and transport of oil. These transformed oil components are mixed and diluted with other organic compounds deriving from terrestrial sources, natural oil seeps, and marine biological sources to form the dissolved organic matter (DOM) in the water column and eventually partially deposit at the seafloor.

Several experiments were carried out to study the diverse sources of DOM in marine systems such as marine/terrestrial biogenic sources, pyrogenic and petrogenic sources. In addition, DOM in water bodies was correlated to the DOM in the corresponding sediments and the organic matter of the sediments to evaluate their relationship. All these results were combined with the observations made on the composition of DOM in the water column and the organic matter in the sediments of the Gulf of Mexico for a more comprehensive understanding of the long-term transformation of petroleum. Cutting edge ultra-high resolution mass spectrometry was necessary to study these extreme complex mixtures on a molecular level. A 12T Bruker Fourier Transform Ion Cyclotron Resonance mass spectrometer combined with intelligent software tools were used to study the transformation and fate of the spilled oil in this marine environment.

These studies will help to better understand long term impacts of oil transformation products on marine ecosystems and to improve modeling systems which ultimately will provide guidance and assessment during oil spill accidents.

Distribution of Deposited Petroleum Hydrocarbons after the Deepwater Horizon Oil Spill
**I. C. Romero**[1], A. Diercks[2], K. Daly[1], J. Chanton[3], D. Hollander[1]
[1]University of South Florida, St Petersburg, FL, [2]University of Southern Mississippi, Abbeville, MS, [3]Florida State University, Tallahassee, FL

The Deepwater Horizon (DWH) was the largest accidental oil spill in history, with 4.9 million barrels of oil released, a discharge over approximately seven times larger than the average annual input of oil into the Gulf of Mexico (GoM). During the DWH spill, a large sedimentation event occurred of oil-associated marine snow that impacted a variety of ecosystems in the water column and seafloor. Despite the multiple reports on DWH oil on the seafloor across a broad range of environments, a comprehensive discussion of the distribution of specific petroleum-derived hydrocarbons at a large-spatial scale in the GoM is not available. Between 2010 and 2011, 688 sediment cores were collected at depths ranging from 79 to 2400 m to evaluate the sedimentary footprint of DWH. Results indicate 85% of the study sites were contaminated with DWH oil up to a distance of 180 km from the DWH site in deep-sea areas. About $17x10^5$ kg of petroleum hydrocarbons (higher than C9 saturated and aromatic fractions) were deposited (minus background concentrations) in the deep-sea sediments or about 2% of the total DWH hydrocarbon release. Chemical profiles in sediments indicate spilled oil underwent weathering during both lateral and vertical transport, and mixed with hydrocarbons in the water



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column. Hydrocarbon chemical composition will be discussed relative to primary and weathered DWH oil sources.

The temporal evolution of sediments and suspended particulate carbon following a massive oil spill in the northern Gulf of Mexico: 2010-2015

**K. Rogers***[1], J. Montoya[2], S. Weber[2], S. Bosman[1], B. Rosenheim[3], J. Chanton[1]
[1]Florida State University, Tallahassee, FL, [2]Georgia Tech, Atlanta, GA, [3]University of South Florida, St Petersburg, FL

Hydrocarbons released from natural seeps and the Deepwater Horizon blowout have been found incorporated into suspended particulate organic carbon in the water column and deposited on the sea floor in the northern Gulf of Mexico (GOM). We hypothesize that carbon pools with temporary, episodic sources of hydrocarbons, such as the Deepwater Horizon blowout (DWH), will recover to their "background" carbon isotope signatures over time, while sites influenced by submarine hydrocarbon seepage will not vary temporally. Particulate and sediment samples have been collected from 2010-2015 from across the northern GOM. Depth plays a significant role for water column suspended particulates; all shallow samples (< 300m) ($\delta^{13}C$ = -23.7‰±2.4; $\Delta^{14}C$ = -113‰ ±136) were enriched in both isotopes relative to deeper samples ($\delta^{13}C$ = -26.7‰ ±3.0; $\Delta^{14}C$ = -412‰ ±184). We have also observed significant isotopic depletion associated with major inputs of hydrocarbons, including GC600 ($\delta^{13}C$ = -26.1‰ ±2.2; $\Delta^{14}C$ = -584‰ ±94) and the DWH hydrocarbon plume ($\delta^{13}C$ = -24.9‰ ±3.0; $\Delta^{14}C$ = -271‰ ±184). However, we find no difference in isotopic composition between minor eastern seep sites ($\delta^{13}C$ = -28‰ ± 3.0; $\Delta^{14}C$ = -463‰ ±283) and GOM background sites ($\delta^{13}C$ = -27.8‰ ± 3.8; $\Delta^{14}C$ = -328‰ ±175). Sediments tell a different story. Areas affected by the DWH blowout are recovering towards background levels ($\Delta^{14}C$ = -501‰ in 2010 to $\Delta^{14}C$ = -237‰ in 2011), while seep sites show depletion throughout the entire core ($\Delta^{14}C$ = -800‰).

$^{13}C$ and $^{14}C$ isotopic distributions in sediment and suspended particulates in the southern Gulf of Mexico

**S. Bosman**[1], J. Chanton[1], D. Hollander[2], P. Schwing[2], I. Romero[2], E. Goddard[2], A. Gracia[3], E. Escobar[3], B. E. Rosenheim[2]
[1]Florida State University, Tallahassee, FL, [2]University of South Florida, St. Petersburg, FL, [3]Universidad Nacional Autónoma de México, Mexico City, Mexico

Over 100 sediment and water-column particulate samples were collected during 2015 and 2016 expeditions to the southern Gulf of Mexico (SGoM). Our objective is to develop both stable and radiocarbon isoscape maps of the current isotopic signature of core top/surface sedimentary organic carbon and suspended particulate organic carbon collected from filtered water at various depths throughout the water column in the SGoM. Ultimately, we intend to provide an isoscape of the 1980 immediate post-Ixtoc sediment surface. Surface sediment $\delta^{13}C$ values ranged from -19.9 to -22.4 ‰, with more depleted values located closer to the IXTOC-1 wellhead and coastal areas to the south and southwest. Surface sediment $\Delta^{14}C$ values ranged from -69.2 to -270.7 ‰. Water-column particulates, on the other hand, were considerably more depleted for both $\delta^{13}C$ (-22.5 to -28.2 ‰) and $\Delta^{14}C$ (-114.4 to -809.2 ‰). Particulates from surface waters and those filtered at the chlorophyll maximum (for sites >100 m in total depth) were generally more depleted in $\Delta^{14}C$ than those filtered below the chlorophyll maximum and near the sea floor, with the exception of the shallow site LT1 (16 m depth), located approximately 30 nm NW of Laguna de Terminos, Mexico. Particulates filtered at the chlorophyll



*Student presenter

maximum were most depleted in $\delta^{13}C$. Furthermore, surface particulates in the northern area of the sampling region were more $\Delta^{14}C$ depleted than those sampled in the southern region, becoming considerably less depleted toward Laguna de Terminos. A similar spatial pattern for $\delta^{13}C$ was observed. These results will provide the basis for mapping the background surface isotopic signature of sedimentary organic carbon and suspended particulate organic carbon in the SGoM, information necessary to guide assessment, impacts, recovery, and response efforts for future oil spills.

From Spill to Sink: Using Bacterial Lipid Biomarkers to Trace and Predict the Fate of Deepwater Horizon Hydrocarbons in Gulf of Mexico Sediments

**S. A. Lincoln**, U. Nguyen, K. H. Freeman
The Pennsylvania State University, University Park, PA

Microbial carbon assimilation and remineralization influence the ultimate fate of most hydrocarbons released into marine environments. These processes operate over a broad range of time scales; for instance, plumes of dissolved gases promoted blooms of methanotrophs within weeks of the Macondo well blowout (1), while the biodegradation of complex crude oil components buried in anoxic sediments may be insignificant over millennia. Genetic studies are valuable in identifying key microbial agents and mechanisms of Deepwater Horizon hydrocarbon degradation but their temporal utility is limited by the short half-lives of nucleic acids in the environment. In this study, we mapped sediment inventories of membrane lipid biomarkers to better understand patterns and magnitudes of microbial responses to the DWH oil spill. In particular, we focused on bacteriohopanepolyols (BHPs), polar lipids that can represent specific bacterial clades and, by extension, biochemical processes. 3-methyl BHP, considered a marker for aerobic methanotrophy, was present in sediments near the Macondo wellhead, and is likely derived from methanotrophs active in plumes of dissolved gases associated wth the DWH event. We also mapped distributions of other informative BHPs including adenosylhopane, a tracer of terrestrial organic matter input potentially delivered to the seafloor by a post-DWH sedimentation pulse (2); and a BHP isomer synthesized by anammox bacteria (3), likely reflecting transient suboxia in the water column or surface sediments. (1) Crespo-Medina, M., et al., 2014. *Nature Geosciences* 7, 423-427. (2) Brooks, G., et al., 2015, *PLOS One*, DOI /10.1371/journal.pone.0128371 (3) Rush, D., et al., 2014, *Geochimica et Cosmochimica Acta* 140, 50-64.

Potential for Iron-Driven Degradation of Hydrocarbon in Sediments near the Macondo Blowout

**J. Beckler**[1], E. Eitel[2], S. Owings[2], R. Sekar[2], T. DiChristina[2], M. Taillefert[2]
[1]Mote Marine Laboratory, Sarasota, FL, [2]Georgia Institute of Technology, Atlanta, GA

The characterization of sediment biogeochemistry at high spatial resolution is a necessary step in predicting the pathways and extent of oil degradation in areas affected during and after a spill. However, geochemical data for sediments from deeper environments are scarce, and most studies do not measure the full suite of terminal electron acceptors (TEA) involved in sediment diagenesis ($O_2$, $NO_3^-$, $NO_2^-$, Fe(III) and Mn(IV) oxides, $SO_4^{2-}$). In this study, sediments from the northern GOMEX were profiled using voltammetric Au/Hg microelectrodes to determine the vertical distribution of the main TEAs or their reduced metabolites with a high spatial resolution. Drastically different profiles were obtained for shelf and slope sites with respect to pore water and solid phase chemistries, suggesting spilled oil may have been exposed to different conditions after sedimentation. Surprisingly, microbial metal reduction dominated on the continental slope, farther away from terrestrial sources, whereas $SO_4^{-2}$ reduction was much more prevalent on the shelf. On the other hand, microbial metal reduction



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may be an important process in salt marsh sediments subject to tidal irrigation and thus intermittent regeneration of Fe(III) via oxygenation. Moreover, in recent laboratory incubations with the dissimilatory iron-reducing bacterium *Shewanella oneidensis*, high concentrations of organic contaminants were degraded rapidly via Fenton reaction during controlled oxic/anaerobic cycling with iron(III) as a substrate. These results highlight the potential importance of this process near the sediment-water interface in continental margin sediments dominated by Fe(III) reduction, as well as at greater depths in sediments in hydrodynamic environments where sediment irrigation is significant (e.g. estuaries and salt marshes). Although this process is largely dependent on the depositional regimes of terrigenous minerals, it may also be controlled by other factors such abiotic titration of the Fe(III) oxides substrate by $\Sigma H_2S$ in the seasonal hypoxic zone or shelf-spillover during storms and mass-slumping. Together, these results demonstrate the potential for a novel, natural pathway for oil degradation and suggest modeling efforts must consider sediment heterogeneity when predicting the fate of oil in sediments.



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## Session 017: Genomics and Modeling of Biological Communities to Improve Predictions of Ecosystem Response to and Mitigation of Spilled Oil

### Using omics approaches to track the response of microbial hydrocarbon degraders to natural and anthropogenic hydrocarbon inputs

**S. Joye**
University of Georgia, Athens, GA

Hydrocarbon oxidizing microbial communities are ubiquitous in oceanic environments. However, the diversity and dynamics of these communities remain poorly constrained. While it is clear that their response to hydrocarbon inputs is dynamic and complex, a clear understanding of the factors that regulate these responses remains elusive. Recent advances in meta-omics techniques have driven numerous discoveries regarding the diversity, identity, and activity patterns of hydrocarbon degrading microbial communities. Even though hydrocarbon degraders are present at low abundance under substrate-limited conditions, they respond swiftly to hydrocarbon inputs - whether large or small. Applying metagenomic and metatranscriptomic techniques to field samples and to targeted experimental samples (e.g. stable isotope probing) has helped identify novel hydrocarbon degraders and is allowing us to begin to unravel the environmental factors modulating hydrocarbon degrading microbial networks. In this talk, the response of methane and oil degrading microbial communities to the large hydrocarbon inputs observed in the wake of the Deepwater Horizon incident will be compared to those documented at natural seeps and laboratory experiments. The importance of targeted laboratory experiments, in which exposure regimes can be controlled and well replicated, will be illustrated using several examples. Finally, meta-omics data from both field and laboratory experiments provide valuable insight to help guide and improve response measures; these potential improvements will be highlighted and discussed.

### Mimicking the Deepwater Horizon Blowout in the Laboratory Reveals a Diverse Microbial Population Responsible for the sequential Degradation of Oil in Deep Ocean Plumes

**G. L. Andersen**[1], P. Hu[1], E. A. Dubinsky[1], P. Gardinali[2], C. M. K. Sieber[3], L. M. Tom[1], A. J. Probst[4], J. F. Banfield[4], R. Atlas[5]
[1]Lawrence Berkeley Lab, Berkeley, CA, [2]Florida International University, Miami, FL, [3]Joint Genome Institute, Walnut Creek, CA, [4]University of California, Berkeley, CA, [5]University of Louisville, Louisville, KY

After the BP Deepwater Horizon (DWH) accident that released an estimated 4.9 million barrels of oil and $10^{10}$ moles natural gas into the Gulf of Mexico, indigenous microbial communities have been subjected to many studies on their hydrocarbon degradation activities. Metagenomic, metatranscriptomic and microbial community studies consistently showed a pattern of succession in deep oil plumes during and after the event. In this study, we reproduced the dispersed plumes of fine oil droplets in Gulf of Mexico seawater, and faithfully replicated the occurrence and succession of the principal oil-degrading bacteria observed in the field. Here we showed that patterns of microbial succession observed during the DWH event were likely driven by the availability of liquid petroleum hydrocarbons rather than natural gases. We recovered the near complete genomes that matched the principal biodegrading taxa observed in the field, including DWH *Oceanospirillum*, multiple *Colwellia*, *Cycloclasticus*, other members of Gamma-Proteobacteria, Flavobacteria and Rhodobacteria. Genome analysis revealed metabolic capabilities that explained patterns of species succession among oil-



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degrading bacteria, and potential cooperative or competitive relationships among closely-related taxa. Resolved genomes showed that phylogenetically similar genomes may not possess the same hydrocarbon degradation genes or be equally successful in the community. Highly dispersed oil droplets stimulated a diverse metabolic response by indigenous bacteria that rapidly consumed spilled hydrocarbons at depth.

Assembly, Succession and Activity of Marine Microbial Hydrocarbon-Degrading Communities at Low Temperatures

**L. Vergeynst**[1], P. Lassen[1], T. Dalsgaard[1], K. U. Kjeldsen[1], S. Rysgaard[1, 2]
[1]Aarhus University, Aarhus, Denmark, [2]University of Manitoba, Winnipeg, MB, Canada

Few studies have investigated how low temperatures shape the assembly and succession of hydrocarbon-degrading microbial communities. In this comprehensive study, microcosms with 100mL seawater sampled in Aarhus Bay, Denmark, were incubated with 100µL marine diesel for up to 3, 5 and 9 months at 15, 4 and 0°C, respectively. For each temperature, series of 7 triplicate microcosms were setup and triplicates were periodically sacrificed for analysis of residual hydrocarbons, total bacterial carbon content and community profiling by Illumina sequencing of bacterial 16S rRNA.

The microbial community mineralized ($CO_2$ production) hydrocarbons at all temperatures and produced on average 20 µmol $CO_2$ per day at 15°C, which was 2.4 and 15-times faster than at 4°C and 0°C, respectively. Most genera were enriched at all 3 temperatures, however, at faster rates at 15°C than at 4°C and 0°C. Cluster-based analysis of the microbial community composition revealed that a similar succession of bacterial genera took place in all treatments, but at slower rates at lower temperatures. At 4 and 0°C, the succession was about 2.4 and 15-times slower as compared to at 15°C. Clustering of the whole community into correlated sub-communities showed the succession of that at least 4 consortia of bacterial genera. These consortia were characterized by typical growth patterns, which consisted of an exponential growth phase, followed by a stationary phase and subsequently decay. For example, *Colwellia* spp., a genus found in the deep sea after the Deepwater Horizon oil spill, had doubling times of about 0.7, 2.3 and 8.2 days at 15, 4 and 0°C, respectively and reached in approximately 10, 20 and 100 days a stationary phase with equally high abundances at all temperatures. Similarly, *Cycloclasticus* spp., a genus known as PAH degraders, had doubling times of 0.4, 1.2 and 17.4 days during the exponential phase and reached a stationary phase with equal abundances in about 15, 30 and 150 days at 15, 4 and 0°C, respectively. The community patterns will be related to the observed hydrocarbon degradation patterns.

In conclusion, our results imply that the slower microbial community succession at lower temperature should be taken into account when studying the effect of temperature on the microbial community structure.

Deep Sea in a Can: Selective Evaluation of Crude Oil Biodegradation under High Pressure Conditions

**J. Viamonte***, S. Hackbusch, N. Noirungsee, P. Bubenheim, R. Müller, A. Liese
Institute of Technical Biocatalysis, Hamburg University of Technology, Hamburg, Germany

In April 2010 a vast oil spill was released into the ocean after the explosion of the Deepwater Horizon (DWH) platform in the Gulf of Mexico. Short and long term impacts, which originated after the blowout, are in the focus of investigation. Among them, one of the most significant consequences



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evaluated comprises the appearance and development of specific microbial communities, which are directly responsible for the degradation of crude oil at high pressure conditions present in the deep sea.

Based on data recently published [1], it has been demonstrated that there are differences in the degradation rates of crude oil by biodegrading microorganisms, depending on the chosen pressure conditions, at a given temperature. Aiming at gaining a deeper knowledge of the role of oil degrading microorganisms after the blowout, *in situ* conditions of pressure (150 bar) and temperature (4°C) are simulated in lab-scale high pressure reactors. By means of crude oil clean-up and specific fractionation procedures, the extent and rates of biodegradation for various key target compounds in petroleum is assessed performing selective GC-FID/GC-MS analyses.

Due to the increase in global crude oil demand and oil depletion in existing wells, deeper extraction sites than the DWH are expected in a near future [2]. In order to develop a simple high pressure crude oil biodegradation model (HPOB model) aiming to forecast degradation patterns for future deep water oil spills, different physicho-chemical variables related with the DWH blowout (i.e. pressure, temperature, coexisting compounds) need to be investigated. Therefore, biodegradation extent, determined by correlations of diagnostic ratios for selected target hydrocarbons, will be assessed for several types of crude oil at different pressures (up to 400 bar), evaluating also the effect of dispersants and methane mixtures on the bacterial degrading abilities. [1] Schedler et al. 2014. *AMB Express* 4:77. [2] Miller et al. 2014. *Phil. Trans. R. Soc. A* 372:20130179.

Assessing microbial bioremediation potential for marine oil and transportation fuel spill scenarios across the Canadian Arctic

A. Noël, **C. Hubert**
University of Calgary, Calgary, AB, Canada

The Arctic is experiencing extraordinary changes according to both environmental and socioeconomic indicators. Reduced sea ice cover and ice-free summers have led to a tripling in vessel traffic in the Canadian Arctic since 1990. This brings greater risk of accidental spills of crude oil and transportation fuels. Whether bioremediation holds potential for spill mitigation depends on the capacity for hydrocarbon biodegradation by microbial populations in this permanently cold environment. To assess low temperature bioremediation potential of the marine microbiome in the Canadian Arctic, marine sediment microbial communities were investigated from western, central and eastern regions of the Canadian Arctic (i.e. the Beaufort Sea, Northwest Passage, and Baffin Bay, respectively). Surface sediments were sampled using a box corer deployed from the Canadian Coast Guard's research icebreaker *Amundsen*, and used to establish sediment microcosms that were amended with crude oil, diesel or bunker fuel and incubated at 4 degrees C to simulate different spill scenarios for different geographic regions. In Beaufort Sea and NW Passage experiments crude oil and diesel amendments resulted in more rapid oxygen depletion and $CO_2$ production compared to amendment with bunker fuel. 16S rRNA gene amplicon libraries revealed that under all three conditions for both locations, Gammaprotobacterial *Cycloclasticus*, *Perlucidibaca*, *Oleispira* and *Thalassolituus* spp. were enriched, with different OTUs being most prominent under different conditions. In the Baffin Bay experiments diesel amendment resulted in the slowest response and coincided with an enrichment in Alphaproteobacteria (>33% *Sphingorhabdus*) whereas more rapid metabolism with crude oil and bunker fuel amendments still led to mainly Gammaproteobacterial enrichment. These results demonstrate potential for hydrocarbon-degrading bacterial activity in cold Arctic seas, while also



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revealing that the biodegradation response is not necessarily uniform for different spill types in different regions. Microbial genomics thus holds potential for revealing biogeographic patterns among hydrocarbon biodegrading bacterial populations within this microbiome, and may help to predict bioremediation responses in the Arctic marine environment.

Predicting Benthic Microbial Communities throughout the Gulf of Mexico and Hindcasting Impacts from the DWH

**W. A. Overholt***[1], P. Schwing[2], D. J. Hollander[2], J. E. Kostka[1]
[1]Georgia Institute of Technology, Atlanta, GA, [2]University of South Florida College of Marine Science, St. Petersburg, FL

The microbial ecology of oligotrophic deep ocean sediments is understudied relative to their shallow or natural hydrocarbon seep counterparts, and this lack of understanding hampers our ability to predict responses to current and future perturbations. The Gulf of Mexico has experienced two of the largest accidental marine oil spills, with the 1979 Ixtoc-1 blowout in the Southern Gulf of Mexico (GoM) and the 2010 Deepwater Horizon discharge in the Northern GoM. In the case of the Deepwater Horizon spill, approximately 10% of the oil released was thought to have been transported to the seafloor where it was subject to degradation and transformation by sedimentary microorganisms. However, prior to the Deepwater Horizon disaster, the microorganisms present in the oligotrophic Gulf of Mexico deep seafloor were virtually unknown. Thus, the objectives of this research are to (1) characterize deep ocean sedimentary microbial communities to establish baseline conditions over large spatial scales, and (2) effectively model the microbial community response to sedimentary oil deposition to guide future response efforts. Microbial communities were elucidated through next generation sequencing of SSU rRNA gene sequences for 23 and 10 sites across multiple years in the northern and southern Gulf of Mexico, respectively, representing >500 samples. The results are incorporated into a depth stratified model delimiting microbial community structures across the Gulf, dependent on environmental parameters including: water depth, sediment depth, latitude and longitude. Microbial community structure is linked to oxygen penetration depth and sediment geochemical regime, which are likely controlled through carbon delivery. The distributions of key microbial populations can be calculated and constrained while deviations from these predictions may be evaluated to pinpoint impacted sites.

Storm-driven Transport of Crude Oil Aggregates and Associated Microbial Populations across a Coastal Headland Beach

**V. Elango**, L. Fitch, Z. Romaine, J. Pardue
Louisiana State University, Baton Rouge, LA

Oil deposited on the Fourchon Beach, Louisiana during the Deepwater Horizon event consisted of various aggregates of oil, sand and shell including surface residue balls (SRBs) and submerged oil mats (SOMs). SOMs represent aggregate crude oil form with a higher crude oil content found in the inshore surf zone in troughs between sand bars or, on coastal headland beaches, associated with offshore relict marsh platforms. These contiguous mats can also be buried on the intertidal and supratidal portions of the beach, and exposed to the surface during erosional washover events. The objectives of this study are to evaluate the extent of weathering in different oil forms collected after washover events, along the Fourchon Beach shoreline from 2011 to 2013 and to characterize the microbial community present in SOMs and SRBs that are transported as these aggregates are mobilized. Three-ringed PAHs in onshore and offshore SOMs sampled from 2011 to 2013 were poorly weathered and were similar to oil



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sampled near the wellhead in 2010. SRBs were more susceptible to weathering and had weathering ratios distributed over the largest range. Alkylated dibenzothiophenes appeared to be preferentially weathered relative to alkylated phenanthrenes. Weathering of PAHs in SRBs depended on the time of sample collection with least weathering in SRBs collected close to the washover events. In microbial community structure determined by Mi-Seq genomic sequencing from DNA extracted from the aggregates, Gammaproteobacteria was the most dominant phylotype in most of the samples followed by Alphaproteobacteria. Acetobacteraceae belonging to Alphaproteobacteria was the most dominant group of organisms in the most weathered SRBs, and accounted for 29 to 38% of the total abundance. Clustering of microbial community evaluated by non-metric multidimensional scaling (NMDS) demonstrated the clustering of most weathered SRBs together, while the less weathered SOMs clustered differently. Based on the dominance of Acetobacteraceae in the most weathered samples observed in this study, it is possible that biodegradation components in weathered crude oil may be influenced by Acetobacteraceae.

Aerobic Biostimulation of Buried MC252 Oil: Metagenomic and Biogeochemical Assessment of a New Response Approach

**L. Fitch**, Z. Romaine, V. Elango, J. Pardue
Louisiana State University, Baton Rouge, LA

Hard structure used on Fourchon Beach, LA to mitigate the transport of MC252 oil into adjacent marshes created conditions for oil burial across the beach profile. Mechanical removal did not prevent the vertical transport of accumulated oil into the subsurface and contamination of groundwater and sediments. Groundwater at the site is hypersaline (>50 ppt) and anaerobic (DO below 0.2 mg/L). Persistence of 3-ring PAHs (alkylated phenanthrenes, dibenzothiophenes) and 4-ring alkylated chrysenes were observed in subsurface sediments 5 years after the spill. A multi-well oxygen injection system was installed at the site to evaluate aerobic biostimulation to shift the microbial community with oxygen addition. Initially oxygen was supplied to the groundwater using diffusion based Waterloo emitters before transitioning to more aggressive delivery approaches. Alkylated phenanthrene and dibenzothiophenes levels in pre-aeration sediments evaluated through weathering ratios to alkylated chrysenes were close to the levels in freshly-spilled MC252 oil. Post aeration evaluation of sediment Geoprobe cores demonstrated increased weathering of alkylated phenanthrenes and dibenzothiophenes consistent with aerobic biostimulation. Stable isotopic and radiocarbon analysis of dissolved inorganic carbon also suggested crude oil mineralization post-aeration, even in areas that had the highest level of oil contamination. Oxygen delivery through pressurized tubing increased groundwater dissolved oxygen levels from 15.3±2.6 to 17.3±4.4 mg/L in the oxygen delivery wells. Metagenomics analysis of Geoprobe collected core sections revealed shift in the composition of the diverse, halophilic, hydrocarbon-degrading microbial population. *Marinobacter* was the dominant population in the pre aeration sediments. However, addition of oxygen increased the abundance *Halomonas*.

Monitoring Degradation of Pico-liter Oil Droplets by Physical and Biological Processes

**M. Jalali-Mousavi**, j. Sheng
Texas A&M University-Corpus Christi, Woodbury, MN

Every year a large amount of crude oil enters the marine environment and marks the oil pollution as a significant concern. The indigenous oil degrading microorganisms have been suggested to have a



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substantial role in degrading petroleum hydrocarbons by utilizing the components as a source of nutrition and carbon. In this work we investigated the volume change of oil microdroplets exposed to oil degrading bacteria. We used an oil and oil-surfactant combination to quantify the effect of surfactant, Corexit 9500, on this process. To evaluate the biodegradation, we employed three different bacteria, *Pseudomonas sp*, *Alcanivorax borkumensis*, and *Marinobacter hydrocarbonoclasticus*. To conduct this study, we designed and developed a chamber with a bottom glass substrate printed with an array of pico-liter oil droplets using micro-transfer printing. Since the droplet arrays are highly uniform in dimension and volume in addition to being pinned on the glass substrate and stationary, individual droplets can be monitored during the exposure to abiotic/biotic solutions. Atomic force microscopy was used to measure the precise volume of the droplets prior and after each experiment. To evaluate the actual oil consumption, the dissolution was initially determined. The results indicated that addition of dispersant did not have a significant effect on oil dissolution. Experiments involving different bacterial strains, dispersant concentration, and flow shear rate are on-going.

Dynamics of 3 Phytoplankton Species and their Attached and Free-Living Bacteria in Response to Dispersed and Undispersed Crude Oil

**T. Severin**, D. L. Erdner
Marine Science Institute, University of Texas at Austin, Port Aransas, TX

In the environment, the taxon-dependent phytoplankton oil responses can lead to a phytoplankton community shift, which can in turn affect the entire marine food web. Despite the numerous studies of oil effects on phytoplankton physiology, few of them consider associated bacteria as potential participant in the phytoplankton oil response. Yet, recent studies reveal strong phytoplankton-bacteria interactions that are beneficial for both organisms. Further, some phytoplankton species select their associated bacteria, leading to different bacteria communities from one phytoplankton strain to another. Thus, we hypothesize that the taxon-dependent phytoplankton oil response results from the combination of the phytoplankton physiology and its species-specific bacterial interactions.

To test this, we exposed two armored dinoflagellates (*Heterocapsa* sp. and *Alexandrium tamarense*) and one diatom (*Odontella* sp.) to crude oil and/or dispersant and followed the physiology and activities of both phytoplankton and the associated bacteria, which includes the phytoplankton-attached (PA) and free-living (FL) bacteria community assemblages. For all the phytoplankton strains exposed to oil and dispersant, their lower growth rate in the absence of bacteria confirmed the bacterial involvement in the phytoplankton oil resistance. Moreover, the PA and FL bacterial communities exhibited distinct ectoenzyme activities and community structures. The FL community significantly changed to degrade oil, evidenced by the development of known oil-degraders like *Alcanivorax*, *Marinobacter* and *Nautella*, while the PA community was unchanged and maintained direct exchanges with their host. Finally, the different PA communities associated to each phytoplankton strain could explain the taxon-dependent phytoplankton oil response. Future studies of phytoplankton and PA bacteria meta-transcriptomes will give more insights into these species-specific interactions.



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Oil and Corexit Alter Planktonic Microbial Eukaryotic Community Structure in Mesocosm Experiments
**Z. V. Finkel**[1], C. M. Brown[1], A. S. Quigg[2], S. Setta[2], L. Bretherton[2], A. J. Irwin[1]
[1]Mount Allison University, Sackville, NB, Canada, [2]Texas A&M Galveston, Galveston, TX

To better understand the effects of oil spills and remediation with dispersants such as Corexit, we conducted a mesocosm experiment using natural microbial populations from a coastal region of the Gulf of Mexico. In addition to the control, we employed three treatments, a water accommodated fraction of oil (WAF) and two concentrations of oil combined with Corexit (chemically enhanced WAF or CEWAF, and dilute CEWAF). Each mesocosm was seeded with concentrated plankton slurry collected near Galveston Bay and conducted in triplicate. After 48 hours we collected samples from the water column of the mesocosms, extracted RNA, and used high-throughput sequencing to obtain the transcriptome. We then identified 18S sequences from our transcriptome using 18S rRNA databases from the Moore Microbial Eukaryote Transcriptome Sequencing Project (355 species) and the Silva database of eukaryotic 18S rRNA (36561 samples). In the WAF treatment, the relative abundance of diatoms and dinoflagellates decreased while the relative abundance of a number of diverse heterotrophic flagellates (Bigyra and Chrysophyceae) increased. The most conspicuous changes in the CEWAF and dilute CEWAF treatments were an increase in the relative abundance of decomposers (Ascomycota) and Green algae (Chlorophyta) and a decrease in the relative abundance of some of the dominant heterotrophic flagellates. In summary, WAF and CEWAF treatments are associated with large-scale restructuring of the eukaryotic microbial community, changing the relative abundance of major taxonomic groupings and many individual species.

Using Genomics to Understand Impacts of the Deep Water Horizon Oil Spill on Macroorganisms
**D. S. Portnoy**
Texas A&M University - Corpus Christi, Corpus Christi, TX

Understanding impacts of the Deep Water Horizon Oil Spill on the genetic diversity of wild populations of marine organisms requires a connection between individual-level effects and population-level processes. Mass DNA sequencing provides an important tool for this purpose because it allows efficient production of reduced-representation genomes for multiple individuals in real time. In addition, one can generate whole transcriptomes and identify both functional genes and patterns of DNA methylation (gene regulation) across a genome. Genomic tools also allow changes in gene function to be characterized at the individual level, and heritable changes, both genetic and epigenetic, at the population level. Field samples from wild populations can be screened for whole genome change associated with increased mortality stemming from natural or anthropogenic causes and for changes in specific genes and demographic processes related to selective mortality. Laboratory- and field-based studies can be linked through the use of common study species and/or through comparative genomics. These synthetic approaches have utility beyond oil spills and can be used to understand both natural and human-induced genetic change.



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Comparative transcriptomic analysis of mahi-mahi (*Coryphaena hippurus*) and red drum (*Sciaenops ocellatus*) embryos and larvae reveals key toxicity pathways in response to Deepwater Horizon oil

**D. Schlenk**[1], E. Xu[1], M. Grosell[2], A. J. Esbaugh[3], E. Hazard[4], G. Hardiman[4]
[1]University of California, Riverside, Riverside, CA, [2]University of Miami, Miami, FL, [3]University of Texas, Austin, TX, [4]Medical University of South Carolina, Charleston, SC

The Deepwater Horizon (DWH) oil spill impacted pelagic & shoreline habitats of many commercially important fish species. Exposure to the water accommodated fraction (WAF) of DWH oil causes developmental toxicity in a number of fish species, but the molecular mechanisms of the toxicity are not thoroughly understood. Unraveling the potential molecular mechanism of oil toxicity is essential for understanding & predicting the Adverse Outcome Pathway (AOP) for oil-related toxicities. We investigated the time-course of transcriptional responses to two types of oil exposures as WAF from weathered slick oil & a non-weathered DWH source oil in embryos & larvae of a pelagic species, mahi-mahi (*Coryphaena hippurus*) & a coastal species, red drum (*Sciaenops ocellatus*). By means of high throughput sequencing (HTS), we obtained the *de novo* transcriptomes of the two species. Uniform processing & comprehensive annotation allowed comparison across species of gene ontology (GO) by ToppGene & toxicity pathways by Ingenuity Pathway Analysis. The most impacted toxicity pathways in common included EIF2 signaling, cardiac β-adrenergic signaling, CREB signaling in neurons, & hypertrophy of cardiomyocytes, with more pronounced changes at later larval developmental stages. A list of co-expressed genes was also identified as potential biomarkers, e.g. RPS9 in EIF2 signaling; FHL2 & EDNRA in heart hypertrophy. The results provide information for the construction of an AOP which could be useful in Ecological Risk Assessment. 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).

Enhanced developmental PAH toxicity under adverse environmental conditions in Sheepshead minnow (*Cyprinodon variegatus*).

**D. J. Simning***[1], S. Chen[2], C. Perkins[3], T. Bosker[4], M. Sepúlveda[5], S. De Guise[3], R. Griffitt[1]
[1]University of Southern Mississippi, Ocean Springs, MS, [2]Washington University, St. Louis, MO, [3]University of Connecticut (UCONN), Storrs, CT, [4]LUC The Hague – Leiden University, The Hague, Netherlands, [5]Purdue University, West Lafayette, IN

The oil released from the 2010 Deepwater Horizon oil spill has had many negative impacts on estuarine ecosystems along the northern Gulf of Mexico (nGoM). These same ecosystems are also seasonally affected by extreme environmental conditions such as elevated temperatures, increased salinities, and low levels of dissolved oxygen. The impacts of simultaneous polycyclic aromatic hydrocarbon (PAH) exposure and extreme environmental conditions on ecosystem health are unclear. Past research has documented potential competitive inhibition between the Aryl Hydrocarbon Receptor Signaling pathway (AhR), responsible for PAH metabolism, and the Hypoxia Inducible Factor 1-α pathway (HIF-1α), responsible for resilience to hypoxic stress, during co-exposure to both stressors. The purpose of this research was to investigate potential cross-talk between the AhR and HIF-1α pathways during early life development of the sheepshead minnow (*Cyprinodon variegatus*) using qPCR and RNA sequencing. Early life development was divided into three stages, embryonic (15 hpf), post-hatch (4 dpf), and post-larval (8 dpf). All three developmental stages were exposed to different concentrations of HEWAF under varying oxic and salinity regimes for a 48 h period and then placed into clean, normoxic water for the duration of the experiment. Gene expression from qPCR analysis demonstrated suppression of both defense pathways in high HEWAF concentrations under hypoxic and high salinity conditions.



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Pathway analysis from RNA sequencing data collected from the post-hatch developmental stage identified multiple pathways affected following exposure to PAHs, including the aryl hydrocarbon receptor signaling, xenobiotic metabolism signaling, bupropion degradation, and acetone degradation I pathways. Our data suggest that developing organisms in habitats with extreme environmental fluctuations may be particularly vulnerable to PAH toxicity.

Differential Gene Expression in the Hepatic Tissue of CEWAF Exposed Red Drum (*Sciaenops ocellatus*) Using RNA-seq

**T. A. Sherwood**
Mote Marine Laboratory, Sarasota, FL

RNA sequencing (RNA-seq) technology has become a useful tool for investigating biological processes of fish effected by exposure to oil and dispersant. This technology gives a snap shot of all the gene transcripts that are differentially expressed in a tissue at a given moment of time. One key advantage of this type of gene expression analysis is that no genome information is needed, making it ideal for non-model wild species, such as red drum. For these reasons, this technology was utilized to explore the molecular pathways that are most effected in juvenile red drum that were exposed to a mixture of Louisiana crude oil and Corexit 9500 dispersant as a chemically enhanced water accommodated fraction (CEWAF). This was part of an uptake and depuration study that was conducted in which juvenile red drum were exposed to CEWAF (1ppm) for a period of four days and allowed six days of recovery in seawater. Day three of CEWAF exposure was chosen for sampling the livers for RNA-seq analysis. Liver samples were collected from red drum controls and CEWAF exposures. RNA was extracted from the livers and sequenced using the Illumina HiSeq2500 platform and bioinformatics by Omega Bioservices (Norcross, GA). Differential gene expression in the liver of controls and CEWAF exposed red drum was carried out using the DESeq2 package in which count data from the RNA-seq is assigned to each gene. This analysis generated over a 100,000 gene transcripts of which several hundred were significantly differentially expressed in the livers of CEWAF exposed red drum compared to the controls. These gene transcripts were then annotated using Blast2GO and the biological processes significantly impacted by CEWAF exposure will be presented.

The effects of time, space and the Deepwater Horizon oil spill on the genomes of red snapper (*Lutjanus campechanus*)

**A. T. Fields**[1], J. B. Puritz[2], D. H. Kulaw[1], J. R. Gold[1], D. S. Portnoy[1]
[1]Texas A&M University - Corpus Christi, Corpus Christi, TX, [2]Northeastern University, Boston, MA

Red snapper is a recreationally and commercially important fisheries species in the Gulf of Mexico (Gulf) and thus extensively studied. However, the effects of the Deepwater Horizon oil spill on this species are currently not fully understood. Without knowledge of both the localized effects of the spill on red snapper and how much connectivity there is across the Gulf, we cannot understand the implications of this event. To better understand how the Deepwater Horizon oil spill may have affected red snapper, we compared the genomes of adults caught in 2005 with adults caught in 2011 from the Mississippi-Alabama shelf using double-digest restriction-site associated DNA tags (ddRAD). To account for spatial and temporal patterns of genetic change which are unrelated to the oil spill, we used samples of adults from off the Texas and Louisiana coasts captured over the same time periods for comparison.



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Investigating the response of cold-water corals to oil and dispersant exposure using transcriptomics
**D. M. DeLeo***, E. E. Cordes
Temple University, Philadelphia, PA

The 2010 Deepwater Horizon (DWH) disaster and subsequent cleanup efforts released an unprecedented amount of oil and chemical dispersants in the deep waters of the Gulf of Mexico (GoM). Detrimental effects have since been documented including impacts to cold-water coral communities. Understanding how corals respond to these environmental pollutants, including the effects of exposure at the cellular level, is essential to determining both short and long-term consequences to coral populations in the deep sea. RNA was extracted from two octocoral species experimentally exposed to crude oil and chemical dispersant, *Callogorgia delta* and *Paramuricea type B3*, to investigate the genome-wide influence on coral gene expression. Sequences were mapped to *de novo* reference transcriptomes to explore the stress-induced variations in gene expression and for comparison to expression signatures of an *in situ* exposed octocoral, *Paramuricea biscaya*. The RNAseq analyses revealed a heterogeneous response among genotypes to the treatments, with similarities in global gene expression observed between the control and oil-only treatments and likewise, the dispersant-only and oil/dispersant mixture treatments. A large portion of genes that were significantly differentially expressed were found in the dispersant treatments. A subset of genes differentially expressed *in situ* were also found among experimentally exposed corals. Our results provide insight into the response of cold-water corals to oil exposure, implications of using dispersants and novel reference assemblies for two deep-water species. The gene expression data in addition to the reference assemblies, will be useful for developing biomarkers for assessing and monitoring future spill impacts as resource extraction continues in the deep waters of the GoM.

Ecology and Evolution of Deep Sea Coral Associated Bacterial Communities
**I. Baums**, R. Dannenberg, D. Ruiz, S. Vohsen, C. Fisher
The Pennsylvania State University, University Park, PA

Deep-sea corals form habitat for many associated organisms, including diverse microbial communities. Corals in the Gulf of Mexico are regularly exposed to natural and anthropogenic sources of complex hydrocarbons (oil). The goal of this work is to characterize the microbial communities associated with deep water corals, with a particular focus on the black coral *Leiopathes glaberrima* (Anthipatharia). We aim to understand the role of microbial communities in the response of holobionts to natural and anthropogenic oil and dispersant exposure. Experimental exposure of *L. glaberrima* colonies to low concentrations of oil indicated that the holobiont may be able to metabolize oil, albeit the colonies were sensitive to dispersant and oil-dispersant exposure. Illumina RNA-seq transcriptomic analysis of the holobiont point to intra-species variability of stress response with white coral colony morphotypes showing more signs of stress then red coral colonies. Liquid Chromatography-Mass Spectrometry (LC-MS) metabolomic analysis similarly yielded differences between red and white colonies exposed to oil and dispersant. Metagenome sequencing and bacterial gene expression analyses are underway to characterize the metabolic potential of the bacterial community in the two color morphotypes of this cosmopolitan foundation species. Complementary to the experimental oil exposure experiments, the microbial communities of *L. glaberrima* and other coral species from sites naturally rich in oil and gas was evaluated to provide context for anthropogenic disturbances. This is the first comprehensive analysis of the bacterial diversity, metabolic potential and holobiont molecular response of a black coral to oil and oil-dispersant exposure and builds the foundation for understanding the ecology and evolution of bacterial symbionts in other deep-sea corals



*Student presenter

Genomic Responses to the Deepwater Horizon Event and Development of High-throughput Biological Assays for Oil Spills

**J. Sevigny***[1], F. Leasi[2], K. S. Diaz[1], M. Rohal[3], M. Reuscher[3], K. Morris[1], P. Montagna[3], W. Thomas[1]
[1]Hubbard Center for Genome Studies, University of New Hampshire, Durham, NH, [2]Smithsonian Institution, National Museum of Natural History, Dept. of Invertebrate Zoology and Global Genome Initiative, Washington, DC, [3]Harte Research Institute for Gulf of Mexico Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX

Benthic organisms smaller than 2 mm (meiofauna) are important contributors to ecosystem functioning through their roles in nutrient transport, sediment stability, and food web interactions. Meiofaunal biodiversity potentially reflect environmental changes, which can be revealed almost instantly thanks to the short generation time and low dispersal capability of these animals. Surveying this community is fundamental to the assessment of natural and anthropogenic stresses, pollution monitoring, restoration, and assessment of ecosystem health. Our mission is to establish new genetic resources that convey accurate information of meiofaunal diversity in the Gulf of Mexico; correlate species distribution and community structures to environmental parameters; evaluate the biomarkers that best reflect ecological conditions and community structures. Toward these goals we have established draft reference genomes for 47 meiofaunal specimens representing 14 families and 5 phyla. Investigations performed on single individuals represented by these draft genomes revealed interesting patterns of genomic divergence among populations separated by environmental events. These draft genomes also establish reference DNA sequences for many potentially useful loci. We are now exploring what biomarkers are sensitive to ecological parameters and applying this important information to the environmental samples collected from the GoM. To test the ultimate value of the new reference genomes we have collected metagenomic and metabarcoding data from numerous sediment samples from the GoM. Preliminary results on the diversity of meiofauna investigated across sites sampled from the GoM using a biomarker and metabarcoding approach are presented. These results allow us to evaluate the progress toward improved methods for detailed analysis of population and community structures for a much more inclusive array of these important taxa.

Transcriptomic response to oil contamination in Louisiana Seaside Sparrows

**A. Bonisoli Alquati**[1, 2], P. C. Stouffer[2], C. Bergeon Burns[3], W. Xu[2], S. Woltmann[4], S. Taylor[2]
[1]California State Polytechnic University, Pomona, Pomona, CA, [2]Louisiana State University and LSU AgCenter, Baton Rouge, LA, [3]Indiana University, Bloomington, IN, [4]Austin Peay State University, Clarksville, TN

Oil from the Deepwater Horizon (DWH) oil spill contaminated the terrestrial food web in the marshes of the northern Gulf of Mexico. We have previously shown that Seaside Sparrows (*Ammodramus maritimus*) from oiled sites in Louisiana had oil carbon incorporated into their tissues, as well as greater hepatic expression of the cytochrome P450 1A (*cyp1a*) gene, a biomarker of exposure to polycyclic aromatic hydrocarbons (PAHs), compared to birds from unoiled sites. The genome-wide transcriptomic response to DWH oil, however, has to date only been assessed in fish species. Characterizing how gene expression of Seaside Sparrows responds to DWH oil exposure will clarify the molecular links between oil exposure and its behavioral and life history effects. Understanding this response will also help us develop more efficient biomarkers of oil exposure in birds. Using microarray techniques on liver samples, we identified 19 genes that were differentially expressed in birds from oiled sites compared to birds from control sites (17 upregulated and two downregulated genes). Functional analysis using the Kyoto Encyclopedia of Genes and Genomes (KEGG) Pathway Database indicated that the differentially



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expressed genes are involved in what is known as the intrinsic apoptosis pathway; the ubiquitin proteasome system, which regulates almost all cellular processes; and ion transport. Interestingly, similar pathways had previously been shown to respond to DWH oil exposure in Gulf killifish (*Fundulus grandis*). Thus, our results provide novel insights into the effects of oil contamination on gene expression networks in terrestrial birds, and also indicate that organisms as taxonomically and ecologically different as fishes and terrestrial birds might share similarities in their transcriptomic responses to oil exposure.

Development of a Marine BioAssay for Mutagenic Environmental Contamination

**L. D. McDaniel**, B. Leigh, J. H. Paul
University of South Florida, College of Marine Science, Saint Petersburg, FL

Crude oil spills in the environment release a combination of aliphatic and aromatic hydrocarbons. The aromatic compounds are particularly troublesome because of their persistence in the environment and their capability to damage DNA (mutagenic potential). Mutagenic contaminants in the environment can cause potentially heritable mutations. After the Deepwater Horizon Oil spill the DNA damaging potential of environmental samples was assessed with a microbial bio-assay, termed the Microscreen Assay, based on the *Escherichia coli* / λ phage host system. This lysogenic bacterial host contains a silent viral infection that is activated by DNA damage and the level of mutagenicity is proportional to the number of infectious viruses produced. This assay requires both a virus producing lysogenic indicator strain as well as a non-virus containing, virus sensitive detector strain. This assay has been extensively tested and utilized in freshwater environments. However, the assay has decreased sensitivity in marine samples, leading to increased type II errors. The lysogenic marine bacterial strain *Shewanella fidelis* 3313 has been identified as a candidate for a marine bio-assay analogous to the Microscreen Assay. This strain and its prophage have been genomically sequenced and characterized and the strain is sensitive to the common mutagen, Mitomycin C. As a part of a collaborative project chemically enhanced water accommodated fractions (CEWAFs) were prepared from Macondo surrogate oil and tested with the two bio-assays. The Microscreen Assay was negative, yet the *S. fidelis* strain indicated that the same samples were mutagenic, suggesting increased sensitivity with the new strain. The current marine assay is based on viral counts by flow cytometry but a preparation of a strain with no prophage, which would allow detection of infectious viruses, is in progress.

Carcinogenic effects of oil dispersants: a KEGG pathway-based RNA-seq study of human airway epithelial cells

**Y. Liu**[1], L. Zhang[2], A. Engel[1], S. Saito[1], J. Lasky[1], G. Wang[3], H. Wang[4]
[1]Tulane University, New Orleans, LA, [2]Soochow University, Su Zhou, CHINA, [3]Xavier University of Louisiana, New Orleans, LA, [4]University of Newcastle, Callaghan, AUSTRALIA

The health impacts of the BP oil spill are yet to be further revealed as the toxicological effects of oil products and dispersants on human respiratory system may be latent and complex, and hence difficult to study and follow up. Here we performed RNA-seq analyses of a system of human airway epithelial cells treated with the BP crude oil and/or dispersants Corexit 9500 and Corexit 9527 that were used to help break up the oil spill. Based on the RNA-seq data, we then systemically analyzed the transcriptomic perturbations of the cells at the KEGG pathway level using two pathway-based analysis tools, GAGE (generally applicable gene set enrichment) and GSNCA (Gene Sets Net Correlations Analysis). Our results suggested a pattern of change towards carcinogenesis for the treated cells



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marked by upregulation of ribosomal biosynthesis (hsa03008) (p = 1.97e-13), protein processing (hsa04141) (p = 4.09e-7), Wnt signaling (hsa04310) (p = 6.76e-3), neurotrophin signaling (hsa04722) (p = 7.73e-3) and insulin signaling (hsa04910) (p = 1.16e-2) pathways under the dispersant Corexit 9527 treatment, as identified by GAGE analysis. Furthermore, through GSNCA analysis, we identified gene co-expression changes for several KEGG cancer pathways, including small cell lung cancer pathway (hsa05222, p = 9.99e-5), under various treatments of oil/dispersant, especially the mixture of oil and Corexit 9527. Overall, our results suggested carcinogenic effects of dispersants (in particular Corexit 9527) and their mixtures with the BP crude oil, and provided further support for more stringent safety precautions and regulations for operations involving long-term respiratory exposure to oil and dispersants.



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## Session 018: Oil Spill Modeling: Source to Sink

State of the Practice for Oil spill Modeling: What Research is Most Needed
**C. H. Barker**, W. Lehr
NOAA, Seattle, WA

Oil spill fate and transport models are an integral part of the support for oil spill responders the world over. In the event of a response in the US, the NOAA Emergency Response Division is responsible for providing scientific support to the Federal On Scene coordinator. The division develops many of it's own models to support this mission. As a result, we are in a unique position to understand the strengths and limitations of the current state of oil spill modeling, and have a vision of where research can best support better modeling. We will review the current state of the practice of oil spill fate and transport modeling, with an emphasis on modeling to support response. We will then highlight what we feel are the biggest gaps in our ability to adequately model oil spill behavior and suggest avenues of research to close those gaps.

Two Dimensional, Rotating Plume Models with Application to Deep Water Horizon
**W. Dewar**[1], A. Fabregat[2], B. Deremble[1], A. Stroman[1], N. Wienders[1], A. Poje[2], T. Ozgokmen[3]
[1]FSU, Tallahassee, FL, [2]CUNY-SI, New York, NY, [3]RSMAS, UM, Miami, FL

We explore two and three dimensional turbulence resolving models of buoyant plumes, focusing specifically on the DWH event. The gas/oil/seawater nature of the problem is cast in an Eulerian framework and includes feedbacks between the convection and the environment. Calibrated two dimensional (2d) radially symmetric models are applied to multi-day plume evolution and the results differ importantly from classical non-rotating plumes. However, we argue non-rotating and rotating models are comparable in their ability to explain the DWH observations.

Detailed Modeling of the Dynamic Behavior of Petroleum in the Sea during the Deepwater Horizon Accident
**J. Gros**[1], S. A. Socolofsky[1], A. L. Dissanayake[1], I. Jun[1], L. Zhao[2], M. C. Boufadel[2], C. M. Reddy[3], J. S. Arey[4]
[1]TAMU, College Station, TX, [2]NJIT, Newark, NJ, [3]WHOI, Woods Hole, MA, [4]EAWAG, Dübendorf, Switzerland

Field observations indicate that during the 2010 Deepwater Horizon accident, approximately one quarter of the released petroleum mass became entrapped below the sea surface. A multiphase buoyant plume model was developed that explains field observations in both the sea and atmosphere. The model predicts the independent behavior of hundreds of petroleum compounds and predicts the effect of the changing composition of droplets and bubbles, pressure, and temperature on their properties. Subsea dispersant injection, release depth and orifice size, and petroleum composition and flux were the primary factors that led to a predicted 27% of petroleum fluids becoming dissolved into the sea. Without dispersant injection at the pared wellhead (~1500 m depth), we predict that volatile hydrocarbon emissions to the atmosphere would have increased, increasing exposures of response workers and decreasing exposures of deep-sea biota. The results have implications for environmental impact, human risk, and response strategies during offshore drilling accidents.



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An Aggregation Model to Estimate Oil Removal Rate by Sinking Marine Snow: A Decision Support Tool

**S. Francis**[1], A. Burd[2], K. Daly[3], U. Passow[1]
[1]University of California Santa Barbara, Santa Barbara, CA, [2]University of Georgia, Athens, GA, [3]University of South Florida, Tampa, FL

A significant fraction of the oil spilled during the Deepwater Horizon incident settled to the seafloor. The dominant mechanism thought to be responsible for this sedimentation is the formation of oil-containing marine snow, which allows for rapid sinking of particles along with any associated oil. The formation and sinking of phytoplankton aggregates—a common type of marine snow—is known to play a significant role in the ocean's biological pump by transporting carbon from surface waters to the seafloor. Scavenging of dispersed oil by sinking phytoplankton aggregates thus represents a potentially important pathway for the vertical transport and ultimate sedimentation of spilled oil. A simple aggregation model, based on coagulation theory, is used to estimate the rates at which oil dispersed in the water column can be removed via scavenging by sinking phytoplankton aggregates. This decision support tool is designed for use as a sub-module within NOAA's real-time oil spill response tool, the ADIOS oil weathering model. Hence, oil removal rates are calculated as a function of (1) local chlorophyll concentration, which can be estimated from satellite ocean color data, (2) turbulent shear rate, which can be estimated from wind data, and (3) water-column oil concentration, which is computed within ADIOS. Parameter values used in the model are based on in-house field and experimental data on phytoplankton aggregates. Preliminary results show that dispersed oil concentrations can be reduced by up to 20% per hour via this mechanism.

Oil Slick Elongation as a Result of Dispersion

**M. Zeinstra-Helfrich**[1], W. Koops[1], A. J. Murk[2]
[1]NHL University of Applied Sciences, Leeuwarden, Netherlands, [2]Marine Animal Ecology Group, Wageningen University, Wageningen, Netherlands

Entrainment of oil and subsequent resurfacing has earlier been identified as a mechanism behind the elongation of an oil slick in the up-wind direction. Under the influence of dispersion, the oil slick stretches. As application of dispersants aims to reduce the presence of oil on the surface, understanding the influence of dispersants on this process is critical to assess their added benefit. We investigate the influence of wind speed, oil viscosity and interfacial tension (with and without dispersants) on the oil slick surface development. In our calculations, entrainment and resurfacing of oil are simulated by defining the mixing by breaking waves constant processes, yielding the mass distribution across a transect of the oil slick over time. The simulation outcomes reveal the thickness profile of the surface oil slick after 24 hours:

- Under unfavorable conditions for dispersion (low wind speed, high oil viscosity), the initial thick slick patch remains fairly constant and develops a very long tail of resurfacing oil that is increasingly thin in the upwind direction.
- Under favorable (ideal) conditions most of the oil mass is moved to the water column in a short period of time. The resulting (relatively small) slick is only a temporary expression of the sub-surface oil; it moves much less with wind speed and is nearly symmetrical in the wind-direction.

The dispersability factor for each situation can be determined based on wind speed and oil properties, and this newly defined factor can be used to determine in which situations dispersants are most effective to reduce the slick surface area, and for which combinations of oil properties and conditions there will be no added value or even increased oil slick size.



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Simulation of Wind-Wave-Current Interactions for Oil Spill Applications
Z. Yang[1], A. Xuan[1], B. Deng[1], W. Drennan[2], B. Haus[2], **L. Shen**[1]; [1]University of Minnesota, Minneapolis, MN, [2]University of Miami, Miami, FL

A comprehensive computational framework called Wave-Ocean-Wind (WOW) is developed for simulations at various scales. It includes computation modules for phase-resolved nonlinear wave field, turbulent wind over waves, wave-current interactions, wave breaking, and spray and bubble transport. It has been applied to field-scale simulations and obtained results with unprecedented realism and accuracy. It is also used for laboratory-scale simulation for process study. As part of the GoMRI project "Investigation of Oil-Spill Transport in a Coupled Wind-Wave-Current Environment using Simulation and Laboratory Studies" (GoMRI 2015-V-258), we apply the WOW computational tools to perform collaborative research together with experiment study in the SUSTAIN wind-wave tank at the University of Miami, and obtain valuable data of the flow field with wind, wave, and current interactions.

An Oil Fate Model for Shallow Waters
**J. M. Restrepo**[1], S. Venkataramani[2], S. Moghimi[3], J. Ramirez[4]
[1]Oregon State University, Corvallis, OR, [2]University of Arizona, Tucson, AZ, [3]Portland State University, Portland, OR, [4]Universidad Nacional de Colombia, Sede Medellin, Medellin, COLOMBIA

A new mass-preserving model for the fate of complex hydrocarbons is described. The model is being developed, expressly, for forecasting oil spills in shallow oceans. Details are given on how the extreme spatio-temporal resolutions are being reached, with a model that can handle tens of thousands of interacting chemicals, the interaction of droplet distributions with the fluid and atmospheric background, all the while preserving mass across the whole water column.

Models for barotropic and baroclinic circulation in the Choctawhatchee Bay and River System
**R. Cyriac***[1], C. Dietrich[1], A. Fathi[2], C. Dawson[2], K. Dresback[3], C. Blain[4], M. Bilskie[5], S. Hagen[5], H. Graber[6]
[1]North Carolina State University, Raleigh, NC, [2]University of Texas at Austin, Austin, TX, [3]University of Oklahoma, Norman, OK, [4]Naval Research Laboratory, Stennis Space Center, MS, [5]Lousiana State University, Baton Rouge, LA, [6]University of Miami, Miami, FL

Surface currents at estuarine inlets influence near-shore oil transport, and a proper understanding of their behavior is crucial in predicting the impact of oil spills. Choctawhatchee Bay, situated along the Florida Panhandle, connects to the Gulf of Mexico via the Destin Inlet and receives 95% of its freshwater input from the Choctawhatchee River (CR). In December 2013, a series of experiments (collectively known as the Surfzone Coastal Oil Pathways Experiment) were performed in this region to study near-shore oil transport characteristics. The acquired satellite imagery indicated the presence of a surface ebb freshwater plume at the inlet. The goal of this study is to examine the mixing of fresh- and saltwater within the Choctawhatchee Bay, and simulate the delivery of freshwater onto the adjacent continental shelf during periods of low tide. We study the circulation patterns within Choctawhatchee Bay using the two- and three-dimensional modeling capabilities of ADCIRC (ADvanced CIRCulation), a nearshore circulation model. Starting with an existing triangular finite-element mesh with high resolution in coastal regions, we incorporated freshwater discharge by refining this mesh to resolve the upstream reaches of CR. The two-dimensional, depth-integrated version of ADCIRC is implemented on the modified mesh, and modeled water levels are validated by comparisons with



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observations at NOAA tidal gauges. The model results show that the depth averaged velocities are significantly influenced by the freshwater discharge from CR. Then the vertical flow characteristics within the Bay and at the tidal inlet are analyzed and compared with available measurements. The results indicate the presence of a two layered flow system within Choctawhatchee Bay with limited mixing. The spatial extent and vertical profile of the surface freshwater plume at Destin Inlet is predicted from a three dimensional baroclinic simulation using ADCIRC and validated with satellite imagery data.

Modeling the drift and spread of oil slicks in the Northern Gulf of Mexico using SAR imagery and forcing from a high-resolution hydrodynamic model

**C. Wettre**[1], L. Hole[1], K. Dagestad[1], V. Kourafalou[2], O. Garcia[3], H. Kang[2]
[1]Norwegian Meteorological Institute, Oslo, Norway, [2]University of Miami, Miami, FL, [3]Water Mapping, LLC, Tallahassee, FL

The fate and transport of a surface oil slick over time is controlled by varying components of winds and currents, the turbulent movement of oil within the upper ocean, and oil weathering processes such as evaporation, emulsification and vertical dispersion into the water column. Waves enhance vertical mixing of surface oil, with the actual depth of downward mixing and its possible return to the surface dependent on wave height, turbulence, and wind, along with the oil droplet size, mass, and resultant buoyancy.

In this study, we use SAR images to initialize oil spill simulations from a known active leakage site, the Taylor Energy platform near the Mississippi Delta (leaking oil since 2004). Various horizontal and vertical mixing processes are studied in order to evaluate the relative importance of each individual process, and the drift and spread of a simulated oil slick is compared to the evolution of the real oil slick as picked up in satellite imagery as well as in situ observations. To predict the behaviour of an oil slick, we use a newly developed code for modeling trajectories and fate of objects or substances drifting in the ocean, or even in the atmosphere. This code is called OpenDrift. Ocean forcing is taken from a high-resolution (~1.8 km grid) hydrodynamic model that covers the Northern Gulf of Mexico, while the atmospheric forcing is obtained from the ECMWF model. The possibility to estimate thickness of the oil slick is also investigated. OpenDrift is open source, and is programmed in Python. As the software is very generic, it is rather a "framework" than a "trajectory model" in the traditional sense. Trajectory models for specific purposes (e.g. oil drift, search and rescue, larvae drift etc.) may reuse all common functionality from the core model, and need only implement a Python Class describing the purpose-specific processes (physics/biology etc.). See https://github.com/knutfrode/opendrift/wiki for details.

Dynamical geography of the Gulf of Mexico inferred using satellite-tracked drifters

**F. Beron-Vera**
RSMAS, University of Miami, Miami, FL

We construct a Markov-chain model of the surface-ocean dynamics in the Gulf of Mexico (GoM) using satellite-tracked drifter trajectories. From the analysis of the eigenvalues and eigenvectors of the transition matrix associated with the chain, we identify almost-invariant attracting sets and their basins of attraction. With this information we decompose the GoM into weakly dynamically interacting parts in both forward and backward time. We discuss the implications of this dynamical geography for



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connectivity in the GoM. Joint work with P. Miron, G. Froyland, M. Olascoaga, J. Sheinbaum and P. Perez-Brunius.

Comparing Trajectory Outputs at the Historic Pt. Wells Oil Spill

**J. Whiting**[1], L. Romero[2], R. Duran[2], J. Vielma[2], P. Wingo[2], A. Bunn[3], T. Khangaonkar[1], J. Bauer[2], K. Rose[2]
[1]Pacific Northwest National Laboratory, Seattle, WA, [2]National Energy Technology Laboratory, Albany, OR, [3]Pacific Northwest National Laboratory, Richland, WA

Decades of oil spill modeling have advanced our collective understanding of particle transport across a waterbody. National Oceanic and Atmospheric Administration's General NOAA Operational Modeling Environment (GNOME) has been used for emergency response for decades and National Energy Technology Laboratory's Blowout and Spill Occurrence Model (BLOSOM) was developed over the past 5 years to aid in oil blowout and spill prevention and preparedness with the increase of offshore U.S. oil exploration and production. GNOME and BLOSOM are being run in parallel for the first time, providing an opportunity to identify differences in methodology and practice. Iterative testing explored the effects of hydrodynamic generation methods, initial spill parameters, diffusion settings, time steps, and wind inputs. The setting was the 2003 Point Wells spill in the Puget Sound, Washington, where 4,637 gallons of oil spilled when the Foss tank barge overtopped during refueling. This location was chosen because of access to Pacific Northwest National Laboratory's Finite Volume Ocean Coastal Model (FVCOM) of the Salish Sea (Khangaonkar 2011, 2012; salish-sea.pnnl.gov) and because past attempts to recreate the observed trajectories have been challenging. The Puget Sound region represents an extreme for hydrodynamics as a high-energy, enclosed estuary, quite different from a large basin like the Gulf of Mexico where the majority of oil spill modeling has been conducted. Yet the Puget Sound setting highlights the importance of understanding how variables change regionally and different models and inputs can drastically change the outputs. An iterative analysis of many variables successfully allowed both models to match the historic spill decently well. The next phase of this study will be to assess a recent oil spill in the Gulf of Mexico with both GNOME and BLOSOM. This presentation will highlight model strengths and knowledge gaps, demonstrating a better understanding of site-specific variation in modelling offshore oil spills.

Prediction of the transport of surface oil-slicks in the northern Gulf of Mexico using a cross-scale unstructured finite element baroclinic model

**A. Fathi**[1], C. Dietrich[2], C. Dawson[1], K. Dresback[3], R. Cyriac[2], A. Samii[1], C. Blain[4]
[1]University of Texas at Austin, Austin, TX, [2]North Carolina State University, Raleigh, NC, [3]University of Oklahoma, Norman, OK, [4]Oceanography Division, Naval Research Laboratory, Stennis Space Center, MS

Accurate simulation of ocean currents near coastal regions can be used for the prediction of oil spill transport in such areas. Information from these predictions can help emergency responders make informed decisions regarding the clean-up process, or help fishing industries assess the safety of seafood in uncertain regions. In coastal regions, due to the considerable variation of bathymetry, and also discharge of fresh water from the rivers, the character of the fluid flow is three-dimensional.

During this presentation, we will discuss the application of the three-dimensional baroclinic ADCIRC model for the prediction of surface oil-slick transport, due to the Deepwater Horizon oil spill event. ADCIRC utilizes an unstructured grid that allows it to accurately capture high-resolution bathymetry. For stability, this high-resolution bathymetry needs to be smoothed in regions where it varies



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drastically, which, typically, is the region in the vicinity of the shelf break. Due to the unstructured nature of the grid, higher mesh resolution can be used in regions of interest, or near the mouth of the rivers where fresh water gets mixed with saline water, or in areas where solution gradient is considerable. We will discuss recent improvements made in ADCIRC for computing the baroclinic pressure gradients, and, also, biharmonic horizontal diffusion and viscosity operators, when the unstructured grid encompasses a wide range of spatial scales. We will show simulation results of the northern Gulf of Mexico during the Deepwater Horizon oil-spill event, where a considerable length of the Mississippi and Atchafalaya rivers are modeled, to accurately account for the mixing of the fresh water of the rivers with the saline water of the Gulf. We compare our simulation results with satellite imagery and observations at buoys. To investigate the influence of baroclinicity and vertical mixing, we compare these results against a two-dimensional barotropic simulation. Next, by representing surface oil slicks due to the oil-spill event as Lagrangian particles, we compute their transport due to ocean currents, and compare them with satellite observations.



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## Session 019: Policy-relevant Implications of Science Emerging from the Deepwater Horizon Disaster

Approaches to Understanding Oil Spill Phenomena and Effects: Evidence, Scientific Inference and Implications for Public Policy

**S. A. Murawski**
University of South Florida, St. Petersburg, FL

Oil spill are an inevitable consequence of intensive marine exploration and production activities, with about 200 reported spills per year in United States waters. While none have approached the scale of DWH in volume or impacts since 2010, a significant fraction of spills trigger NRDA processes under OPA-90. In all cases there is a limited toolbox of scientific approaches to understanding factors associated with spills and impacts to ecosystems in the short- and long-term. Given the difficulty in understanding such effects using after-the-fact collected data, it seems inefficient, counter-productive and naïve that more extensive baseline data are not available or required, particularly from areas of high production, risk (e.g., ultra-deep waters), or where particularly vulnerable resources may occur. Ultra-deep waters (>1,500 meters deep) account for a significant and increasing proportion of hydrocarbon production in the Gulf, providing >40% of all production in 2014, whereas no production from these waters occurred in 1994. In this presentation I consider the strengths and challenges associated with various scientific approaches to understanding oil spill effects, including multiple synergistic studies. I also consider the potential value of policy changes requiring pre-spill baselines to be collected, and various strategies for obtaining such data. Policy changes in this arena have the potential to result in more targeted, reliable and less costly methods for assessing oil spill effects and impacts from future significant spills.

Environmental impacts of the deep-water oil and gas industry: a review to guide management strategies

**E. Cordes**
Temple University, Philadelphia, PA

The oil and gas industry is one of the most active agents of the global industrialization of the deep sea. The wide array of impacts following the Deepwater Horizon oil spill highlighted the need for a systematic review of existing regulations both in US waters and internationally. Within different exclusive economic zones, there are a wide variety of regulations regarding the survey of deep-water areas prior to leasing and the acceptable set-back distances from vulnerable marine ecosystems once they are discovered. There are also varying mitigation strategies for the expected impacts of typical oil and gas operations, including active monitoring systems, temporary closings of oil and gas production, and marine protected areas. As the first product of the Oil & Gas working group of the Deep Ocean Stewardship Initiative, a systematic review of existing data on the spatial and temporal extent of impacts from typical oil and gas exploration and production was conducted. We found that discharges of water-based and low-toxicity oil-based drilling muds and produced water can extend over 2 km, while the ecological impacts at the population and community levels on the seafloor are most commonly on the order of 200-300 m from their source. These impacts may persist in the deep sea for many years and likely longer for its more fragile ecosystems, such as cold-water corals. A review of the current state of management across 18 different EEZs found that protections for sensitive communities rarely extend over this entire distance. An ideal management strategy would include activity and temporal management along with spatial management with setback distances that encompass the full



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range of the impacts expected from typical oil and gas operations, and the extent of the impacts from accidental releases in some EEZs.

Informing decision making, reducing risks, and driving technology innovations in the Gulf of Mexico using novel spatio-temporal tools and big data

**K. Rose**[1], J. Bauer[1], A. Barkhurst[2], E. Cameron[3], R. Duran[3], M. Mark-Moser[4], R. Miller III[4], L. Romeo[3], J. Vielma[4]

[1]U.S. Dept. of Energy, NETL, Albany, OR, [2]MATRIC, Morgantown, WV, [3]AECOM, Albany, OR, [4]ORISE, Albany, OR

Recent spills resulting from various natural and anthropogenic events have highlighted significant gaps in exiting technologies and approaches to predict risks associated with various offshore hydrocarbon activities. NETL's Offshore Integrated Assessment Modeling (IAM) system leverages the Department of Energy's (DOE's) competencies in simulating and predicting the behavior of engineered-natural systems to develop a multi-component modeling suite. Building off the lessons learned from previous deleterious events, the Offshore IAM provides data, tools, and techniques to assist with evaluating potential risks and identify possible technology gaps through the use of science based, data-driven assessments. The modules comprising the IAM can be utilized individually or in combination to support analysis of the subsurface, wellbore, and water column to evaluate relationships, trends, risks, and uncertainty. The IAM's flexible and modular design supports the addition of new components, as well as the combination of existing components for different needs. The modules utilize largely publically available datasets to support evaluation of natural, engineering, economic, and environmental properties of those systems. The current Offshore IAM system consists of eight modules that incorporate innovation data acquisition methods, analytical tools, and custom built models integrated in a common operating platform (COP) to support multi-organizational coordination and collaboration. The Offshore IAM has been utilized to understand spatial and temporal trends and identify potential risks associated with offshore activities in the Gulf of Mexico. Some of these analyses include development of a refined assessment of subsurface pressure and over-pressure trends, identification of separate regions with distinct transport characteristics using 12 years of data-assimilative ocean-model solutions, a spatio-temporal evaluation of spill-impact trends, and a spatially explicit gap-analysis of response readiness capabilities. In addition, components of the IAM have been utilized and refined to support offshore spill response readiness needs associated with offshore worst case discharge permit evaluations for other regions including the Puget Sound, U.S. Pacific, and Gulf of Alaska regions.

Decommissioning and Rigs-to-Reefs Programs in the Gulf of Mexico- Current Status and Strategies, and a Review of Decommissioning Cost Estimation

**E. Kobrinski Keen***

Harte Research Institute for Gulf of Mexico Studies, Texas A&M University Corpus Christi, Corpus Christi, TX

In the wake of the Deepwater Horizon oil spill disaster in April of 2010, coupled with a recent surge of storms coming into the region, the United States federal government became very concerned about oil rig platforms being left idle in the Gulf of Mexico, from a safety, environmental and navigational perspective. What followed was the release of the federal 'Idle Iron' policy in October of 2010, shedding light on over 3,000 wells and over 600 platform structures sitting 'idle' in Gulf Coast waters. By law and reinforced by the leasing contract between the federal government and the operator, all



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structures are supposed to be removed. These figures have triggered a heightened interest in rigs-to-reefs programs, and have made the goal of this study to determine the reasoning behind the idle iron list. Furthermore, recent communication with federal regulatory agencies determined that requirements for cost estimation are placing pressure on the federal government to potentially cover decommissioning costs at the conclusion of the lease contract. Research objectives include 1. What the most effective role is for rigs-to-reef programs to play in addressing the idle iron list, 2. How current legal matters, policies, and financial issues are inhibiting successful structural removal procedures, and how these issues are affecting rigs-to-reefs programs, and 3. The implementation of a multi-criteria decision analysis approach applied to specific platforms, to provide transparency among stakeholders and guidance to the federal government when faced with various decommissioning options. The research will also include a review of the United States decommissioning strategy, incorporating international perspectives and global case studies from Australia, Norway, and the Asia-Pacific region. Expected achievements in data collection and analysis include insight into how to update federal and state policies to assist decommissioning process efficiency moving forward.

Reappraisal of the Use of Traditional Response Strategies for Surfacing Oil in Light of the MOSSFA Phenomena- Implication for Policy Change

**D. J. Hollander**[1], I. C. Romero[1], P. Schwing[1], G. Brooks[2], R. Larson[2], D. Hastings[2], J. Kostka[3], J. Chanton[4], A. Gracia[5], M. Machain[5]

[1]University of South Florida, St. Petersburg, FL, [2]Eckerd College, St. Petersburg, FL, [3]Georgia Tech, Atlanta, GA, [4]Florida State University, Tallahassee, FL, [5]National Autonomous University of Mexico (UNAM), Mexico City, Mexico

Defining the processes that govern a Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA) event and determining whether it is a common outcome for surfacing oil is fundamental to predicting the spatial-temporal distribution of spilled oil and real-time planning for specific response strategies. MOSSFA events hypothesize that the formation of marine oil snow aggregates and its accumulation at the seafloor are directly related to various surface-oil mitigation strategies (surface dispersant application, oil burning, and enhanced freshwater discharge - containing abundant nutrients and clays - to move oil offshore away from highly-valued coastal ecosystems). If this hypothesis is correct then MOSSFA takes on an added global significance as 85% of deep-water oil exploration occurs adjacent to deltaic systems. To date, IXTOC (SGoM, MX; 1979-80) and DWH (NGoM; 2010) are the two largest sub-surface oil well blowouts and, although occurring 30 years apart, both used the exact same mitigation strategies for surfacing oil. Comparison of IXTOC and DWH sediment records provides a unique opportunity to juxtapose sedimentological, mineralogical, geochemical and faunal parameters to evaluate if MOSSFA events occurred and if they are associated with traditional spill response strategies. The physical, chemical, biological and visual characteristics of IXTOC and DWH sediment intervals exhibit strikingly similar features indicative of MOSSFA events. Recognizing that traditional oil spill response methods, while commonly used to protect coastal ecosystems, resulted in unexpected negative consequences to offshore benthic ecosystem implies a trade-off in the valuation of offshore vs. coastal ecosystem services must be determined. Response strategies that facilitate MOSSFA events, influence long-term hydrocarbon exposure and controls offshore benthic recovery rates merit discussion when planning oil spill response and policy changes.



*****Student presenter

## Session 020: Bridging Research and Response: Science Discoveries from DWH to Inform Future Oil Spill Response Decision Making and Engage Stakeholders

"Real Time" Science: What Decision makers Need in the Heat of Battle

**M. Austin**
US Coast Guard, Portsmouth, VA

During an oil spill response, decision makers are faced with myriad issues affecting the "whole of response"—environmental impact of both the spilled substance as well as clean up methods, public health concerns, economic considerations, diverse stakeholder support, political dynamics, media scrutiny, to name a few. What they don't have a lot of is time in this very dynamic environment. Members of the scientific community may not be comfortable having to collect and analyze data in the short time window with which decision makers have to choose a course of action and execute it. In the past, the reluctance of members of the scientific community to provide what is considered a "timely" answer has frustrated decision makers and may even have resulted in discounting what the scientific community can provide during a response. At the same time, it gave members of the scientific community the impression that decision makers don't care about science and are making decisions without any analysis or thought. Both of these assumptions are wrong. Decision makers need the best available information in order to make smart choices in a time compressed, highly complex incident. Both sides need to realize the limitations of each other in order to understand why the demand for quick answers is not unreasonable—while at the same time understanding the trade-offs required (e.g. large p values due to small sample size or large error bars due to incomplete data) in order to get relatively quick scientific answers in time for decision makers to take informed response actions.

The Use of NEBA and Associated Comparative Risk Frameworks to Integrate Oil Spill Science for Spill Response and Preparedness Planning

**M. Bock**[1], W. Gardiner[2], R. Wenning[1], M. Pinza[2], M. Rockel[3], H. Robinson[4]
[1]RAMBOLL, Portland, ME, [2]RAMBOLL, Port Gamble, WA, [3]RAMBOLL, Philadelphia, PA, [4]RAMBOLL, Arlington, VA

Net environmental benefit analysis (NEBA) and similar comparative risk assessment (CRA) frameworks have been developed to assist in oil spill response planning and implementation. The NEBA approach focuses on weighing the environmental risks and potential long-term mitigation provided by viable oil spill response options when compared to a no-action alternative. NEBA analyses are holistic and information intensive processes, requiring an understanding of the ecosystems and receptors at risk, the fate and effects of released oil, an understanding and the residues oil spill response alternatives, and the potential short and long term effects of their use. The vast amount of data collected during the Deepwater Horizon oil spill response, as well as other regional spill events provide valuable insights that may be applied to oil spill response planning. In this paper, we discuss the potential for using the comparative risk assessment framework as a mechanism for storing and integration of data. Several different models that organize information have been developed and will be discussed as means of connecting NEBA or CRA evaluations to the available science-base. The types of data needed to support NEBA, the organization of that date to facilitate comparative risk assessment, and the types of damage assessment data (NRDA) that may be used in spill response planning (NEBA) will be discussed.



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The Role of Science and Real-Time Response Decisions: Examples with the General NOAA Operational Modeling Environment

**A. C. Bejarano**[1], A. Mearns[2], G. Watabayshi[2], A. Davis[3]
[1]Research Planning Inc., Columbia, SC, [2]Emergency Response Division, NOAA, Seattle, WA, [3]Emergency Response Division, NOAA, Mobile, AL

Oil spills provide opportunities for the advancement of science, but the practical application of new or revised findings is often restricted by the unique nature of each spill. In the Gulf of Mexico and excluding the Deepwater Horizon (DWH) oil spill, between 2000 and 2015 there were on average 307 oil spills per year of ≥10 gallons, averaging 456 gallons per spill. During the same period, 25 spills involved releases >10,000 gallons and dispersants were used in 3 occasions (excluding DWH). Several tools are available to inform real-time response decisions, communicate tradeoffs and address concerns by stakeholders. One such tool is the General NOAA Operational Modeling Environment (GNOME), a three-dimensional model that simulates oil mass balance, environmental concentrations, and spatial and temporal oil trajectories. GNOME includes levels of concern based on consensus opinions among experts, but an alternate quantitative could be employed by integrating time-varying Hazard Concentrations (HC) of total hydrocarbon concentrations from Species Sensitivity Distributions (SSD). The 5$^{th}$ percentile HC (HC5), or concentration protective of 95% of all species on the SSD could be used as a surrogate level of concern. HC5 could be compared to modeled environmental concentrations from scenarios based on realistic oil spills volumes, providing quantitative outputs that could be used to inform response decisions and support communication efforts. In order to evaluate the SSD approach, hypothetical spill scenarios will be developed based on model runs without and with chemical dispersants at operational levels of effectiveness. Improvements to the SSD approach could be made by incorporating toxicity data generated during the DWH, including new data on early life history stages of offshore species (e.g., yellowfin and Southern bluefin tuna, yellowtail amberjack, mahi mahi). Integrating new science into GNOME could facilitate an understanding of the scales of potential impacts of physically and chemically dispersed oil to water-column organisms, and improved quantitative outputs used to help inform evaluations of oil spill response options and facilitate discussions on their tradeoffs.

Engaging Local Stakeholders through Citizen Science Projects Using GoMRI-Funded Oil Spill Research Tools

**L. C. Bracken**[1], T. CARTHE[2]
[1]CARTHE/University of Miami, Miami, FL, [2]University of Miami, Miami, FL

Through quality research, community collaborations, and carefully crafted messages, oil spill science can be used to benefit a wide variety of geographic locations and environmental issues, including but not limited to oil spill response. To bridge the gap between the scientists and the stakeholders, outreach personnel utilize creative resources, such as citizen science projects, to illustrate the consortium's valuable work. Outreach personnel have a deep knowledge of the research being done by the consortium as well as experience communicating this complex science to a variety of audiences. This session will discuss ways researchers can work with outreach staff to highlight their relevant, usable science when working with local stakeholders.

Actively engaging the public in current research can allow them to be aware of the numerous environmental issues in the area and how the science from the consortium can be used in the event of a future marine disaster. The Bay Drift study is an example of how to involve citizen scientists and



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inform local municipalities and response agencies of how GoMRI science and tools can be used to help determine the disaster's potential impacts for the local ecosystem. This current study looks at how oil, marine debris, sediment, larval fish, and even boaters are transported by the currents that move into and within Biscayne Bay (Miami, FL). By partnering with local organizations and using the expertise we gained from GoMRI funded experiments, we are now able to give the greater Miami area a better sense of how the currents are effecting the way particles move in Biscayne Bay. Citizen science experiments and other hands-on opportunities introduce a greater number of individuals and organizations to your capabilities and tools, leading to informed citizens, stakeholders, and decision makers, and adding to the GoMRI legacy.

When a naval officer emails for help on how to sink a ship

**C. Reddy**
WHOI, Woods Hole, MA

Oil spills are usually thought to be accidental, but releases also result from deliberate actions, such as the sinking of vessels during military conflicts. In 2015 and early 2016, U.S. forces were preparing a military exercise with NATO and partners to conduct operations in cold-weather environments. The exercise, called COLD RESPONSE 16, placed fictional countries in the real-world geography of Norway. Planners had to consider environmental, economic, and political impacts from damage to fisheries and aquaculture, if they sank fueling ships containing diesel and jet fuel. Norway has the largest fishing industry in Europe and second by value in the world. A US Navy officer was charged with minimizing damages from a spill. He and his cohorts were concerned that they could create another Deepwater Horizon disaster. They emailed us and we provided background knowledge on spills and facilitated collaboration among experts in government agencies and in industry. With the knowledge gained, a refueling ship was fictionally "sunk" in the exercise at a time and in an area with near-ideal conditions to prevent and mitigate environmental damage. Beyond a successful military exercise, we see this as a successful, mutually beneficially exercise in communication between the military and academic researchers. This case exemplifies the value of stakeholders taking the simple but often overlooked step of "exchanging business cards". It's nothing new for the military to get advice from academia, and the Navy had other resources. For academics, there's no built-in incentives to develop or create more pre-existing relationships outside the ivory tower, but we feel it's worth it. We have begun to enjoy this aspect of being scientists: providing clarity, information, and expertise to policymakers and other stakeholders before, during, and following oil spills. In the wake of Deepwater Horizon, Jane Lubchenco stated that scientists who had pre-existing relationships with the federal agencies had the greatest success in helping to mitigate the crisis. In this case, a single email perhaps one day could protect kilometers of coastal waters, people's livelihoods, and our relationships with allies. Which arguably could have a greater impact than a paper cited 1,000 times.

Stakeholder Participation in the 2016 Comparative Risk Assessment (CRA) of Response Options for an Uncontrolled Subsea Oil Well Blowout

**A. H. Walker**[1], D. French McCay[2], J. Rowe[3], R. Wenning[4], H. Robinson[5], M. Bock[4]
[1]SEA Consulting Group, Cape Charles, VA, [2]RPS ASA, Kingstown, RI, [3]RPS-ASA, Kingstown, RI, [4]Ramboll Environ, Portland, ME, [5]Ramboll Environ, Arlington, VA

A year-long comparative risk assessment (CRA) project, funded by industry, evaluated combinations of response strategies to help identify the set of strategies that could provide the greatest overall benefit



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in mitigating the environmental, socioeconomic and human health and safety impacts of a deep water blowout in the northern Gulf of Mexico (GOM). The project used a quantitative assessment approach, that incorporated 3-dimensional oil spill transport and fate modeling with research data on ecological effects, to evaluate the consequences of various response alternatives, with a focus on subsea dispersant injection at the source, in addition to other response strategies, i.e., mechanical recovery, in-situ burning, and surface application of dispersants. The goal of the project was to provide decision makers with objective, science-based and transparent information to enable technically-sound choices regarding appropriate strategies for mitigating impacts from oil and gas released during a deep water blowout. A technical advisory committee (TAC), consisting of Gulf of Mexico federal and state agency representatives who have oil spill roles defined in the US Oil and Hazardous Substances Pollution Contingency Plan (NCP) as well as two representatives from universities in the GOM, was established to guide the implementation of this program to support project objectives. This presentation will describe the ongoing participation by TAC members, e.g., TAC input on the approach, assumptions for the CRA analyses, TAC interactions with the project team and the API Subsea Dispersant Injection Program Committee in conducting the CRA, and TAC input on identifying significant potential uncertainties. Finally, the presentation will summarize the interactive workshop held for the TAC and other participants, as well as the workshop findings, which may be used to inform to future oil spill preparedness and response decisions in the Gulf of Mexico.

Understanding What Happens to the Composition of Crude Oils Spilled in Marine Environments

**E. B. Overton**[1], C. M. Reddy[2]
[1]Louisiana State University, Baton Rouge, LA, [2]Woods Hole Oceanographic Institution, Woods Hole, MA

An understanding of the carbon cycle, and thus the chemistry of oil, can inform response actions that promote Mother Nature's natural mechanisms for responding to the environmental stressors like oil spills. Hydrocarbons in crude oil originate from the conversion of atmospheric CO2 via photosynthesis into biomolecules that make up all living organisms. Photosynthesis converts the most chemically stable form of carbon, CO2, into biomolecules that store the Sun's energy in the form biomass (i.e., CH2O type biomolecules). Once biomass is buried deep within the earth's crust, this biomass is further striped of any oxygen atoms to form the highly reduced hydrocarbon mixtures that make up crude oil. Therefore, crude oils, being composed of the most highly reduced forms of carbon, are subjected to natural processes that use this stored energy to convert spilled oil back to bacterial biomass and CO2 in aerobic environments. This reduced form of carbon is in contrast to chlorocarbon pollutants where the carbon is in a highly oxidized and thus stable state, and does not readily react in aerobic environments. Oil released into the marine environment in quantities exceeding the local environment's ability to assimilate and degrade the oil, can cause harmful impacts via several mechanisms. First, some of the compounds in oils, which typically constitute 5 to 10% of the weight of oils, are toxic to a wide variety of organisms. Second, oil is a hydrophobic material that will foul, coat or stick to plant materials, feathers and solid surfaces such as shells. This coating/smothering caused disruption of the normal functions of the coated/smothered surfaces and frequently causes death to that coated organism. Third, virtually all compounds in oils can be degraded by microorganisms. This degradation involves oxygen consumption, and can cause aquatic environments to become anoxic. Fourth, as oil is degraded by microorganisms, the population of these oil degraders greatly expands and this can cause natural food chain impacts. This presentation will discuss the chemical composition of oils produced by both conventional and un-conventional methods, and discuss various response actions that can help minimize harmful environmental impacts from oil spills.



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Engaging Multi-Ethnic Fisher Folks in Oil Spill Research

**J. Kastler**[1], T. Vu[2], C. Forbes Bright[3]
[1]University of Southern Mississippi, School of Ocean Science and Technology, Ocean Springs, MS, [2]Mississippi Coalition for Vietnamese American Fisher Folks and Families, Biloxi, MS, [3]University of Southern Mississippi, Department of Political Science, International Development, and International Affairs, Hattiesburg, MS

During and after the 2010 oil spill, members of the public appeared to lose trust in science and scientists because of the lack of clear information needed to respond to the 2010 oil spill and predict its results on human and ecosystem health. The northern Gulf Coast commercial fishing community was greatly impacted by Hurricane Katrina in 2005 and the oil spill sustained and increased the threat to fisher folks' livelihoods. The education and outreach effort of the GoMRI project CONCORDE is exploring trust in science among several target audiences, including the multi-ethnic commercial fishing community. Key outreach efforts included research cruises and community presentations. Research Cruises: CONCORDE researchers conducted several research cruises using a broad assemblage of research platforms to explore oceanographic processes coincident with plankton distributions in the coastal zone subject to changing freshwater flow. A basic set of measurements collected on these cruises was conductivity, temperature, and depth. Community Presentations: Two community presentations were held in Spring 2016, one in Biloxi, Mississippi and one in Chalmette, Louisiana to describe the nature of the research and recruit commercial fishermen to act as citizen scientists. The Biloxi presentation was made in English with coincident translation to Vietnamese. Of the ~50 people who attended these sessions, 2 were trained during independent sessions preceding the presentations and 17 were trained during an afternoon workshop held in English and Vietnamese at the USM Gulf Coast Research Laboratory in March 2016. The citizen scientists were encouraged to take a portable YSI Castaway CTD aboard their vessel during a cruise to collect depth profiles of temperature and salinity. Those fishers are engaged with CONCORDE researchers in a year-long training series to collect, analyze and interpret the data the fisher folks collect and discuss how those data support the larger dataset of the CONCORDE project. Work continues to observe the development of the relationship among researchers and fisher folks and whether it influences the use of and trust in science in decision-making regarding commercial fisheries and the participation of fisher folks in the decisions making process.

The DWH Oil-Associated Marine Snow Sedimentation Event and Future Oil Spill Response

**K. L. Daly**[1], A. Remsen[1], K. Kramer[1], U. Passow[2], S. Francis[2], G. Jackson[3], A. Burd[4]
[1]University of South Florida, St Petersburg, FL, [2]University of California, Santa Barbara, Santa Barbara, CA, [3]Texas A & M University, College Station, TX, [4]University of Georgia, Athens, GA

The Deepwater Horizon (DWH) oil spill resulted in an unexpected and prolonged sedimentation of oil-associated marine snow to the seafloor. This marine oil snow (MOS) sedimentation event is a newly recognized pathway for the distribution and fate of oil, accounting for as much as 14% or more of the total DWH oil released. Knowledge of marine snow seasonal dynamics and its governing processes are important for predicting future oil spill sedimentation events in this region and elsewhere. In the NE Gulf of Mexico, marine snow concentrations typically are most abundant in spring and summer when primary and secondary productivity are highest. Total particle volume also is positively correlated with river discharge (presence of low salinity water). Particle flux, however, may be uncoupled from production, with maximum fluxes occurring from spring to fall. Particle resuspension across the continental shelf also may impact deeper water aggregate concentrations post settlement. The DWH MOS sedimentation occurred due to a nexus of events, (1) the DWH site was located in a very



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productive region of the Gulf of Mexico governed by Mississippi River outflow, (2) the spill occurred during spring and summer when particle concentrations were at a maximum and surface microbial community activity rates were relatively high, (3) the 2010 extended, high Mississippi River discharge enhanced phytoplankton production and suspended particle concentrations, and (4) there was increased microbial mucus formation in the presence of weathered oil. Responders to future oil incidents should consider the possibility of marine oil snow sedimentation when evaluating appropriate actions to limit the impacts of oil spills. To address this need, a new decision support tool was developed to estimate the rate of oil removal via phytoplankton aggregation as a component for NOAA's oil spill response tool, the ADIOS oil weathering model.

Engaging High School Students in Studying Marine Mammals Observed near the BP Oil Spill
**K. Leftwich***, J. W. Ioup, C. Seab
University of New Orleans, New Orleans, LA

The Littoral Acoustic Demonstration Center - Gulf Ecological Measuring and Monitoring (LADC-GEMM) project partnered with Warren Easton Charter High School to analyze the underwater acoustic data collected in the northern Gulf of Mexico during the summer of 2015, returning to sites previously surveyed by LADC. Results presented here are produced using underwater acoustic data recorded by Environmental Acoustic Recording Systems (EARS) at the site closest to the BP oil spill. The aim of the of the outreach project is for students to learn to work independently using scholarly works to analyze and interpret data, as well as to communicate and collaborate in a professional environment. Students have used computer programs to detect acoustic sounds from various marine mammals, including sperm whales, beaked whales (Cuvier, Blainville, Gervais, BWG), and dolphins (bottlenose, Rizzo). The numbers and types of marine mammals are possible indicators of the health of the area and the marine mammals around the oil spill. Changes will indicate possible future problems.

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.

Development of a Web-based Virtual Lab Application to Disseminate and Communicate GoMRI Science
**D. DiNicola**[1], K. Grinfeder[2], J. Stieglitz[1], J. Johansen[3], E. Mager[4], D. Benetti[1], A. Esbaugh[3], M. Grosell[1]
[1]University of Miami RECOVER, Miami, FL, [2]University of Miami, Miami, FL, [3]University of Texas RECOVER, Port Aransas, TX, [4]University of North Texas RECOVER, Denton, TX

The RECOVER Consortium is currently developing and testing a web-based interactive teaching app geared for students grades 4-12 and beyond on aerobic swim performance in fish. The app will allow 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. In this web-based teaching app, real experimental footage and data will populate simulated experiments performed by students. As part of the simulations, students will select experimental animals and experimental conditions and be introduced to data analysis and complex physiological considerations. 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 assessment is capable of gathering detailed demographic data allowing for evaluation of impact of this outreach effort. In the future, different modules and updates will be added to the existing app to broaden its reach and utility. This



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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.

Two Years Later: An Evaluation of Oil Spill Science Communication in the Gulf

**C. Ellis**[1], S. Sempier[2], L. Swann[2], V. McCown[3]
[1]NOAA Office for Coastal Management, Charleston, SC, [2]Mississippi-Alabama Sea Grant Consortium, Ocean Springs, MS, [3]College of Charleston, Charleston, SC

In 2014, the Gulf of Mexico Research Initiative (GoMRI) supported the development of a new oil spill science outreach program administered by the four Sea Grant College Programs based in the Gulf of Mexico. The program's purpose is to increase the use of oil spill science by people whose livelihoods depend on a healthy Gulf. In 2014, the program conducted a social network analysis (SNA). The purpose of the SNA was to understand the communication network and flow of oil spill science information among the people Sea Grant programs serve. The program administered a second SNA in 2016. The purpose of this second analysis was to examine how the communication and structure of the oil spill science communications social network changed over time. This SNA also contributed to the evaluation of the Sea Grant outreach program. This presentation will focus on the results of the 2016 SNA and offer a comparison between the 2014 and 2016 SNA, highlighting how the oil spill science communication structure has changed over time.



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## Session 021: Marine Oil Pollution Monitoring Methods: New and Emerging Techniques for Obtaining and Analysing *in-situ* Observations and Laboratory Data

### Tactical Oil Spill Observations: Recent Developments in Remote Sensing of Oil Spills

**O. Garcia Pineda**[1], G. Staples[2]
[1]Water Mapping, LLC, Tallahassee, FL, [2]MDA, Corporation, Vancouver, BC, Canada

Monitoring oil spills with remote sensing technology is a well-established task that nowadays still requires validation with in situ measurements of oil thicknesses. In this context, RADARSAT-2 quad polarized Synthetic Aperture Radar (SAR) data was acquired over the Taylor Energy oil leak in the Gulf of Mexico. Due to the oceanographic regime, oil emulsions tend to occur in a band that stretches about 80 km to the southwest and the northeast. The persistent formation of oil emulsions coupled with the quasi-deterministic location provided a test-bed location to assess the detection of emulsified oil using quad polarized data. RADARSAT-2 imagery in conjunction with aerial observations (including UAS thermal) and in situ sampling was acquired between June 2014 and August 2016. For *in situ* validation, a newly designed method for measuring oil thickness on the field has been developed. We designed an electro-mechanical device that collects a sample of floating oil on surface water with minimal disturbance to the oil slick. This device consists on a floating apparatus that allows the surface water (and the floating oil) to flow freely through a horizontal tube. Using a radio frequency remote control, an operator triggers a mechanism that traps the water and the oil inside the tube. Samples collected by this device are then used to quantify the thickness of the oil using two different methods. The first method consists on a photographic and imaging analysis of the sample, and the second method is a chemical separation of the oil contained on the sample which is then measured volumetrically. Analysis of the insitu measurements with the 2014/16 SAR data based on extraction of the entropy and comparison with in situ observations indicated that the location of the emulsified oil detected in the radar image was correlated with the in situ observations. The results suggest that polarimetric entropy can be used to detect emulsified oil based on the relative difference in the radar response between sheen and emulsified oil.

### Ground-truth Monitoring and Aerial Surveillance of Light Crude Oil Slicks Behaviour and Effect of Response Options during Full-scale Field Experiments

**P. S. Daling**[1], I. Gjesteland[2], A. Lewis[3], H. Jensen[4], F. Leirvik[1], T. Pettersen[1], D. Krause[1], K. Sørheim[1]
[1]SINTEF, Trondheim, Norway, [2]University of Bergen, Bergen, Norway, [3]Oil Spill Consultancy, Staines, Middx, United Kingdom, [4]NOFO (Norwegian Clean Seas Association for Operating Companies), Stavanger, Norway

As a part of the annual NOFO "Oil on Water field trials" in the North Sea in June 2016, three experimental slicks (each of $10m^3$) of a Norwegian condensate/light crude oil were released onto the sea surface under controlled conditions. The purpose of these experiments was:

- To document the behaviour of lighter oils when spilled at sea;
- To assess the efficacy of different response methods on thin oil slicks; and
- To document the potential risk of human exposure to the VOCs evaporating from the slicks.

A Norwegian Coast Guard vessel released the oil and a response vessel employed different response methods including low-dosage dispersant application, mechanical dispersion using a fire monitor and high-capacity water flushing bow booms. A variety of platforms were used to monitor the behaviour of



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the oil on the sea surface, the VOCs in the air and the oil in the water under the oil slicks. These included:

- Marine surveillance aircraft from Finland, the Netherlands and Norway using SLAR (Side Looking Airborne Radar), FLIR (Forward Looking Infra-red Cameras), IR / UV Line Scanners and HD video cameras. Quadcopter drones were also used for obtaining aerial video and air sampling.
- A USV (Unmanned Surface Vessel) deployed an Aerostat equipped with Visible/IR video and sampling boats with instrumentation for measuring VOC in the air concentrations.
- The oil slicks on the sea surface were sampled to determined oil layer thickness and the physico-chemical properties of the oil as they changed due to 'weathering'. The water column under the slicks was monitored for oil-in-water concentrations and dispersed oil droplet size distribution.

The overall results and findings from the field trials, and the experiences of the instrumentation, methods and monitoring platforms used for the scientific documentation of the slicks' behaviour and the response operations will be presented.

Hydrostatic pressure increases the toxicity to metals in *Daphnia magna*

J. Strickler, **J. F. Rubio***, M. Carvan
University of Wisconsin-Milwaukee, Milwaukee, WI

The majority of acute toxicity testing has and is been performed in laboratories at atmospheric pressures, around 0.101MPa. However, in oceans and deep lakes many creatures encounter toxic environments at hydrostatic pressures of up to 111MPa. To investigate whether or not hydrostatic pressure influences the toxicity of some metals we tested *Daphnia magna* at 10MPa and at atmospheric pressure for cadmium ($CdCl_2$), copper ($CuSO_4$), nickel ($NiCl_2$), and zinc ($ZnSO_4$). The protocols were the EPA approved ones as were the test animals. Daphnia magna survived 100% the assent and descent to higher pressures up to 20MPa. However, there were differences in LC50 between atmospheric pressure and 10 MPa hydrostatic pressure. For cadmium, the LC50 at atmospheric pressure was at 40PPB, and at 10MPa 20PPB, a 50% increase in toxicity. For copper, the LC50 at atmospheric pressure was at 120PPB, at pressure 100PPB, a 20% increase. For nickel, the LC50 at atmospheric pressure 400PPB, and at 10MPa 160PPB, a 60% increase. For zinc, the LC50 at atmospheric pressure 400PPB, and at 10MPa 340PPB, only a 10% increase in toxicity. This baseline research points to the necessity to test toxicity at hydrostatic pressures.

Assessment of oil spill from the former Taylor platform in the Gulf of Mexico

**S. Sun***[1], C. Hu[1], O. Garcia-Pineda[2], V. Kourafalou[3]
[1]University of South Florida, St Petersburg, FL, [2]Water Mapping LLC, Tallahassee, FL, [3]University of Miami, Miami, FL

The former Taylor energy oil platform, 12 miles off the coast of Louisiana coast which was destroyed by hurricane Ivan in 2004, continues to leak oil into the Gulf of Mexico for more than a decade. This oil spill received more public attentions after the Deepwater Horizon oil spill, yet to date there has been no systematic assessment of the spill. In this study, satellite data from multi-sources are used to map the oil distribution. Medium-resolution optical remote sensing images from Landsat (TM, ETM+ and OLI), Hyperion, ALI, ASTER, and Sentinel-2 are used to delineate oil slicks that appeared to originate from the Taylor platform since 2004. Concurrent satellite SAR data are also used to cross check the



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optical remote sensing results. Oil slick sizes and areas are statistically recorded, and then analyzed to determine if there is any temporal trend since 2004. The study is meant to provide an overview of the Taylor oil spill over the past 12 years, which may serve as baseline information for assessing future oil spills.

An Inventory of Natural Seeps using Archived Acoustic Backscatter Data
**D. Di Iorio**, M. Razaz, J. Kelly
University of Georgia, Athens, GA

Our new RFP V grant will be focused on a natural seep of gas bubbles and/or oil droplets in order to measure the vertical upwelling velocity using acoustic forward scatter methods in summer 2017. In order to select such a seep site, our work has included cataloging the archived acoustic backscatter data from echo sounders and multi beam sonars from various cruises and submersible platforms obtained at different times. The data will be used to identify the spatial scale of the seep and its backscatter signature. Since some of these seeps have temporal variations that are unknown, we hope to engage the scientific community in identifying a well-studied and important seep for our measurements

Large-scale Experimental Observations of Subsea Gas Blowouts
**E. J. Davies**, P. Skjetne, D. Krause, J. Olsen, G. Eidnes
SINTEF, Trondheim, Norway

Subsea blowouts of oil and gas are pose immediate risk to nearby operations and longer-term risk to the environment. While behaviour of oil is often the focus for environmental consequences, understanding how gas migrates through the water column also has implications for the near-field hydrodynamics affecting oil transport and is critical for safe operation and reliable Quantitative Risk Assessments in the offshore oil and gas industry. Through well documented measurements and thorough understanding of such releases, we are able to calibrate and validate accurate numerical predictions of such releases. Properties of buoyant gas plumes with release rates of up to 20 kg/s of gas and depth of 360m from a live gas pipeline are documented. We demonstrate the use of 3D acoustic imaging technology to track the geometry and movement of starting plumes and make use of a novel in-situ particle imaging system to quantify the size distribution of gas bubbles within gas plumes. Aerial imagery is used to provide information on the dynamics of the boiling zone and expansion rate of the surfacing plumes. The study demonstrates novel approaches to visualise and quantify the characteristics of subsea releases of gas, which are applicable on large scales relevant for offshore subsea releases, which we believe represents a substantial step-forward in our ability to understand real-scale risks associated with subsea releases. Our successful integration of scientific measurements and standard offshore operations provided access to experimental configurations using subsea infrastructure that would otherwise be inaccessible for scientific projects alone.



*****Student presenter

*In situ* Focused Shadowgraph System for the Study of Oil Droplets

**C. Guigand**[1], C. Cousin[2], M. Boufadel[3], G. Novelli[1], T. Ozgokmen[1]
[1]University of Miami, RSMAS, Miami, FL, [2]Bellamare LLC, San Diego, CA, [3]New Jersey Institute of Technology, Newark, NJ

The behavior of rising oil plumes strongly depends on oil droplet size distribution which remains difficult to measure in the field. Building upon our past experience with the design of *in-situ* plankton imaging systems, we propose a new field apparatus capable of accurately measuring oil droplet size distributions as well as other environmental data such as temperature, depth and salinity. Using focused shadowgraph imaging scheme, we plan to detect and quantify particles from 100 microns to centimeter scale. Preliminary design and tank experiments show the potential of this new instrument.

Combining Multibeam Acoustics and *in situ* Imaging to Resolve Patch Structure of Shrimp Aggregations and Gelatinous Zooplankton in Relation to Hypoxia

**A. T. Greer**[1], I. Church[2, 1], L. M. Chiaverano[1], M. H. Williamson[1], C. Briseno-Avena[3], R. K. Cowen[3], W. M. Graham[1]
[1]University of Southern Mississippi, Stennis Space Center, MS, [2]University of New Brunswick, Fredericton, NB, Canada, [3]Oregon State University, Newport, OR

Describing zooplankton distributions in detail over large areas of the ocean is important because zooplankton are critical links in the Gulf of Mexico (GOM) food web, and the patchy nature of zooplankton affects their vulnerability to predation, access to prey, and potentially their rate of exposure to pollutants. Multibeam acoustics, which are used extensively in hydrographic surveys, have the potential to resolve plankton patches at high resolution and in 3D, but it is currently difficult to determine the acoustic characteristics of organisms or physical features producing the backscatter. To resolve this issue and evaluate the utility of the multibeam for biological studies, we towed a high resolution *in situ* imaging system (with CTD, dissolved oxygen, PAR, and chlorophyll-a fluorescence) with synoptic multibeam (Reson SeaBat 7125, 400 khz) backscatter data from suspended targets (biological and non-biological) and described the distributions of zooplankton in relation to hypoxic bottom waters. Multibeam data were processed to make them directly comparable to the imaging system data (i.e, transformed to 2D - depth and distance along transect). We were then able to measure the target strength (TS, dB) of the acoustic scatterers and identified them as shrimps. Once the TS of the shrimp aggregations was determined, the full swath of 512 beams was used to map the 3D structure of the patches. Multibeam water column backscatter data can provide high resolution and 3D observations of zooplankton patches. However, gelatinous zooplankton and other groups were not reliably detected, and sharp gradients in salinity, which are common in the stratified waters of the northern GOM, produced an acoustic return even where zooplankton aggregations were not seen by the imaging system. We found that shrimps tended to associate with oxyclines, a habitat which could serve as a refuge from predators with higher oxygen requirements. Combining in situ imaging and multibeam acoustic data can help with interpreting the source of acoustic backscatter and differentiate biological from non-biological targets. This kind of information can be used to evaluate shrimp habitat preference over large scales in relation environmental conditions.



*****Student presenter

A Water Tank Study of Oil-on-Sediment by Acoustic Backscattering and Reflecting Measurements
**Z. Lu**, C. J. Hickey
National Center for Physical Acoustics, The University of Mississippi, University, MS

In order to gain better understanding and modeling of acoustic responses of oil contamination on sediments, a water tank experiment was conducted to simulate field sonar measurement in a small scale and under controlled oil-on-sediment conditions using acoustic transmissions, reflection, and back-scatter measurements. The experimental system consists of a water tank (1.6 meters in diameter and 1 meter in height), two ultrasonic transducers (chirp transducer, 130 kHz-210 kHz), and a hydrophone array buried within the sediment. The ultrasonic transducers are mounted on a 5 meter-long test frame and driven by a stepper-motor with adjustable grazing angles and heights. Two preliminary tests were conducted to measure reflection coefficient and back-scatter strength as a function of grazing angle on (1) clean sediment and (2) oil-sediment mixture (a 2 inches mixture layer). The results show increasing trends for both the reflection coefficient and back-scatter strength as oil mixed with sediments, confirming the feasibility of detecting oil impacted sediments using acoustic reflection and back-scatter measurements.

Bacterial community composition in the sea surface microlayer with a focus on surfactant-associated bacteria in application to satellite oceanography
**K. L. Howe***[1], C. Dean[1], J. Kluge[1], A. Soloviev[1], A. Tartar[1], M. Shivji[1], S. Lehner[2], W. Perrie[3]
[1]Nova Southeastern University, Davie, FL, [2]German Aerospace Center, Bremen, Germany, [3]Bedford Institute of Oceanography, Bedford, NS, Canada

The sea surface microlayer (SML) is a vital environmental boundary involved in Earth's biogeochemical processes, such as heat, gas, and momentum exchange at the air-sea interface. The rates of these processes may be altered by the presence of organisms and the by-products of their lifecycles in the near surface layer of the ocean. Microbial communities are extremely variable in space and time, especially in the microlayer, which is easily disturbed by physical forces (wind, waves, bubble scavenging, etc.). This study focuses on surfactant-associated bacteria in the near surface layer of the ocean and their possible role as indicators of slicks on the sea surface. Natural surfactants are the by-products of life processes of marine organisms, such as phytoplankton, zooplankton, seaweed, and bacteria. Surfactants can also be associated with oil spills. Surfactants decrease surface or interfacial tension forces and are known to dampen Bragg waves, causing sea slicks under low wind speed conditions. These natural slicks are visible in synthetic aperture radar (SAR) imagery, just as oil spills are. A new approach to reduce contamination during sample collection, handling, and lab processing developed as a part of CARTHE/GoMRI has been further expanded upon and implemented in this study. Over 100 sea surface microlayer and subsurface water samples were collected in the Gulf of Mexico near De Soto Canyon in February 2016 during LAgrangian Submesoscale Experiment (LASER). Quantitative PCR (qPCR) analysis of these samples shows a wide variability of relative abundance of *Bacillus spp.*, a well-known surfactant-associated bacteria, between the SML and SSW. All samples have been sequenced via Illumina MiSeq and results are currently being analyzed to determine the exact community composition of the SML and SSW samples focusing on the presence of surfactant and oil associated bacteria.



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Exploring the Multidimensionality of Luminescence Spectroscopy to Face Analytical Challenges in the Gulf of Mexico

**A. Campiglia**
University of Central Florida, Orlando, FL

The multidimensional nature of photoluminescence phenomena provides fluorescence and phosphorescence techniques with unique potential for the analysis of complex matrixes. The combination of excitation and emission spectra to lifetime information within the fluorescence and phosphorescence time domains yields at least three qualitative parameters for compound determination, namely, one excitation and one emission wavelength and one lifetime. The simplicity of experimental procedures makes room-temperature luminescence techniques the most popular approach. The main limitation of room-temperature techniques is the broad nature of excitation and emission spectra. The diffuse character of such spectra limits the information content for the selective analysis of target compounds in complex matrixes. Reducing the sample temperature often leads to spectral narrowing, which is especially pronounced in the so-called high-resolution techniques. In this talk, I will present significant improvements we have made to line-narrowing luminescence techniques. The full dimensionality of photoluminescence is obtained with a pulsed tunable dye laser for sample excitation, a spectrograph and an intensifier-charged coupled device. Wavelength time matrices and time-resolved excitation-emission matrices are efficiently recorded in short analysis time. I will discuss the application of time-resolved high-resolution luminescence spectroscopy to the environmental analysis of high molecular weight polycyclic aromatic hydrocarbons (HMW-PAHs). Similar chromatographic behaviors and almost identical mass fragmentation patterns make separation and identification of HMW-PAHs difficult. Since the carcinogenic properties of those pollutants differ significantly within isomers of the same molecular weight, it is of paramount importance to determine the most toxic isomers even if they are present at much lower concentrations than their less toxic isomers.



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# Session 022: Deepwater Horizon Oil Spill Natural Resource Damage Assessment: Comprehensive Integrated Ecosystem Restoration

## Session Introduction: Comprehensive Integrated Ecosystem Restoration

**A. Smith**
NOAA Restoration Center, Silver Spring, MD

The Deepwater Horizon (DWH) settlement of $8.8B for the Natural Resource Damage Assessment (NRDA) portion was finalized on April 4, 2016. The Trustees determined that injuries to natural resources caused by the DWH oil spill constituted an ecosystem-level injury due to the effects on such a wide array of linked resources over such an enormous area. Just as the injuries to individual resources cannot be understood in isolation, restoration efforts must also be considered and implemented from a broader perspective. Consequently, the Trustees developed and will implement a comprehensive integrated restoration portfolio. This presentation will provide an overview of the integrated restoration portfolio and how it addresses the diverse suite of injuries that occurred at both regional and local scales. The portfolio allocates restoration funds across thirteen restoration types, making investments across Regionwide, Open Ocean and each of the five Gulf states restoration areas to restore coastal and nearshore habitats, improve water quality in priority watersheds, protect and restore living coastal and marine resources, and enhance recreational use opportunities. By making investments across resource groupings and supporting habitats, the Trustees will ensure that the public is appropriately compensated for all the resources and services injured by the spill.

## Monitoring and Adaptive Management to Support Restoration of Resources Impacted by the Deepwater Horizon oil spill

**M. Carle**[1], T. Davenport[2], J. Redding[1], J. Cowan[3], K. Carney[4], T. Hollweg[4], G. Steyer[5], M. Meyers[6], C. Kellogg[7]
[1]ERT, Inc./NOAA Restoration Center, Silver Spring, MD, [2]Formerly, ERT, Inc./NOAA Restoration Center; Currently, Northeastern University, Silver Spring, MD, [3]Formerly, NOAA Restoration Center; Currently, RESTORE Council, Baton Rouge, LA, [4]Abt Associates, Boulder, CO, [5]U.S. Geological Survey, Baton Rouge, LA, [6]U.S. Geological Survey, New Orleans, LA, [7]U.S. Geological Survey, St. Petersburg, FL

The Oil Pollution Act (OPA) Natural Resource Damage Assessment (NRDA) regulations require that restoration plans to address natural resource injuries include monitoring to document restoration effectiveness, or the need for corrective action. Given the unprecedented scale of the Deepwater Horizon incident and its associated restoration plan, the Deepwater Horizon Natural Resource Trustees recognize a need for a robust, scientifically based, monitoring and adaptive management framework to support restoration decision-making and measure restoration benefits. To support the recovery of natural resources and services injured by the spill, the Trustees have identified the need for monitoring and adaptive management (MAM) at multiple scales, including for individual restoration projects, injured resources, and across the entire Deepwater Horizon NRDA restoration effort. Within the NRDA Trustee Council, a Cross-TIG MAM work group has been formed with representation from each Trustee Council member to encourage consistency in NRDA restoration monitoring across restoration areas and make recommendations to the Trustee Council on effective evaluation of restoration outcomes across multiple scales. The Cross-TIG MAM work group is currently focusing on developing standard formats for project monitoring and adaptive management plans, developing monitoring and data standards for restoration projects, and establishing mechanisms to coordinate with other restoration programs in the



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Gulf of Mexico on monitoring topics. As a foundational element of the Deepwater Horizon Programmatic Damage Assessment Restoration Plan (PDARP), this monitoring and adaptive management framework will provide broad scientific support for restoration activities and increase the likelihood of successful restoration in the northern Gulf of Mexico region.

The Mississippi Restoration Landscape: Connecting the dots across funding streams

**R. Kroger**
Covington Civil and Environmental, Gulfport, MS

The Deepwater Horizon oil spill (DWH) triggered one of the largest restoration efforts in history. Given the scale of funding available to the various Gulf States as a result of DWH, as well as the temporal duration of those funds, it is imperative that States develop a Game Plan to effectively implement ecological restoration. Furthermore, as championed by Gulf stakeholders and articulated in numerous visions and plans, coordination and leveraging of funding streams should be a quintessential ingredient for restoration. The State of Mississippi, in striving to "Make Mississippi Whole", has made a dedicated effort to strategically use funds from the Natural Resource Damage Assessment (NRDA), the RESTORE Act, and the National Fish and Wildlife Foundation Gulf Environmental Benefit Fund (NFWF GEBF) to connect various efforts towards a common goal of maximizing the ecosystem service benefit of projects to enhance regional efforts. The State of Mississippi's slate of NRDA Restoration projects fits with a comprehensive vision for restoration in the State, that is designed to be dynamic; it is flexible enough to shift and adapt to changing strategies, ideals, and objectives as environmental conditions and ecosystem priorities change. This integration showcases how restoration projects in NRDA can be integrated across funding streams to meet broader restoration goals.

Restoring marine life comprehensively across political boundaries

**M. Love**[1], A. Baldera[2], C. Robbins[2], R. Spies[3]
[1]Ocean Conservancy, Fairhope, AL, [2]Ocean Conservancy, Austin, TX, [3]Applied Marine Sciences, Little River, CA

Ecosystem-based approaches for comprehensive marine resources restoration illustrate the need for an integrated approach that incorporates the diverse stressors impacting ecosystem condition influencing species distributions, migratory pathways and overall environmental suitability. In addition to the complexity of stressors impacting the Gulf of Mexico marine environment, many resources targeted for restoration span multiple agency jurisdictions. If restoration projects are planned in isolation, they could result in a lower or even negative return on restoration investment than if state and federal agencies actively collaborate. When agencies have a comprehensive understanding of the distribution of priority natural resources with cumulative impacts, restoration can be planned across jurisdictions to mitigate the greatest threats with restoration projects implemented within the comprehensive context required to coordinate concerted restoration. Ocean Conservancy presents a methodology for articulating and illustrating how, why and where restoration priorities can be integrated and implemented within a multi-jurisdictional framework based on science and restoration need. We use sea turtles for illustrative purposes and a spatially explicit approach to quantify cumulative stressors across the Gulf that impact these species. Marine turtle species in the Gulf of Mexico are a priority restoration target after the BP Deepwater Horizon oil disaster. This assessment combines priority stressors for marine turtles using a relative index score based on expert opinion and compared with marine turtle and habitat distributions to identify hotspots of areas with high



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restoration need and high resource value. We identify restoration options within the purview of each relevant agency based on the results of the cumulative stress assessment. By using a cumulative stressor index within the context of spatial jurisdictions of entities implementing restoration in the Gulf, an integrated strategy for comprehensive project planning emerges that can mitigate key stressors and thus aid species survivorship and recovery.

Managing and Sharing Data Using the Deepwater Horizon DIVER (Data Integration, Visualization, Exploration, and Reporting) Tool

**M. Peccini**[1], M. McGuire[2], A. Merten[3], B. Shorr[3], N. Wallace[1], J. Redding[1]
[1]NOAA, Silver Spring, MD, [2]NOAA, St. Petersburg, FL, [3]NOAA, Seattle, WA

The DIVER application is a data warehouse and query tool that manages the integration of environmental data and restoration project information and monitoring data, and makes this data available to stakeholders and the public for querying and download for further analysis. The Deepwater Horizon DIVER application was designed for the trustees responsible for assessing damage and implementing restoration in the Deepwater Horizon Natural Resource Damage Assessment (NRDA). DIVER facilitates sharing restoration monitoring data from trustees and other partners across the Gulf of Mexico. DIVER currently contains over 13 million publicly available records and the scale of the data ranges from broad datasets that cover the entire Gulf of Mexico to very specific samples collected at a specific location. The magnitude of both the assessment and restoration aspects of the Deepwater Horizon case is large and the timeframe to accomplish restoration is long. Given the unprecedented scope and scale of this case and the complexity and volume of projects to be implemented under the Programmatic Damage Assessment and Restoration Plan (PDARP), the trustees recognize the need to have a robust approach to long-term monitoring and adaptive management of restoration projects as well as to the associated data management needs. DIVER's centralized reporting platform can help facilitate consistent and efficient aggregation of information and project reporting. Standard operating procedures developed by the trustees address reporting project status, financial information, environmental compliance, and project monitoring activities. DIVER supports making this information accessible for decision-making throughout the NRDA process. The specific focus of this presentation will be on how DIVER supports the trustees through restoration planning, implementation, and the aggregation and synthesis of restoration monitoring data.

Open Ocean Restoration Planning

**K. Benson**
NOAA Restoration Center, Galveston, TX

The Deepwater Horizon (DWH) oil spill impacted resources and habitats throughout the Gulf of Mexico ecosystem, including many for which restoration is not commonly conducted. To address the diverse suite of injuries that occurred at both regional and local scales, the Trustees' allocated settlement funds to Restoration Types based on the understanding of injury and the capacity of each programmatic goal and Restoration Type to restore for injuries. Additionally, the Trustees allocate restoration funds geographically based on their understanding and evaluation of exposure and injury to natural resources and services, as well as their evaluation of where restoration spending for the various restoration types will be most beneficial within the ecosystem-level restoration portfolio. By allocating restoration funds across resources, supporting habitats, and geographic areas, the Trustees will maximize the likelihood of providing long-term benefits to those resources and services injured by the spill. The Open Ocean



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Restoration Area includes restoration for Fish and Water Column Invertebrates, Sturgeon, Sea Turtles, Marine Mammals, Birds, and Mesophotic and Deep Benthic Communities. For some of these restoration types, there are existing plans and program initiatives that can be relied upon to inform project selection and implementation. However, for other resources where there is limited restoration experience; it will require novel application of restoration concepts. Therefore, an essential element of successful restoration will be employing an adaptive management approach to restoration decisions that both capitalizes on and catalyzes advancements in the state of the science. This presentation will explore the next steps for restoration planning for the Open Ocean restoration types and the challenges and opportunities for implementing restoration that best addresses the array of resources, species, and life stages that were impacted by the spill.

Estimating the Benefits of Crab Trap Removal Programs to Restore Fish and Water Column Invertebrates in the Gulf of Mexico

**C. Arthur**[1], S. Friedman[1], D. Van Nostrand[2], J. Reinhardt[3]
[1]IEc, Cambridge, MA, [2]NOAA Restoration Center, Mobile, AL, [3]NOAA Restoration Center / ERT, Silver Spring, MD

Ghost fishing in derelict blue crab traps kills target and non-target fish species and remains a substantial problem in bays and estuaries throughout the Gulf of Mexico. Projects that reduce ghost fishing in blue crab traps may, therefore, help restore a number of estuarine fish and shellfish that were injured during the Deepwater Horizon oil spill or via other disturbances. This presentation will focus on restoration of estuarine resources by removal of derelict blue crab traps. We estimated (1) the density of derelict blue crab traps across Gulf of Mexico waterbodies and (2) Gulf-specific crab and finfish mortality rates due to ghost fishing, and subsequently evaluated the potential ecological benefits of trap removal programs. Parameters were estimated using available data, best professional judgment, case studies in other locations, and the peer-reviewed literature. Our results indicate that a Gulf-wide program to remove 10 percent of derelict traps would prevent hundreds of thousands of crab and fish mortalities over a five-year period. The approach used in our study to estimate ecological benefits can easily be extended to other trap fisheries. Similarly, our framework lays the groundwork for assessments of other ecological and human-use benefits such as fewer entanglements of marine mammals and sea turtles, improved aesthetics, and economic benefits for fishers and communities.

A Meta-analysis to Evaluate Catch Rate and At-vessel Mortality of Circle Hooks in Pelagic Longline Fisheries: Management and Conservation Benefits

**J. Weaver**[1], J. Reinhardt[2], P. Latham[3], A. Dell'Apa[2], M. Christman[4]
[1]Research Planning, Inc., Columbia, SC, [2]NOAA Restoration Center / ERT, Silver Spring, MD, [3]Research Planning, Inc., Tallahassee, FL, [4]MCC Statistical Consulting, LLC, Gainesville, FL

Pelagic fish, such as marlins and tunas, were exposed to oil during the Deepwater Horizon Oil spill. Longline commercial fishing methods that capture these species as bycatch presents opportunities to restore for DWH losses by implementing gear modifications that reduce bycatch. One such approach could encourage the use of circle hooks in pelagic longline fisheries. Circle hooks have been shown to reduce the severity of injuries, therefore lowering mortality rates to some species captured in pelagic longline fisheries. To quantify the potential ecological benefits of programs incentivizing the use of circle hooks, we conducted a literature review and meta-analysis of existing studies to estimate the relative differences in catch rate and at-vessel mortality when circle hooks are use compared to



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traditional hook types. Data from 42 empirical studies were analyzed using a random effects model to compare the effects of circle hooks and J-hooks on catch rate (43 species) and at-vessel mortality (31 species) of target and bycatch species. The impact of circle hooks on catch rates was variable across species. Catch rates on circle hooks were significantly lower for seven species examined, higher for eleven species, and non-significant for 25. Mortality rates were significantly lower on circle hooks compared to J-hooks for all 12 of the species for which significant effects were observed. Using publicly available catch data, results from the meta-analysis were then applied to available information on the Atlantic Taiwanese pelagic longline fishery to predict changes in landings for two target species (albacore and bigeye tuna), and changes in post-release survival for two discard species (white and blue marlin). For the species examined, results indicate that using circle hooks instead of traditional hooks could increase the biomass of target species landed and decrease the mortality of discarded species.

Compensatory Restoration Concepts for Offshore (Deepwater) Benthic and Aquatic Resources

**N. Gard**[1], A. Morrison[2], K. Palmquist[1], L. Semenova[2], T. Ginn[3]
[1]Exponent, Bellevue, WA, [2]Exponent, Maynard, MA, [3]Exponent, Sedona, AZ

In natural resource damage assessments (NRDAs) compensatory restoration is required to restore or replace interim losses of resource services that accrue until a return to baseline is achieved. Natural resource trustees generally favor restoration-based approaches that restore in-kind services to those lost during a spill or release. However, development of compensatory restoration projects for offshore aquatic and deepwater benthic resources following an oil spill presents challenges that may not be encountered in shallow water or nearshore spills. First, the biology of many offshore species is often poorly understood, which limits understanding of their ecological requirements and appropriate restoration strategies. Second, deepwater restoration projects may be technically challenging, not cost effective, or experimental with little certainty of success. As part of restoration evaluations following the Deepwater Horizon oil spill, we conducted an analysis to identify possible restoration concepts for specific offshore resource categories including pelagic fishes, reefs, and *Sargassum* communities. The evaluation exercise involved identifying relevant ecological service flows from restoration concepts to impacted resource categories and defining scaling approaches and factors for non-in-kind restoration alternatives. Benefits of restoration concepts to non-target resource categories were also assessed. Restoration concepts identified as potential alternatives through this exercise included *Sargassum* stocking, stocking of selected fish species, construction of shallow and mesophotic artificial reefs and creation of National Marine Sanctuaries. This presentation provides an overview of the process used to identify and scale these restoration concepts, major sources of uncertainty in the analyses and recommendations for consideration if similar evaluations of restoration options are required in the event of future oil spills in offshore ecosystems.

Deepwater Horizon Oceanic Fish Restoration Project - Applying Natural Resource Damage Assessment in Offshore Environments

**J. F. Reinhardt**[1], L. Keeling[1], D. R. Blankinship[2], M. Landry[3], L. Jennings[4], G. Silva[5]
[1]Earth Resources Technology, Silver Spring, MD, [2]NOAA, St. Petersburg, FL, [3]NOAA, Baton Rouge, LA, [4]Earth Resources Technology, Seattle, WA, [5]NOAA, Silver Spring, MD

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



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bycatch in the Gulf of Mexico pelagic longline fishery. By partnering with volunteer longliners who are compensated to stop using pelagic longline gear 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. Now that the project is in its initial stages of implementation there are already lessons learned regarding how to conduct restoration planning in offshore environments and within the context of important fisheries. Important considerations need to be made for existing management systems and other socio-economic factors. Having systems in place to monitor and adaptively manage novel restoration types/projects may be critical for ensuring restoration success in offshore environments.



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## Session 023: Environmental Baseline and Oil Spill Impacts: Utilizing Big Data and Synthesis to Support Decision Making

### Assessing Broad-Scale Abundance and Distribution of Marine Mammals, Sea Turtles, and Seabirds in the Gulf of Mexico - The New GoMMAPPS Field Program

**R. Green**[1], J. Gleason[2], M. Lamont[3], K. Mullin[4]
[1]BOEM, New Orleans, LA, [2]UWFWS, Lacombe, LA, [3]USGS, Gainesville, FL, [4]NOAA, Pascagoula, MS

The Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS) proposes a framework to reduce uncertainty related to abundance and distribution of marine mammals, sea turtles, and seabirds within the GoM with respect to oil and gas (O&G) activities. The data collected will be invaluable to BOEM for informing NEPA analyses, exploration and development plans, and oil spill risk analyses, as well as to the FWS and NOAA for Section 7 consultations and planning of O&G activities on the Outer Continental Shelf to reduce or mitigate associated impacts. The GoMMAPPS field program is currently set to launch a multi-year field campaign in Spring/Summer 2017 to include aerial surveys, ship-based surveys, telemetry monitoring, and ancillary habitat data. For BOEM regulatory needs, it is critical to provide time-series and abundance and trend information which can be used for identifying any significant changes in the quality of the environment, and when practicable, to identify agents of change. GoMMAPPS represents a multi-agency partnership between BOEM, USFWS, NOAA, and USGS, all of whom desire information for large marine vertebrates to provide improved spatially-explicit density distributions to inform multiple management issues. The lack of broad-scale abundance data has been identified as a gap across multiple GoM stakeholders. The data collected should provide additional information for the long-term recovery of the GoM ecosystem. The Science Plans detailing the GoMMAPPS field surveys will be presented including methodologies, survey designs, anticipated data analyses and modeling, and data management and dissemination. Potential for education and outreach will also be discussed. A large and multi-faceted dataset is expected to result from this program. A data management framework is being developed to ensure that data stewardship guidelines are implemented and that resulting datasets are available to support decision-making related to protected species in the GoM.

### Establishing Baselines for Benthic Habitat and Reef Fish Populations on the West Florida Shelf Using Ultra-High Resolution Multibeam Sonar and Towed Video

**S. Grasty**[1], C. Lembke[1], M. Hommeyer[1], S. Locker[2], J. Gray[1], J. Brizzolara[1], S. Murawski[1]
[1]University of South Florida, St. Petersburg, FL, [2]United States Geological Society (USGS), St. Petersburg, FL

It has been demonstrated though hydrographic modeling that oil from the Deepwater Horizon blowout likely reached the West Florida Shelf (WFS) in 2010 at the time of the spill. Fortunately the extensive hard bottom habitat in this area was less impacted compared to the ecosystems in the immediate vicinity of the wellhead. This ecological disaster emphasized to researchers and marine resource managers in the eastern Gulf that there is need for more baseline data to better understand the potential impacts of future oil spills. The WFS in particular possesses several management categories that are currently noted as being “data poor”. Among them, benthic habitat and living marine resources are considered categories for which increased research and study should be prioritized. The Continental Shelf Characterization, Assessment and Mapping Project (C-SCAMP) is mapping areas likely to possess essential habitat for reef fish and sea turtles using sub-meter resolution multibeam sonar



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and a towed camera system for collecting bottom type and fish abundance data. As of the end of 2016, this project has mapped over 800 $km^2$ of new area and collected over 80 hours of imagery. By the end of 2018, we anticipate increasing the mapped area of the WFS by approximately 30% of what existed prior to when C-SCAMP efforts began. The results of the benthic habitat analyses and fish assessments will be presented for some of these newly mapped regions which have been found to possess extensive hard bottom communities and support high reef fish abundance and diversity. The overall aims of the project and other areas of research will also be briefly discussed which includes pairing EK-60 sonar and towed camera data as well as benthic faunal analysis.

Gulf of Mexico Zooplankton Synthesis and Data Portal

**K. B. Huebert**, M. R. Roman, J. J. Pierson
UMCES Horn Point Laboratory, Cambridge, MD

We are creating a large database of oceanographic measurements related to Gulf of Mexico zooplankton, which will be freely accessible online via a state-of-the-art data portal by late 2017. The bulk of our data was collected during six summer cruises (2003, 2004, 2006, 2007, 2008, 2010) near the seasonal hypoxic zone in the Northern Gulf of Mexico, using a suite of optical and acoustic instruments. For example, we have over 25,000 vertical profiles with high-resolution mesozooplankton particle size distributions measured by an Optical Plankton Counter mounted to a towed ScanFish vehicle. Numerous colleagues have already contributed additional datasets for inclusion in the synthesis and data portal project, and we are actively seeking more such data! A suite of included environmental and geographic variables (temperature, salinity, chlorophyll, oxygen, bathymetry, stratification, proximity to hypoxia, proximity to river plumes, etc.) will be used for statistical modeling of zooplankton. Online tools will allow users to interactively generate maps of observed and modeled zooplankton biomass, vertical distribution, size distribution, and taxonomic composition. Interactive demonstrations of data visualization and retrieval tools will take place at the Gulf of Mexico Tools Café.

Coming into Focus: Improved Understanding of the Spatial Dynamics of Reef Habitat in the Eastern Gulf of Mexico

**S. F. Keenan**[1], T. S. Switzer[1], A. R. Knapp[2], E. J. Weather[1]
[1]Florida Fish & Wildlife Research Inst., St. Petersburg, FL, [2]Florida Fish & Wildlife Research Inst., Cedar Key, FL

The prevalence of reef habitats on the eastern Gulf of Mexico continental shelf is a primary driver of reef-fish productivity that, in turn, supports highly-diverse commercial and recreational fisheries. Nevertheless, our understanding of spatial variability in habitat quality, quantity, and distribution, especially at a sufficient resolution to support sampling efforts, is generally lacking. Habitat mapping at appropriate spatial scales is essential for stratifying fishery surveys and advancing spatially-explicit ecosystem modeling capabilities. Accordingly, the state of Florida initiated a habitat mapping survey in 2014 to identify reef habitats throughout the eastern Gulf of Mexico (from the Florida Keys to the Florida-Alabama border) and direct subsequent sampling efforts. This survey employs a stratified-random design whereas locations of specific mapping surveys are randomly selected and stratified by region and depth. Mapping data are collected using side scan sonar, and supervised classification techniques are used to identify and delineate reef habitats. To date 30 unique habitats have been characterized from approximately 1,400 surveys which cover approximately 2,900 $km^2$. While the vast majority of surveyed area consisted of unconsolidated sediment, reef features, such as low-relief hard bottom, were identified and comprised the majority of reef habitats. Artificial reef habitats were the



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most common in the north-eastern Gulf while natural reefs were more prevalent in the eastern Gulf shelf waters. Implications of spatial variability in habitat quality, quantity, and distribution, especially in terms of ongoing restoration and monitoring activities, will be discussed.

Adding to the Baseline: Integrating Spatio-Temporal Big Data Analytics into Decision-Support Tools for Offshore Spill Prevention

**J. Bauer**[1], K. Rose[1], V. Baker[2, 3], A. Barkhurst[2, 3]
[1]National Energy Technology Laboratory, Albany, OR, [2]National Energy Technology Laboratory, Morgantown, WV, [3]MATRIC, Morgantown, WV

Efforts to prepare for and reduce the risk of hazards, from both natural and anthropogenic sources, that threaten our oceans and coasts require an understanding of various physical, ecological, and socio-economic systems and the interactions between them. Synthesizing and analyzing the growing amount of data from these systems is essential to improving baseline knowledge and evaluating potential risks and impacts to offshore systems. This is particularly key as oil and gas exploration and production push into harsher environments where risks and uncertainty both increase. To work with these large volumes and varieties of data, researchers are turning towards big data computational methods to efficiently identify, integrate, and analyze these data and complex relationships between them. In order to quantify risks for the full offshore environment, from the subsurface, through the water column, to coastal ecosystems and communities, we are leveraging spatio-temporal methods with big data analytics to develop a suite of integrated web-based decision-support tools. These tools provide the capabilities to identify and combine data from several scales and disciplines, evaluate potential environmental, social, and economic impacts, highlight knowledge or technology gaps, and reduce uncertainty for a range of 'what if' scenarios relevant to oil spill prevention efforts. In this presentation, we will discuss our methods for integrating big data computing and spatio-temporal methods with online analytics to enable rapid analysis and effective communication of results to improve the baseline knowledge of potential risks to the offshore environment and support of a range of decision-making needs.

Regional Monitoring of Indicators to Assess Ecosystem Restoration

**A. Freeman**, S. Khalil, P. Kolic
Coastal Restoration and Protection Authority, Baton Rouge, LA

An estimated quarter of Louisiana's productive coastal landscape has been lost over the past century, and greater losses are predicted, with future conditions highly uncertain due to the dynamics of riverine and marine processes, storm events, climate change, population growth, economic activity, disasters, and ongoing human reliance on the natural resources the coast provides. Ecosystem restoration on the scale of Louisiana's 50 year Master Plan has not previously been either conceptualized or implemented. 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. A suite of indicators have been previously identified to evaluate changes for both the natural and human systems. 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. A regional scale pilot



*****Student presenter

implementation program is underway, focusing on monitoring natural system indicators in the Barataria Basin in Louisiana. Baseline conditions are being quantified, and methods to assess change in the biophysical and sedimentary environment developed to support the strategic implementation and evaluation of restoration projects. Initial results indicate at least four large-scale regions in the basin with distinct spatial coverage of bottom types, including hard-bottom and oyster areas. It is expected that the results of this pilot-scale monitoring program will inform the development and implementation of SWAMP on a coast-wide scale.



*****Student presenter