Abstracts for Oral Presentations

Organized by Session

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Session 001: Modeling for Synthesis – Integrated Assessment of Ocean Environment, Ecosystems, Human Health, and Socioeconomics

Towards Integrated Assessment Modeling of the Long-Term Impacts of Oil Spills

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Through the efforts of the Gulf of Mexico Research Initiative (GoMRI) great progress has been made in advancing the scientific understanding of oil spills. One objective of GoMRI synthesis and legacy efforts has been to integrate this new knowledge and develop a conceptual framework that could be used to address long-term societal questions about oil spill impacts. Given the breadth of the questions to be addressed, the assessment was separated into four knowledge domains (ocean environment, ecosystems, socio-economics and human health) from which a systems dynamics approach was used to develop the conceptual framework. A series of online workshops solicited expert input, defining the state-of-the-art within each knowledge domain and connecting models to stakeholder questions. This exercise resulted in causal loop diagrams and an initial quantitative stock and flow model from which the interconnectivity of the system could be better understood. Mapping the extent of existing models to the underlying system structure indicates that the system naturally separates in two tiers, ocean environment and ecosystems versus socio-economics and human health. The systems and existing models within each of these tiers are intertwined with each other. As a result, the existing detailed ocean environment and ecosystem models can be used to drive rich human health and socio-economic scenarios. Although data gaps are identified in all four model domains, the socio-economics and human health domains are the least developed and require considerable future work in order to develop reasonable quantitative models that can be used for longer term decision-making

Integrated Model System for Oil Spill Natural Resource Damage and Risk Assessments

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The integrated model system SIMAP (Spill Impact Model Application Package) has been developed over several decades for natural resource damage assessments, as well as for risk analyses evaluating response alternatives and consequences from oil spills. The oil transport and fate model of SIMAP uses a Lagrangian approach, in which sublots and chemical components of the released pollutant mass are followed in space and time as they are transported, dispersed, and physically/chemically changed (e.g., entrainment, droplet/particulate formation, dissolution, volatilization, degradation, adsorption), accessing pathways of stressors and their concentrations. Results from meteorological and hydrodynamic models are used as inputs of winds and currents. An integrated Lagrangian activity-based exposure model tracks the exposure history (i.e., concentrations of each chemical component, and temperature and light exposures, over time) of aquatic biota to oil and the mixture of chemicals throughout the affected environment using behavioral information and accounting for physical transport of plankton by currents. The effects of the integrated exposures are evaluated with a pharmacokinetic-based toxicity model, accounting for the relative composition of the chemical mixture, as well as the influence of temperature and duration of exposure on the dose-response relationship. Wildlife effects are evaluated via exposure to floating oil and atmospheric emissions. Long-term losses, as well as restoration/mitigation needs, are quantified using population modeling and food web

* Student presenter

modeling. Socio-economic impacts are based on quantified injuries from and physical exposures to oil, considering recreational losses, catch losses, hunting losses, wildlife-viewing losses and lost non-use values. Applications of the integrated system and its parts include development of regulatory models for NRDA and spill cases such as the North Cape and Deepwater Horizon oil spills.

Regional Earth System Modeling for Integrated Prediction of Hazards and Societal Impact Over the Gulf of Mexico

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The air-sea-land interactions are a key to improving environmental prediction for high-impact weather and hazards over the Gulf of Mexico. Oil spill and hurricanes are two examples that have shown the urgent need for integrated, coupled atmosphere-wave-ocean-land modeling and accurate forecasting. This study presents the development and applications of a regional, coupled Earth System modeling system and its new capabilities and implications for addressing societal impacts.

A Coupled Modeling System for Simulating Oil-Biological-Sediment Interactions in the Ocean

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Over the past decade, numerous studies have yielded a better understanding of the processes governing the eventual fate of oil released in the ocean. Oil spill models have been developed with parameterizations simulating processes such as sedimentation, biodegradation, and atmospheric weathering for removing oil from the system. However, such models are limited in their ability to fully simulate pathways for hydrocarbons moving through seawater into sediments and the marine ecosystem. The Consortium for Simulation of Oil-Microbial Interactions in the Ocean (CSOMIO) has developed a modeling system that dynamically couples components for simulating ocean hydrodynamics, oil transport, dispersion and weathering, oil-mineral aggregate (OMA) formation, flocculation and settling, and the lower trophic level marine ecosystem. This CSOMIO Coupled Model is an adaptation and extension of the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) modeling system. A biogeochemical modeling component incorporating a microbial model is implemented in the system and adapted for the presence of hydrocarbons. The sediment transport component of COAWST (the Community Sediment Transport Modeling System, CSTMS) is modified to include computationally efficient flocculation parameterizations for OMAs developed from laboratory experiments. The ocean modeling component of COAWST (the Regional Ocean Modeling System, ROMS) is modified to simulate three-dimensional oil transport and compositional changes (weathering). These modeling components are linked together using a two-way Lagrangian-Eulerian mapping technique allowing for interaction between all of the modeling components for tracking of hydrocarbons from a source blowout to deposition in sediment, microbial degradation, and evaporation while being transported through the ocean, and can be run offline to increase computational speed.

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A 3-D Fate and Transport Model Explains Measured Changes in PAH Concentrations from Weathered Oil

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Determining the concentration of oil spill chemicals (OSCs) of concern in human exposure zones, such as beaches and other nearshore environments, is a primary step in assessing the health risk due to marine oil spills. Crude oil contains thousands of chemicals each with varying toxicity to marine ecology and/or human health. Once spilled to the marine environment, weathering processes alter the proportion of higher to lower toxicity chemicals in the oil. Increasing the certainty of risk estimates requires expanding current knowledge to include predictions for the individual concentrations of the more toxic OSCs, such as Polycyclic Aromatic Hydrocarbons (PAHs). We hypothesize that PAH concentration changes in oil pre-landfall are related to the weathering history from its "age at sea", which could be predicted by an oil fate and transport model. Here we integrate PAH and TPH concentrations measured from surface weathered oil slick samples collected at the time of the Deepwater Horizon oil spill with a 3D oil spill module of the Connectivity Modeling System (CMS). The PAH and TPH measurements were statistically processed to determine overall changes with respect to the raw oil, and the CMS output was used to estimate "age at sea" for the weathered oil slick samples. Our goal is to test our hypothesis that "age at sea" can be used to explain the variability in measured PAH concentrations. Preliminary results show that concentrations for a subset of PAHs in weathered oil slicks correlate well with TPH concentrations (R^2=0.76). We further examined the oil-CMS predictions of oil concentrations coincident with each sample's location and time to derive a correlation between "age at sea" and spatial and temporal variability observed in measured concentrations. Ultimately, the output of the oil-CMS will be used to predict concentration distributions for individual OSCs, such as PAHs, as a starting point for health risk assessments.

Modeling Hydrodynamics and Environmental Effects of Different Hurricane Types in an Industrialized Estuary

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Tropical cyclones and severe storms can have devastating effects on estuaries especially highly industrialized and urbanized ones such as Galveston Bay in Texas. While post-observation studies are necessary and important, predicting land inundation and water quality behavior prior to the event is key in damage mitigation and rapid response. This study develops predictive hydrodynamic and water quality models driven by surge and storm flows at their boundaries in order to forecast the potential land inundation and environmental pollution that accompanies a hurricane and/or a severe storm as it approaches the coast, makes its landfall and recedes. The environmental fluid dynamic code (EFDC) was coupled with the ADvanced CIRCulation (ADCIRC) and Simulation Waves Nearshore (SWAN) models to develop a nested model that can predict water surface elevations and spill trajectories from industrial facilities during different hurricanes types. The results of EFDC modeling revealed the need for consideration of local runoff flows from rainfall events that typically accompany hurricanes and may coincide with storm surge. Unlike a rainfall-based hurricane, fate and transport of spills during a surge-based hurricane is a function of the time of release relative to the timing of the surge hydrograph. Although spills can spread upstream of the release point during surge-based hurricanes, under a spill

* Student presenter

scenario, rainfall-based hurricanes caused a larger environmental footprint. For all scenarios, 90% of total spill mass reached Galveston Bay in less than 48 hours while 1% and 0.7% of the spill mass was retained on land for rainfall and surge-based hurricanes, respectively.

Comparison of the Spatial Extent and Ecosystem Impacts of Oil Spill Scenarios in the Gulf of Mexico

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The increase in deep-sea oil explorations in the Gulf of Mexico (GoM) has been raising concerns with regard to future oil spills. Major oil spills in the GoM such as the Deepwater Horizon (DWH) resulted in extensive pollution of the pelagic, benthic, and coastal ecosystems. Oil spill transport and fate models are effective tools which enable a spatiotemporally explicit reconstruction of oil spills, accounting for key processes such as evaporation, sedimentation, biodegradation, and dissolution. Oil transport data can be fed into an ecosystem model to help estimate system-scale changes in biodiversity and impacts on the delivery of ecosystem services. However, each spill scenario is a complex 4-D problem, hence it is difficult to effectively evaluate the differences between various oil spill scenarios. Here, we examine quantifiable variables, which enable an effective comparison of the outcomes of four different scenarios: the DWH hindcast, and three theoretical alternatives for a DWH like blowout: a fall spill, an east and a west GoM spill. Specifically, we evaluate the total area and volume of oil-affected waters, the total water area and volume affected by toxic oil concentrations, the length of the shoreline affected by oil, and the total area of the sedimented oil. The oil transport model is coupled to Atlantis, a biochemical ecosystem model, to examine changes in the ecosystem biota. We consider relative impacts on pelagic and demersal food webs, shifts in age structure, changes in diet, and impacts on the sustainability of exploited species. Overall, the results differed slightly and not significantly between the four scenarios, suggesting that a “DWH” occurring at a different time or place in the GoM would result in impact similar to the actual DWH. Considering both the spatial and the ecosystem effects is important for a comprehensive comparison between oil spills, both for risk and for impact assessment. This is especially important given the increasing anthropogenic pressure on the marine ecosystems in the GoM and worldwide.

Impacts of Deep-Water Spills on Mesopelagic Communities and Implications for the Greater Pelagic Food Web

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Mesopelagic species are intricately tied into the food webs of both the epipelagic and bathypelagic zones. Thus, any negative impacts on the mesopelagic zone can potentially transfer across the food web. For example, deep-sea benthos is dependent on the flux of organic materials from surface waters for food, which makes it especially vulnerable to oil spills that can lead to the formation of deepwater plumes of oil and gas and the deposition of oil onto the seafloor. Exposure of mesopelagic fish to polycyclic aromatic hydrocarbons (PAHs) may cause lethal and sublethal effects, such as endocrine disruption, growth inhibition, and genetic damage, even at low concentrations. Reduced abundance of mesopelagic fish could shift predation pressure by pelagic species to small pelagics or other food web components. Here, we explore this hypothesis using the Atlantis model for the Gulf of Mexico (Atlantis-

GOM). Atlantis is a spatially-explicit marine and coastal modeling framework that incorporates multiple submodels that integrate biophysical, chemical, ecological, and fisheries dynamics in a three-dimensional, spatially-explicit domain that uses an irregular polygon structure to represent important climatic, biophysical, or jurisdictional features. We explored the effects of increased mortality of mesopelagics on the Gulf of Mexico food web, while accounting for diet uncertainty. We sampled the fish diet composition distribution that informs the food web in the Atlantis-GOM and analyzed the variability of functional group biomass and catch predicted by Atlantis-GOM under different food web configurations. The resulting biomass and catch were then used to fit statistical emulators of the ecosystem model using a neural network approach and to predict biomass and catch given a larger set of the diet parameter space. We use the simulated and emulated data to assess changes in the food web, as a proxy for oil spill effects.

Prey Evolution of Toxicant Resistance Enables Survival of a Stage-Structured Predator

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The Deepwater Horizon oil spill in the Gulf of Mexico (GoM) is considered to be the largest marine oil spill in the history of the petroleum industry and one of the largest environmental disasters in American history. Due to the months-long spill, along with the detrimental efforts resulting from cleanup, this spill has caused massive environmental stress to the marine and wildlife habitats. This resulted in various species being exposed to toxicants for extended periods of time. While the impact of these toxicants may change over time as the effects of the spill go away, they may also change as species respond to the toxicity. In particular, long-term exposure to a toxicant may result in the rapid evolution of toxicant resistance in relatively short-lived species. In this study, we use mathematical modeling to investigate the possible effect of such evolution on predator-prey dynamics with stage-structure in the predator. We assume that only the prey population evolves to develop resistance to the toxicant. This kind of scenario may happen when, for example, the lifespan of the prey population is considerably shorter than the predator population, such as sperm whales and their main food source giant squid. We consider a predator population with two stages, juveniles and adults, and we assume that only adult predators consume the prey species. Our results show that the evolution of toxicant resistance in the prey population may enable both populations to survive when, without evolution, both may go extinct.

Modeling Food Web Dynamics in the Gulf of Mexico

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The holistic management of ecosystems and their associated resources has become more apparent over the last several decades. Relationships between various species are still poorly understood which makes predicting the impact of threats across an ecosystem hard to quantify. Various modeling programs have been created and utilized to inform managers and guide decision making. Within marine ecosystems, these models have helped to better predict the impact of decisions regarding catch limits, gear restrictions, seasonality, and protected areas on commercial species; however, the downstream impact of these decisions across various trophic levels is not well understood. Threats from fishing, oil exploration, and invasive species are all currently impacting species within the Gulf of Mexico with very little understanding of the overall impact to food-web dynamics. The purpose of the current study is the

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creation of a representative marine food-web comprising all major clades of marine organisms using the mass balance approach found in Ecopath with Ecosim. Inclusion of marine fishes, birds, reptiles, invertebrates, and mammals will allow for a better understanding of the complex dynamics occurring in the marine ecosystem. Further addition of known threats to this model can be used to inform local or regional scale conservation initiatives by managers and help to identify species or groups at greatest risk.

Agent-Based Models as an Integrating Boundary Object for Interdisciplinary Research on Coastal System Dynamics

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Increasingly, there is agreement that to understand and solve the most pressing social, environmental, and economic challenges in the Coastal US will require a synthesis of knowledge from numerous disciplines. These disciplines range from anthropology to coastal engineering to environmental science. Unfortunately, these disciplines lack a common knowledge base and lexicon, and this can quickly lead to confusion, clashes, and ultimately, unsuccessful outcomes. One way to overcome come this challenge and to encourage participation is to have a common model, or boundary object, that can integrate knowledge from numerous disciplines. This also can be a vehicle to enable more productive communication and encourage researchers to work toward a shared goal.

This talk will focus on two complementary discussions: the requirements for useful boundary objects in the fields of disaster and coastal science (ABMs) and results from a large interdisciplinary study exploring how the vulnerability of coastal communities may evolve over time under different climate conditions and hurricane scenarios. The work on boundary objects identifies four requirements and demonstrates how agent-based modeling uniquely satisfies these requirements. The discussion will then turn to a multi-year interdisciplinary coastal vulnerability study in which used agent-based models as its boundary object. Researchers from economics, civil and coastal engineering, climate science, and behavioral science each contributed modules to an agent-based model focusing on coastal community dynamics with particular attention paid to its building stock. We demonstrate how various choices that individuals make with regards to mitigation in response to their hazard environments could create drastically different outcomes for regional vulnerability. This is useful for local and state governments for understanding when and how to target interventions for reducing regional vulnerability to hurricanes.

Integrated Assessment and a Participatory Modeling Initiative to Support Ecosystem-Based Fisheries Management in the Gulf of Mexico

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In 2016 NOAA Fisheries released its National Ecosystem-Based Fishery Management (EBFM) Policy, affirming a commitment to support an ecosystem approach to management, applied at regional scales. To engage stakeholders in planning for EBFM and to support evolution of a holistic governance

approach, the NOAA Southeast Fisheries Science Center initiated a series of participatory fisheries system modeling workshops in fishing communities along Florida's Gulf coast. The result of these workshops is a qualitative conceptual model of the ecosystem that conveys the main physical, biological, social and economic components of the ecosystem, and defines the important linkages between these components. The model and workshop outputs provide decision-makers with information on priority research gaps and components that should be monitored, the key risks that need to be considered, and what stakeholders value in the system. A key finding from the initial workshops was that water quality issues, and in particular harmful algal blooms known as "red tides," are perceived to be major threats to sustainability of fisheries in the region. The participatory workshops brought to light a number of stakeholder concerns beyond the evident effects on fish mortality, including the effects of water quality on habitat condition, commercial and for-hire fishing businesses, aquaculture, tourism, protected species, and human health. These additive or potentially synergistic impacts have further implications for the stock assessment, the ecosystem, and fishing communities as a whole. We will discuss how a multi-faceted integrated modeling and assessment approach has been used to address the influence of water quality and red tide in the region, within the EBFM management context.

Session 002: On the Resiliency of Living Marine Resources to Gulf Oil Spills

On the Resilience of Coastal/Nearshore Living Resources to Deepwater Horizon: A Harbinger of Future Coastal Restoration Efforts?

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Coastal and nearshore living marine resources were impacted by transport of weathered Deepwater Horizon (DWH) oil and countermeasures intended ameliorate oil impacts. These effects were documented a variety of resources ranging from sedentary shellfish (American oyster, periwinkle), coastal pelagic fishes (red drum, speckled seatrout) and marine mammals (bottlenose dolphin). In particular, enhanced freshwater inputs from the opening of bypass spillways reduced estuarine salinity in lower estuaries to the detriment of a number of resources. Long-term sampling data collected before, during and after DWH show a wide range of outcomes related to the spill. The duration of impacts varied considerably, primarily related to the life history of the species (e.g., longevity, reproductive strategy, degree of ongoing contamination, and mobility). In this paper we discuss coastal/nearshore impacts of DWH, drawn from a synthesis of published materials and data sets. Most (but not all) species have recovered to pre-spill abundance. Post-spill restoration planning has included proposals to permanently divert water and sediments from the main-stem Mississippi River to coastal marshes to help slow wetland loss. Results of DWH monitoring studies provide important insights regarding how such strategies may influence iconic resource populations.

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A Review of Deepwater Horizon Impacts and Evidence of Resiliency in the Northern Gulf of Mexico Continental Shelf Ecosystem

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The northern Gulf of Mexico continental shelf is a highly productive system that supports a diverse biota and myriad ecosystem services, with numerous negative to catastrophic effects to its organisms, populations, and communities having been documented in the years following the DWH. In this talk we will attempt to provide a comprehensive synopsis of those impacts, from plankton to mammals, as well as review evidence of resiliency in the system. Studies examining DWH effects on fishes, from sub-cellular to community levels, are particularly well-represented in the literature, with some analyses, such as tissue stable or radio isotope analysis or ecosystem modelling, integrating signals or signatures across multiple trophic levels in the shelf food web. Confounding effects, such as climate change, fisheries, and invasive species, provide numerous challenges to isolating DWH effects and measuring system resiliency. Other factors that affect our ability to discern DWH effects and recovery include noise (process and measurement error) in long-term time series of nGOM biota, as well as the relative lack of data for key ecosystem components, such as higher vertebrates. We will highlight those challenges as well as offer suggestions for future monitoring.

Assembling the Benthic Record of Species and Community Change for the Gulf of Mexico Following the Deepwater Horizon Event

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The Deepwater Horizon (DWH) event significantly impacted the Gulf of Mexico (GoM) benthos (>50 m water depth) at different spatial scales and affected all community size hierarchies (microbes, foraminifera, meiofauna, macrofauna, megafauna, corals, benthic fishes). The resilience of these communities was heterogeneous and may take decades to fully recover. In an effort to provide a quantitative synthesis of ecosystem impact, recovery following DWH, the Gulf of Mexico Research Initiative (GOMRI) Core 3 synthesis group subdivided the GoM into four ecotypes: coastal, continental shelf, open ocean, and benthic. Here we present a synopsis of the benthic ecotype status and discuss progress made on five tasks: 1) summarizing pre-, post-oil spill trends in abundance, species composition and dynamics; 2) identifying missing data/analyses and propose a strategy to acquire such data; 3) constructing a conceptual model of important species interactions and impacting factors; 4) evaluating resiliency and recovery potential of species; and 5) providing indicators for future ecosystem monitoring programs and reports. To address these tasks, we investigated time series to detect measures of population trends. Moreover, a GoM benthic conceptual model was developed to allow for holistic interpretation of the interrelationships among ecotypes, resources, and stressors. The DWH event exemplifies the overall need for a system-level benthic management decision support tool based

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on long-term measurement of ecological quality status (EQS). The only way to produce such a decision support tool is to establish temporal baselines from time-series collections. This approach provides EQS for multiple stressors affecting the GoM beyond oil spills. In many cases, time-series collections were initiated through GOMRI (2010-2018). Continued funding of these initiatives from other sources is essential to fill the information gaps identified following the unprecedented DWH deep-sea oil spill.

A Summary of Post-Deepwater Horizon Oil Spill Open-Ocean Faunal Population Dynamics: Vulnerability, Resilience, Data Gaps, and Management Implications

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To summarize the extensive and comprehensive GoMRI-funded ecological/ecosystem impact research ("Core 3") conducted during the GoMRI tenure (145 projects, 661 publications to date), the Core 3 leadership group organized the ensemble information into four major ecotypes: coastal, continental shelf, benthic, and open-ocean. Such an effort requires cross-cutting integration to develop higher-level takeaway syntheses for future decision making. One useful approach is to rank key taxa in terms of oil spill risk, a product of taxon-specific vulnerability and resilience to oil spill events. Here we summarize the post-spill population dynamics of the open ocean fauna based on available information, highlighting the numerous data gaps that exist (e.g., pre-spill abundance data, information on life-history processes, quantified exposure metrics). Numerous taxa exhibited dramatic population declines since the oil spill, likely the confluence of high vulnerability and low resilience capacity. Other taxa exhibited small population decreases, suggesting low vulnerability (perhaps due to avoidance capacity) and/or high resilience (high productivity over short time frames). For many taxa, the dispersion capacity of the open gulf may have exacerbated the impact of the spill rather than ameliorated it. Evidence suggests the potential of an ecosystem-level cascade that may indicate an altered ecosystem state in the oceanic Gulf of Mexico. Continued ecosystem monitoring is therefore critical to fully understand the dynamics of the putative impacts to, and the latent recovery capacity of, the gulf's open-ocean ecotype.

On the Age and Growth of Mesopelagic Fishes, with Case Studies of Four Ecologically Important Species from the Gulf of Mexico

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Mesopelagic fishes provide important ecosystem services, such as carbon sequestration via the biological pump and provision of food for economically important (billfishes and tuna) and federally protected (cetaceans and seabirds) species. These attributes are becoming increasingly recognized, while simultaneously mesopelagic fisheries are becoming of interest as coastal fisheries have become overexploited. Additionally, climate change, ocean acidification, and seabed mining threaten deep-sea fishes. With increasing interest in deep-sea fisheries and anthropogenic threats, age and growth information on these fishes is a necessity for management. A serious constraint for conservation and management of these resources is that very few age estimations of mesopelagic fishes have been validated. In order to address information gaps, age estimations and otolith shape and microincrement descriptions linked to life histories will be presented for the meso/bathypelagic fish species

* Student presenter

Lampanyctus lineatus (lanternfish), *Omosudis lowii* (hammerjaw), *Stomias affinis* (dragonfish), and *Chauliodus sloani* (viperfish). These fishes were collected during seven research cruises from 2010 - 2011, as part of the DWHOS NRDA, and during six research cruises from 2015 - 2018, as part of the GOMRI-supported DEEPEND Consortium. We found that *Stomias affinis* grow exponentially, with a slow initial growth followed by a rapid increase in growth with time. *Chauliodus sloani* exhibits logistic growth, with a gradual increase in growth at first followed by period of rapid growth and then a decrease in growth. *Omosudis lowii* and *Lampanyctus lineatus* grow isometrically, which is the normal growth pattern for most fishes. These are the first growth curves produced of these species for the Gulf of Mexico, which serves as an analog for the world's low-latitude, oligotrophic domain

Oil and Gas Impacts on Pelagic Food Webs in the Gulf of Mexico: Isotopic Time Series Reveal the Time Scale of Ecosystem Response and Recovery

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Petrocarbon enters offshore waters of the Gulf of Mexico via many natural seeps as well as occasional accidental releases through human activities (spills), but seeps and spills inject petrocarbon into pelagic ecosystems on very different spatial and temporal scales. Seep inputs are relatively constant but spatially variable, while spills typically inject petrocarbon into offshore ecosystems from point-sources over shorter time scales. Here we synthesize data from multiple annual cruises spanning the years since the Deepwater Horizon spill in 2010 through 2016. We used the stable isotopic contrast between average marine organic matter (ca. -20‰) and petrocarbon (oil $\delta^{13}C$ = ca. -27‰, methane $\delta^{13}C$ = ca. -57‰) as a robust tool for exploring the pathways and mechanisms of assimilation of petrocarbon into both phyto- and zooplankton in offshore waters of the Northern Gulf of Mexico. We complemented this with an exploration of nitrogen cycle dyamics using the clear isotopic signature of nitrogen fixing organisms ($\delta^{15}N$ = ca. -2‰). Our measurements provide a multiyear record of the contribution of oil and gas to the planktonic food web in the years following the Deepwater Horizon disaster, specifically petrocarbon penetration into the food web, alterations in the nitrogen cycle, and the time-course of recovery of Gulf ecosystems since the spill.

Long-Term Monitoring of Deep-Sea Coral-Associated Infaunal Communities in the Gulf of Mexico After the Deepwater Horizon Oil Spill

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Deep-sea corals (DSC) create complex habitats that support distinct sediment communities, harboring significant biodiversity and enhanced abundances. Multiple deep-sea coral habitats were impacted by the 2010 Deepwater Horizon (DWH) spill, and recovery of associated sediment communities may take several years to decades. 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 that can persist over time. Here we examine the long-term effects of the DWH oil spill on DSC ecosystems in the Gulf of Mexico and describe if particular taxa and functional groups serve as indicators of ongoing impact and/or recovery at these sites. Between 2010 and 2016, we examined infaunal 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). Macrofaunal densities at impacted sites varied over time, while diversity was lower than at reference sites. The relative proportion of sensitive and tolerant taxa varied among years as did key sediment parameters (e.g. organic carbon content and δ13C), whereas no changes were documented within reference sites. Feeding group composition changed significantly within impacted sites, with an increase in deposit feeders and decrease in omnivores over time since the spill, and a similar decrease in the proportion of omnivores observed at reference sites. Additional community and environmental data from 2017 will be presented. This unprecedented 8-year post-spill assessment enables us to track changes in coral-associated sediment communities in natural habitats. These results will help inform future monitoring and restoration activities and lead to the development of effective adaptive management and conservation strategies for these vulnerable ecosystems.

Health Trends of Bottlenose Dolphins (*Tursiops truncatus*) in the Eight Years Following the Deepwater Horizon Oil Spill: Evidence for Lack of Resilience

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The Deepwater Horizon Natural Resource Damage Assessment (NRDA) found significant injuries to Gulf of Mexico bottlenose dolphins. NRDA population models integrated estimates of immediate post-spill mortality and reproductive failure derived from empirical data, along with informed predictions of how long elevated mortality and reproductive failure would persist. Predictions were based on the chronicity of observed sublethal effects (e.g., lung disease, hypoadrenocorticism), established through *in situ* health assessments. Utilizing input from veterinary experts, the models assumed that dolphins exposed to DWH oil would require many years (mean=10.7 years) to return to baseline health state, but dolphins born after the spill would not exhibit oil-related health effects. Three additional years of health assessments under GoMRI provide a time series to assess temporal trends in health and test these model assumptions. Veterinarians assigned prognosis scores for dolphins sampled 2011-2018 in Barataria Bay, LA (BB) and 2011-2015 in Sarasota Bay, FL (SB), a comparison site not exposed to DWH oiling. We estimated ages using observations of births or analysis of dental x-rays to categorize BB dolphins as being born prior to the spill (prespill) or after the spill (postspill). We then applied a General Additive Model to examine temporal trends in prognosis scores among the three dolphin groups. For prespill BB dolphins, we found the probability of a “good” or “fair” prognosis versus “guarded” or worse prognosis increased slightly through 2014 then significantly declined after 2015 (p=0.03), particularly in 2016 and 2018. Postspill BB dolphins had higher scores relative to prespill BB dolphins, but also had fewer good/fair scores in 2016 and 2018. SB scores were consistently high. We hypothesize that BB dolphins exposed during the spill had begun a slow recovery, but were more vulnerable when exposed to other environmental stressors in the later years.

Shrimp Population Resiliency and Response to Potential Large Oil Spills

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Shrimp species are the most important fishery resource in the entire Gulf of Mexico (GoM), based on their economic value and social relevance. Consequently, the effect of large-scale oil spills on these resources has been of great concern in the GoM. The impact of accidental mega oil spills (Ixtoc 1 in1979 and Deepwater Horizon in 2010) on shrimp populations and their responses are analyzed. In the Southwestern GoM Pink and White Shrimp did not show a population collapse during and after Ixtoc 1 oil spill. Recruitment and Spawning Stock indexes fluctuations following Ixtoc 1 oil varied within natural fluctuations (±20%). Shrimp stocks in the NGoM did not decline coincident with Deepwater Horizon blowout, and stock assessments documented a general increasing trend in spawning biomass and recruitment. Stock - Recruitment Relationships show that shrimp population have a high potential to opportunistically take advantage of good environmental conditions. Shrimp life history aspects including: 1) early maturity, 2) extended spawning throughout the year, 3) high fecundity, 3) two annual generations, which contribute to integral spawning and 4) high larval dispersal that allows connectivity with other populations along the GoM, make shrimp populations highly resilient to environmental or man-made stressors including oil spills. Oil spill impacts on shrimp resources could be mitigated by cumulative population reproductive potential and connectivity among stocks if they are in a healthy condition. However, if stocks are in an overfished condition, impacts could be bigger and resiliency potential compromised.

Changes in Reef Fish Community Structure Following the Deepwater Horizon Oil Spill

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Large-scale anthropogenic disturbances can have direct and indirect effects on marine communities, with direct effects often taking the form of widespread injury or mortality and indirect effects manifesting as changes in food web structure. Here, we report a time-series that captures both direct and indirect effects of the Deepwater Horizon Oil Spill (DWH) on northern Gulf of Mexico (nGoM) reef fish communities. We observed a significant change in community structure, a 38% decline in species richness, and 26% decline in Shannon-Weiner diversity immediately followed DWH. Initial shifts were driven by widespread declines across a range of trophic guilds. However, patterns of recovery were less uniform. Densities of small demersal invertivores, small demersal browsers, generalist carnivores, and piscivores remained persistently low with little indication of recovery seven years after the DWH. These initial declines occurred prior to the arrival of the invasive lionfish (*Pterois* spp.), but the lack of recovery among small demersal browsers and invertivores suggests lionfish predation is impacting recovery. The driver of persistently low densities of generalist carnivores and piscivores is less clear but warrants further study given the myriad ecosystem services provided by nGoM reef fishes.

The Impact of Crude Oil and Chemical Dispersant on Prey Susceptibility to Jellyfish Grazing

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Scyphomedusae are important zooplankton grazers in both coastal and pelagic marine ecosystems. Despite their role in trophic dynamics, the interactions between jellyfish and their prey remain largely understudied with regards to the effects of exposure to oil pollution. We investigated the impact of

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crude oil and chemical dispersant (Corexit 9500) on the trophic interaction between planktonic prey and the rhizostome medusae *Cassiopea* spp. Two types of crustacean prey, both evasive (*Acartia tonsa*) and non-evasive (*Artemia salina*) were compared in this study. Both prey types were exposed to the water accommodated fraction (WAF) and chemically enhanced water accommodated fraction (CEWAF) of an ecologically relevant concentration of crude oil. Timed feeding trials were conducted and the prey capture rates were determined for each *Cassiopea* spp. specimen. Additional feeding experiments were conducted exposing both the jellyfish and prey to WAF and CEWAF to replicate ecologically relevant conditions. We show that *Cassiopea* spp. capture non-evasive prey at a significantly higher rate relative to evasive prey at all oil/dispersant concentrations. There was no significant difference between the *A. salina* captured by *Cassiopea* at any of the WAF and CEWAF treatments. However, copepods were captured at a significantly lower rate when they were exposed to CEWAF conditions. To understand the differences in capture rates, we also performed high resolution videography of the predator-prey interaction. The implications of the results from this study are discussed in the context of trophic interactions and ecosystem resilience to oil spills.

A Multi-Taxonomic Petrochemical Vulnerability Index for Gulf of Mexico Marine Species

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In order to facilitate improved decision-making, the main goal of this project is to provide a variety of stakeholders with spatially-explicit species-specific information, including distribution, population, extinction risk and a novel petrochemical vulnerability ranking for more than 2,000 marine species across the entire Gulf of Mexico Large Marine Ecosystem. Included species groups comprise all known marine vertebrates (e.g. mammals, sea turtles, seabirds, fishes) and complete clades of invertebrates and plants (e.g. reef-building corals, mangroves, seagrasses, sea cucumbers, cephalopods, lobsters and oysters). As the vast majority of these species do not have species-specific toxicological information on the potential impacts from exposure to petrochemicals, a trait-based approach to estimate species and population-level vulnerability (or resilience) across multiple taxonomic groups was developed in conciliatory process. In a peer review setting, we established a framework of key life history and other traits important for a multi-taxonomic petrochemical vulnerability ranking system, based on traits related to probability of exposure, individual or species-specific sensitivities, and population resilience. Here we present the overarching multi-taxonomic framework and assumptions, along with suggested indicators, scoring methods and statistical approaches for implementation.

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Session 003: New Tools and New Strategies in the Assessment and Forecasting of MOSSFA in Support of Emergency Response and NRDA

Marine Oil Snow: Particle Size, Shape, and Fractal Dimensions

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The Deepwater Horizon oil spill resulted in a prolonged sedimentation of marine oil snow (MOS) to the seafloor. Previous reports indicated that MOS sedimentation also occurred during the Tsesis and Ixtoc-I oil spills; thus, MOSSFA events may occur during future oil spills, particularly since 85% of global deep-water oil exploration sites are adjacent to deltaic systems where marine snow concentrations are elevated. A recent numerical model of the interactions between oil and marine snow (Dissanayake et al. 2018) indicated that aggregate fractal dimension, stickiness, and disaggregation properties were important parameters that controlled model predictions. Here we report particle size, shape, and fractal dimension of marine snow aggregates observed by a camera imaging system during and after the Deepwater Horizon oil spill. Intermediate sized particles (3 mm to 1 cm) were elevated during May - September 2010 compared to follow on years (2011-2014). Although models of marine snow assume that particles are spherical, in fact most marine snow particles have an elongated shape (elongation ratio geometric mean: 0.5, range: 0-1), which may impact sinking rates. Elongation ratios did not always increase with particle size or depth. Fractal dimensions of particles were significantly higher during spring 2010 (geomean 1.48) than during summer 2010 (geomean: 1.41), but not significantly different than follow on years (spring 2011 & 2012: geomean 1.44; summer 2011-2014: geomean 1.47). The range of fractal dimensions for all samples was 0.925 - 1.94. Fractal dimension increased with particle size (particle size 0.272 - 0.482 mm ESD, fractal geomean: 1.44; 0.531 - 1.51 mm, geomean: 1.61; 1.76 - 2.68 mm, geomean: 1.75) in a similar manner during each season and year and at shallow and deep-water stations. There was little change in fractal dimension with depth for the same particle size.

Observed Changes in Particle Abundance Driven by Variations in the Diel Thermocline

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Marine snow plays a key role in the global carbon cycle, particularly CO_2 sequestration into the deep ocean. A thorough understanding of particle formation and settling is important for understanding the impact that increased atmospheric CO_2 levels have on the oceans carbon cycle and ocean acidification. After the Deepwater Horizon spill in the Gulf of Mexico (GoM), previous studies identified marine snow as the main mechanism for the removal of oil from the water column and deposition in sediments. This study utilizes existing data, from the northern GoM, to examine marine snow settling processes. Data from a recent cruise in the GoM are used to examine diel trends in marine snow abundance, which are then compared with data collected in the past five years to examine seasonal and annual trends. Here, we determine the processes and depth at which changes in physical water column properties enable the settling of marine snow particles out of the mixed layer to the deeper water column, through the use of high-resolution time series data. To determine the size specific distribution of particles with depth and time, particle abundance images from a marine snow profiling camera were used. CTD data from the ships' rosette and also collected with the camera system, are analyzed for variations in temperature, salinity, density, oxygen, and fluorescence with depth. The upper 250m of the water column, where

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there are large variations in these properties with depth, are examined at two-meter intervals. Initial results suggest that diel heating and cooling cycles potentially enable particles to escape the mixed layer, due to variations in the depth of the diel thermocline. When particles are isolated below this thermocline during such cycles, they potentially can settle and then contribute to the export of surface materials. Our future goal is to determine how much marine snow is introduced into the sub-thermocline layers of the diel and seasonal thermocline.

The Effect of Oil on Aggregation of Marine Snow

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In an effort to better understand the conditions present when large scale Marine Oil-Snow Sedimentation and Flocculent Accumulation (MOSSFA) events take place we present results from our stochastic, Lagrangian model of sinking aggregates (SLAMS). SLAMS simulates individual particles and oil droplets using a super-droplet approach and includes aggregation and disaggregation, respiration of organic material by bacteria, dissolution of minerals and settling of MOS. Using different oil-regimes (REF, SEEP, DWH) model fluxes are compared to sediment trap fluxes. Oil is a decisive component of the organic carbon flux as well as the oil flux: How much oil is present at the surface determines the efficiency at which that oil reaches the seafloor. Examining the relationship between primary production (PP) and sediment load to oil flux, we find that when the amount of oil in the surface approaches DWH scenario, oil flux to the seafloor is positively correlated to sedimentation and PP but when the oil load is low, a relationship is less clear. For a given PP and sedimentation, the amount of oil that settles to the seafloor increases with surface oil up to a certain point, or until the carrying capacity of MS is reached. We show the effect of oil on aggregate radius and density and subsequently settling velocity. Initially oil works to increase flux as its sticky quality works as a binding agent, increasing the aggregate size. At some point the buoyancy the oil provides leads to a decrease in the sinking velocity. The model is also sensitive to temperature and functional groups: cooler temperatures and a larger fraction of diatoms increases the flux of oil to the seafloor.

Comparison of Estimated Oil Equivalent Half-Lives in ADDOMEx Controlled Mesocosm MOSSFA Studies

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Six separate 90L mesocosm experiments (M2 to M7) each with 3 to 7 replicates using coastal or open-ocean surface seawater from the Gulf of Mexico were performed. The water accommodated fractions (WAF), water soluble fraction (WSF), chemically enhanced WAF (CEWAF) and diluted CEWAF (DCEWAF) were produced using Macondo surrogate oil with and without Corexit. Experimental treatments were different with M2, M6 and M7 enriched with microbes, M3 and M4 enriched with nutrients and M5 not enriched with either. For M4 triplicate WSF treatment were produced by placing surrogate oil in silicon tubing and allowing the hydrocarbons to diffuse out of the tubing into the water for 24 hrs. Experiments ran from 3 to 16 days. Estimated oil equivalents (EOE) were determined on dichloromethane extracts on a fluorescence spectrophotometer calibrated with Macondo surrogate oil. Environmental half-lives were determined from the mean EOE concentrations after 3 or 4 days. EOE decreased exponentially following

first-order decay rate kinetics for all treatments. EOE concentrations at day 0 for the WAF, DCEWAF and CEWAF for the mesocosms ranged from 0.26 to 5.24, 0.54 to 8.31 and 39 to 81 mg/L, respectively. The highest concentrations for WAF and DCWAF were achieved using higher energy mixing. WAF, WSF, DCEWAF and CEWAF treatment half-lives ranged from 0.9 to 4.7 days agreeing with reported estimates from other mesocosm and field studies. Taking into consideration uncertainty between replicates, there were no significant differences in the half-lives for WAF, WSF DCEWAF or CEWAF treatments. There was no correlation between EOE concentration and half-lives. There was no difference in half-lives for mesocosms enriched with nutrients or microbes. The WSF (M4) had a mean EOE of 0.13 mg/L, the lowest of any treatment, but the third highest half-life of 2.9 days. Additional oil analyses indicate that biodegradation was an important removal mechanism. Heterogeneity was observed in all treatments.

Developments in Numerical Modeling of MOSSFA Events and the Challenges Still Remaining

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A MOSSFA (marine oil snow sedimentation and flocculent accumulation) event that occurred during the Deepwater Horizon (DWH) oil spill carried a substantial amount of oil to the seafloor, potentially adversely affecting the ecosystem in the water column and at the sea floor. Formation of marine snow and oil aggregates with the incorporation of mucus from bacteria (transparent exopolymer particles, TEP and extracellular polymeric substances, EPS) and the mineral particles in the water column is an evolving complex bio-geo-chemical and physical process. The behavior of these aggregates is controlled by the composition, size distribution and concentration of different components that form the aggregates, formation rates of TEP and EPS, packing patterns of aggregates (porosity), composition of oil, dissolution and bio-degradation rates of components in the oil, degradation of TEP and EPS that reduces their stickiness, and turbulence levels that are responsible for natural and artificial dispersion of oil from the surface slicks into the water and aggregation and breakup of aggregates. These processes and mechanisms are understood to varying extents and needed modelling approaches may differ. Moreover, defining input parameters for models is challenging due to variable nature of these events. Several models have been developed using coagulation theory to predict the formation and settling of marine oil snow aggregates and others to predict the general three-dimensional transportation of different sized aggregates in the water. They have identified various methods to define input parameters (such as using satellite imagery to define phytoplankton concentrations in water) and point out sensitivity of model predictions to different modeling approaches and internal model parameters. Here, we present these recent model developments, their applicability, limitations and further challenges in the numerical modeling of MOS/MOSSFA events. Moreover, additional research needs will be presented.

Modeling Marine-Oil-Snow and MOSSFA Events: Progress and Perspectives

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The Deepwater Horizon oil spill provided one of the first opportunities to study the formation of Marine-Oil-Snow (MOS) and the effects it has on the fate of oil and organisms. Sediment cores showed high

accumulations of MOS on the sea floor, oil was detected in sediment traps located at different depths throughout the water column, and MOS was observed in surface waters both visually and by camera systems. Models of the aggregation of mineral particles with oil have existed for a while, but models of aggregation of mineral particles, organic particles, and oil have not. We have extended existing models of marine snow formation to include the formation of MOS and the sinking of this material through the water column. These models reproduce size distributions of MOS observed in the water column after the Deepwater Horizon and predict fluxes of oil to the seafloor that fall within the range of values inferred from the detection of petrochemical markers in the sediments. Results of the models also agree with fluxes of oil and biogenic particles caught in sediment traps. Given the success of these models, we can use them to predict the environmental conditions and oil properties that are likely to lead to MOS formation and MOSSFA events. In spite of these successes, there remain gaps in our understanding that provide fruitful avenues for further research. In particular we do not fully understand the factors governing the strength of interactions between oil and organic particles. We also do not fully understand the role that oil can play in changing characteristics of the aggregates such as their porosity and sinking speed. In addition, with knowledge of how dispersant use changes the oil droplet size distribution and particle interactions, we can make predictions of how dispersants could affect MOS formation and MOSSFA events.

Investigation of the Deepwater Horizon Natural Resource Damage Assessment Data for Markers of MOSSFA in the Gulf of Mexico Sediment

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Recently, White *et al*. (2019) have reported the co-occurrence of biogenic, phytoplankton-sourced hydrocarbons and petrogenic hydrocarbons in surface water sheens collected in the northern Gulf of Mexico (nGoM) in 2015, and proposed *n*-C15 and *n*-C17 alkanes as suitable molecular markers of phytoplankton inputs, specifically of cyanobacterial *Trichodesmium* genus. They applied this approach to the Deepwater Horizon (DWH) Natural Resource Damage Assessment (NRDA) Data and found that ~10% of the water samples, collected and analyzed in the aftermath of the 2010 incident, contained a signature of phytoplankton-derived hydrocarbons overprinting petroleum alkane distributions. Very similar processes of interaction of phytoplankton biomass and the surfaced Macondo Well oil are hypothesized to be responsible for a rapid sedimentation event (MOSSFA: Marine Oil Snow Sedimentation and Flocculent Accumulation) which transported a large amount (up to 14%) of Macondo Well oil to the deep sea. Despite recent advancements in the characterization of this event, robust molecular markers are still needed to precisely delineate the temporal and spatial extent of this complex biogenic-petrogenic geochemical signal. Herein, we are extending the White et al. (2019) approach to sediment-related data in the NRDA DWH dataset to investigate whether conclusive molecular records of the MOSSFA can be identified, which could then be used to track the long-term fate of sedimented DWH oil, but also as fingerprinting tools in future oil spills to detect MOSSFA-like post-spill processes.
Reference: Helen K. White, Charles T. Marx, David L. Valentine, Charles Sharpless, Christoph Aeppli, Kelsey M. Gosselin, Veronika Kivenson, Rachel M. Liu, Robert K. Nelson, Sean P. Sylva, and Christopher M. Reddy, *ACS Earth and Space Chemistry* 2019 3 (7), 1329-1337

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Seeding Snow: Mississippi River Plume Interaction with Oil in the Northern Gulf of Mexico

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Glider data collected in the upper 200 m during a month-long mission in the northern Gulf of Mexico indicate formation of marine oil snow (MOS) after the arrival of fresh river plume water over the continental slope site approximately 200 nm offshore. The putative MOS signal, captured near Green Canyon lease block 600 (GC600), appears in the fluorescence data as large particles with high concentration of both colored dissolved organic matter (CDOM) and chlorophyll-*a* fluorescence, extending well below the photic zone to at least 190 m depth. Closer examination of the time series suggests a strong diel cycle in concentration of MOS aggregates, with distribution through the upper 190 m during the day and zero signal between local sundown and sunrise. ADCP backscatter from a nearby ship shows diel vertical migration of scatterers of approximately 800 um in radius, consistent with mesozooplankton. The implications for this previously unknown process of MOS formation and zooplankton-mediated export are explored, along with the potential role for gliders in observing marine snow and associated carbon export to the seafloor.

Sedimentary Processes on Monthly to Decadal Time Scales: Applications for MOSSFA

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Investigations of the sedimentary impacts of the Deepwater Horizon oil spill over 10 years has defined the short-term (months to years) impacts as well as begun to assess longer term (years to decades) implications for the sedimentary and benthic ecosystem. The rapid scientific response and use of high-resolution approaches allowed for the use of time-sensitive indicators to identify MOSSFA processes resulting in the sedimentation pulse and ecosystem impacts. The sedimentation pulse was characterized by increased short-term (months) sedimentation rates (4-10 times higher than baseline) and lack of bioturbation, as defined by excess Thorium-234 ($^{234}Th_{xs}$; monthly time scale) geochronology, fluxes of degraded petroleum and contaminants to the seafloor in 2010/2011 and post-depositional redox and benthic ecosystem impacts. Baselines were determined using downcore (pre-event), as well as a post-event, annual time-series collections using the same high-resolution approaches. The post-event time series (2012-2017) validated the sedimentation pulse by indicating lower short-term sedimentation rates ($^{234}Th_{xs}$ geochronology) and site-specific return of bioturbation ~2-3 years following the spill. Investigations of longer-term impacts (years to decades) focus on the remobilization and down-slope transport of MOSSFA sediments to depocenters by gravity flow processes, which may modify distribution and re-expose benthic ecosystems years after the event. It could be years to decades before the extent of redistribution and related impacts are fully characterized, and the ultimate fate of MOSSFA sediments determined. Therefore, short and long-term time scales should be considered assessing potential seafloor impacts of future oil spills. Continued studies would allow for the development of

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baseline information of sedimentary processes on multiple time-scales (months $^{234}Th_{xs}$, years to decades$^{210}Pb_{xs}$) as well as a continuous assessment of an oil spill from months to years to decades.

Can Regional Assessment of Sediment Accumulation Rates Be Useful to Forecast the Fate of MOSSFA Derived Sedimentation Events? A Case Study from the Southern Gulf of Mexico

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Natural and anthropogenic impacts, such as changes in continental hydrology and land-use, and industrial activities such as gas and oil exploration/production, have profoundly modified many earth processes, including sedimentation in aquatic ecosystems. The Gulf of Mexico (GoM) is no exception, and there is widespread evidence of accelerating sedimentation from coastal to basinal settings. These changes have been attributed to elevated rates of river discharge associated with land use changes (i.e. river catchment deforestation), river channelization and climate induced changes in rainfall. However, the recent discovery of regionally distinct sediment pulse events associated with Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA) processes during the Ixtoc 1 and DWH events, raise the need to predict the sedimentary fate of MOSSFA events. Recent past (~100 years) and contemporaneous sedimentation rates can be estimated from ^{210}Pb activity profiles in undisturbed sediment cores. In this work, we review decades of published ^{210}Pb profiles from sediment cores and present some new data from coastal to deep-sea settings in the southern GoM. Mean sediment accumulation rates (SAR) were re-assessed using a common mathematical approach. Preliminary analysis show that SAR values have a regional coherence with water column depth, the influence of major rivers, and active sediment focusing processes in sedimentary depocenters. These characteristics in sedimentation rates and processes can be used in MOSSFA forecasting by i) providing high resolution indicators of pulse sedimentation events, ii) identifying potential hotspots of benthic contamination, and iii) predicting the ultimate fate of MOSSFA derived sedimentary materials.

The Potential Role of Marine Snow in the Fate of Spilled Oil in Cook Inlet, Alaska

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While extensive research has been conducted on minerals aggregating with spilled oil, larger organic aggregates, such as marine snow, have only recently been studied as a transport mechanism. This knowledge gap in understanding the fate of oil was highlighted following the 2010 Deepwater Horizon (DWH) blowout in the Gulf of Mexico when a significant percentage of the spilled oil reached the seafloor as a result of association with marine snow. The U.S. Geological Survey and others have noted that understanding particle fluxes in areas of petroleum exploration and extraction is urgently needed to enhance response preparedness. The objective of this research is to inform response decision-making and understanding of the potential association of spilled oil with marine snow in Cook Inlet, Alaska and in other shallow regions with high seasonal primary productivity. During Summers 2018 and 2019 and January 2019, the particle flux in southeastern Cook Inlet was measured with a surface-tethered

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sediment trap, deployed for 1 to 3 h, below the mixed layer at a depth of 20 m. Fluxes were similar at three sites along the axis of Kachemak Bay, and significantly larger at Anchor Point. In both summers, there was a strong and consistent organic flux indicating high primary productivity across the region. In Kachemak Bay the total flux ranged from 104-152 g m^{-2} d^{-1}. At Anchor Point, there was significantly higher sedimentation with a mean flux of 297 g m^{-2} d^{-1}. Throughout the region, 20-36% of the particle composition was organic. In laboratory experiments, roller-bottles with surface water from Kachemak Bay were used to explore the interaction of surface oil and natural assemblages. The results corroborate findings from the Gulf of Mexico and other regions; oil enhanced aggregation and there is potential for surface oil to become incorporated in marine snow. Estimates from microscopy and image analysis indicate that 0.6-9.3% of the total oil added to surface water samples became incorporated in neutrally buoyant or sinking aggregates. The results suggest oil would likely become incorporated in submerged organic aggregates in lower Cook Inlet in May-June conditions. Oil-related marine snow must be considered as an exposure route, as marine snow is a food source for pelagic and benthic species.

A New Approach to Predicting MOSSFA Prone Areas to Guide Future Oil Spill Response and Natural Resource Damage Assessment

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The recognition of widespread MOS formation during the 2010 DWH oil spill and the regionally expansive sediment pulse events associated with MOSSFA processes during the 1979-1980 Ixtoc 1 and DWH events, identify the critical need for predicting MOSSFA events in the future. The ability to predict MOSSFA events in time and space will contribute to developing more accurate surface oil budgets and to provide information needed to inform decision makers on the location and application of specific surface oil remediation techniques. In addition, predictions of the geographic extent of sedimentary oil deposition will provide critical information needed for planning short-and long-term environmental and natural resource impacts with the NRDA process. This work presents a new approach to identifying MOSSFA prone regions in areas of current and future oil exploration/ production activity where potential oil spills and sub-surface oil well blowouts are likely to occur. This new approach utilizes a combination of high-resolution satellite imagery products and advanced oil spill trajectory modeling. Satellite imagery allow assessment of seasonal changes in water column productivity and mineral content and when combined with advanced oil trajectory modeling based for seasonally-dependent simulated spills, we are able to forecast the location and co-occurrence of algae, mineral particulate matter and oil/dispersant components needed to initiate MOS formation and predict the region prone to a sedimentary MOSSFA event. We develop this MOSSFA prediction strategy for regions throughout the Gulf of Mexico (including the Florida escarpment, the Mexican-American boarder, the Bay of Campeche in the southern Gulf and offshore Cuba) and globally (including offshore west Africa, off shore Brazil and the Indo-Pacific) in order to infer the probability of future MOSSFA events are likely to occur. These maps of MOSSFA event probability are important for oil spill responders who will be deciding the locations and which oil spill response strategies will be employed (i.e. application of large volumes of dispersants and/or increasing riverine discharge to preserve coastal environments and ecosystems). These maps are also critical for NRDA in determining marine resources at risk, spatial constraints on benthic environmental impacts and quantitative assessment of long-term contamination and ecologic injury.

* Student presenter

Session 004: Understanding and Predicting the Gulf of Mexico Loop Current

Predictability in the Deep Gulf of Mexico

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Ocean prediction is typically a problem in which we specify an initial condition, and numerical integration of the equations of motion provide the future evolution. Predominantly for the deep ocean, the initial condition accuracy is a critical part of this problem. Through an observation system simulation experiment (OSSE), we first show that the forecast accuracy is dependent on the observation density, which is primarily dependent on satellite observations. Some of the features such as the Loop Current Eddy and shingle eddies are mesoscale features in which prediction skill increases as observational density increases. Secondary features occur within the fronts between mesoscale features, and these have predictability conditioned on the accurate forecast of the mesoscale eddies. The skill in predicting these features is more difficult to attain and requires more observational information on a regular basis to reach skill forecasts than the general mesoscale eddies. High-resolution models developed and evaluated throughout the GoMRI research can generate a wide range of scales from hundreds of kilometers to hundreds of meters. Thus, we next examine the predictability across scales of features. The LASER experiment of 2016 deployed over 1000 surface drifters, and these instruments covered a broad range of large and small-scale features across the Loop Current and other mesoscale features. We show scales larger than 53 km e-folding scale have skill on average in the predictions, while smaller features do not have skill. After filtering the small-scale variability from the model predictions, we show trajectory forecast errors can be reduced by 20%. The scales that observations constrain can also be derived from OSSEs, which produce similar length scales. The OSSEs used in the experiments are fraternal twins in which the Nature run and the Assimilative runs use the same dynamical systems. The implications are that the errors in the dynamical system are small relative to the errors in the initial conditions. Observation density is a primary source of uncertainty in ocean forecasts. This small-scale variability is important in deriving uncertainty, particularly in the frontal features that strongly affect mixed layer depth. Typically, ensemble approaches provide the spread or variance of forecast ocean parameters. We find that the mixed layer depth variance from an ensemble at moderate resolution (3km) has structure and amplitudes similar to the variance created by small-scale features not constrained by observations. The larger scale field modulates areas of small-scale structure generation. This motivates forecasts at resolution higher than observations typically can constrain.

Understanding and Predicting the Gulf of Mexico Loop Current: A Numerical Modeling Synthesis Study

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We will provide an update on an ongoing Gulf of Mexico Loop Current numerical modeling synthesis project funded by National Academies Gulf Research Program. The overarching goal of this project is to

* Student presenter

achieve greater understanding of the physical processes that control circulation in the Gulf of Mexico (GOM), specifically the Loop Current and Loop Current eddy separation dynamics, through advanced data assimilative modeling and analyses. The project, closely following recommendations made in the National Academies consensus report (2018) "Understanding and Predicting the Gulf of Mexico Loop Current Critical Gaps and Recommendations", in particular Recommendation 22, is performing a new skill assessment of existing GOM prediction systems to test current model performance in resolving both surface and subsurface circulation, evaluate long-range prediction capabilities, and better inform the observing campaign's final design. Outcomes of this project will include: (1) new knowledge of GOM circulation dynamics; (2) new evaluations and improvements in ocean forecasting methodology; and (3) ensembles from multi-model OSSEs that will be used to provide a reference for observational design criteria, instrument locations, and sampling intervals for the field campaign.

Modeling and Predicting Velocity of Loop Current System Using Auto-Encoders and Recurrent Networks

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Forecasting the Loop Current (LC) and its associated eddies remains a challenge for most ocean numerical models. Recent anthropogenic and natural disasters have revealed our limited ability to accurately predict the LC evolution. Earlier this year, our team reported a method for modeling and forecasting LC evolution and eddy formations. In the published prediction model, each iteration of the prediction algorithm consisted of the following three steps: The region of interest was first divided into a number of partitions. In each partition, a deep long short-term memory (LSTM) neural network was then applied to model the dynamics of the LCS from Sea Surface Height (SSH) anomaly data. Finally, a smoothing function was applied to stitch together the predictions from the individual partitions. This study is our continuous effort in modeling and predicting the LC evolution with deep learning methodology. In this study, SSH anomaly data is again used as a predictor of the LC evolution, eddy detachment, westward movement and velocity profile of loop current systems (LCS). A forecasting model, which is the product of integrating auto-encoders (AEs) with LSTM neural networks, is used to model and predict the velocity of LC eddies. It has been shown in the machine learning literature that AEs are effective in dimension reduction while preserving essential statistical information of the data. In Oceanography, researchers often apply Empirical Orthogonal Functions (EOF) to reduce the dimensions of the input data (i.e. SSH) and to extract temporal and fixed spatial features of LCEs. In this paper, the effectiveness of using AEs to perform the same task of representing temporal and spatial features is explored. After feature extraction, LSTM networks are applied to model and predict LCE velocities. In the study, experimental results from both the EOF and AE methods are compared and concluding remarks are given.

Finding Murphy: A $200,000 Slocum Glider Saved by a Numerical Ocean Model

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The Deep-Pelagic Nekton Dynamics of the Gulf of Mexico (DEEPEND) consortium, funded by the Gulf of Mexico Research Initiative, is a multi-institutional consortium whose objectives include the characterization of biophysical variability in the Northern Gulf of Mexico. Observational and multi-model approaches are used to increase understanding of the dynamics of deep-pelagic (0-1500 m) ocean environments and animal assemblages at multiple temporal and spatial scales. During the second DEEPEND cruise (August 08-20, 2015), Murphy, a University of South Florida Slocum glider loaded with bio-optical-physical instrumentation, was deployed, and on August 15, after 5 days of sampling, it lost communication with its operators. Running in near real time, a 1/25° resolution Hybrid Coordinate Ocean Model (HYCOM), implemented to support DEEPEND research and field campaigns, was utilized to help in the glider's search. Once the glider lost communications, the model's real-time forecasts were used in conjunction with a Lagrangian advection scheme to track the possible paths of the glider according to the model's predicted circulation. During the entire cruise period, the Gulf of Mexico exhibited dynamic Loop Current and mesoscale activity that culminated with a Loop Current intrusion high into the Northern Gulf. The model's initial forecasts were slightly off and predicted that Murphy would drift in the vigorous Loop Current and into the Atlantic Ocean, but upon assimilating more recent observations, updated model forecasts accurately helped in tracking the predicted location of the glider and ultimately isolated its fate to a small frontal cyclonic eddy in the Eastern Gulf. Fortuitously, the glider eventually surfaced and communicated its position, within this eddy, exactly where the model had predicted its drifted location. Murphy was recovered on August 22, 2015.

Understanding the Dynamics of the Gulf of Mexico Loop Current and Associated Eddies Using Satellite Observations and Model Simulations

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Surface circulation in the Gulf of Mexico is dominated by the Loop Current System, including the Loop Current and its associated eddies, as well as a highly-active mesoscale eddy field. The Gulf of Mexico also displays long-term surface gradients of temperature and salinity due to climatological features such as the intrusion of warm, saline waters from the Caribbean Sea and the seasonal deposition of freshwater from the Mississippi river system. This research aims to increase the understanding of the Loop Current System through the investigation of its relationship with these surface gradients. We develop a classification system of Loop Current and eddy interaction with seasonally-present freshwater in order to explore how the Loop Current System can deform the salinity gradients within the Gulf by combining satellite-derived measurements of sea level anomaly with sea surface salinity [Soil Moisture and Ocean Salinity (SMOS); and Soil Moisture Active Passive (SMAP)] to observe lateral freshwater fluxes. We find that through interaction with the Loop Current System, riverine-sourced freshwater can have numerous fates and redistribution patterns throughout the Gulf of Mexico. We further explore the physical characteristics of the greater mesoscale eddy field through the application of an automatic eddy-tracking algorithm to absolute dynamic topography derived from satellite altimetry and sea surface height from HYCOM simulations. We then analyze the spatial distribution and evolution of eddy properties, as well as the variation of these properties between the eastern and western Gulf. Surface eddy composite analysis reveals that long-term gradients present in the Gulf of Mexico greatly affect eddy properties at the surface in characteristics such as salinity, temperature, and chlorophyll-*a* concentration. Through the use of model simulations, we also observe eddy properties with depth, which vary greatly between the eastern and western Gulf of Mexico.

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Observed and Simulated Loop Current Eddy Shedding During the Past Four Decades

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We explore the Loop Current (LC) eddy shedding in the Gulf of Mexico using both satellite observations and fully coupled high-resolution global climate model simulations. Based on satellite observations, including satellite altimetry, ocean color, and sea surface temperature, we identify 58 LC eddy separation events in the 40-year time period from July 1978 through November 2017. In terms of mean and standard deviation, the eddy shedding period is 256.4±144.8 days and the retreat latitude is 25.4^{o}N±0.8^{o}. The seasonal peak of LC eddy shedding occurs in August and September during which 20 LC eddy separation events (over one third of the total) have been discovered. All these observed characteristics of LC eddy shedding, moreover, can be well simulated in the present-day control run by a fully coupled global climate model that has a 0.1-degree resolution in ocean. During the 40-year model simulation, we identify 56 LC eddy separation events and estimate the eddy shedding period as 260.0±168.8 days and the retreat latitude as 25.1^{o}N±0.5^{o}. The simulated LC eddy separation events also show a pronounced seasonal peak in August and September, with 20 events occurring during these two months. Furthermore, we find that this seasonal peak of LC eddy shedding is tightly related to the fluctuating inflow at the Yucatan Channel. Driven by seasonal winds, the Yucatan current transport reaches a maximum in July, which triggers LC eddy shedding in the Gulf of Mexico after 1-2 months due to enhanced shear instability.

Statistical Characteristics of Surface Mesoscale Eddies in the Gulf of Mexico

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Mesoscales eddies can transport heat, salt, nutrients and so on over long distances, and thus exert various impacts on the ocean environment. As far as we are aware, a statistical analysis of the surface mesoscale eddies in the Gulf of Mexico (GoM) has not been reported before. In this study, we present the statistical properties of the surface mesoscale eddies in the GoM, which are identified from sea surface height anomalies. Mesoscale eddies in the GoM have similar distributions of lifetime, radius and propagation speed to the global eddies, but have much larger amplitudes and maximum rotational speeds. Both cyclonic and anticyclonic eddies are concentrated around the Loop Current and the western GoM (at about -95^{o}W). The largest mean amplitude and mean rotational speed of surface eddies appear in the Loop Current region as well. Propagation speeds of eddies are higher in shallow water along the Florida coast, the northern GoM coast and the Yucatan peninsula coast than those in the deep water. Moreover, eddies are more likely generated along the Florida escarpment and the Bay of Campeche, and terminated along the western boundary of GoM. In addition to the mean state, the seasonal and interannual variations of the mesoscale eddies in the GoM will also be presented.

Letting Go: (In)Coherence on the Path to Final Detachment of Loop Current Rings

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The shedding of Loop Current Rings (LCRs) from the Loop Current (LC) fundamentally changes the connectivity of the eastern Gulf of Mexico and impacts transport properties across the basin, as the LCRs

begin their westward journey. Frequently, LCR shedding, however, is not a clean, well-defined event. Eddy Franklin, which detached from the LC in the late summer of 2010 finally ending concerns that Deepwater Horizon oil might hitch a ride to Miami beaches, was a classic example of an indecisive LCR: The standard definition of a closed 17-cm sea surface height (SSH) contour shows multiple detachment and re-attachment events between June and September 2010. Here we apply Lagrangian methodologies developed from dynamical systems theory to identify coherent water masses and differentiate the LCR from the rest of the LC. We describe the evolution of these water masses and how their timeline compares to that of the 17-cm SSH contour to determine the coherence characteristics of the developing, detaching, re-attaching, and finally departing LCR.

On the Fundamental Physics of Gap Leaping Systems

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Fundamental aspects of three different gap leaping oceanographic flows (Gulf of Mexico Loop Current, South China Sea Loop Current and Northeast Channel of the Gulf of Maine) will be compared and contrasted to gain insight into the complexity of gap leaping systems. By considering idealized scenarios and fundamental geophysical fluid dynamics principles, it will be shown that: 1) The competition between current inertia and vorticity constraints can lead to multiple steady states, hysteresis and eddy shedding events. 2) The competition between current inertia and vorticity dissipation can lead to periodic eddy shedding states, which are distinct from eddy shedding events (ie not all eddy shedding is the same). 3) The differential accumulation of dissipation between splitting and reconnecting isobaths can result in gap leaping flow states.

These results will be cast into a global framework based on the theoretical works of Reid [1972], Hurlburt and Thompson [1980], Sheremet [2001], Kuehl and Sheremet [2009, 2014], Nof [2005], and Weissberg and Liu [2017] to illustrate the complexity of gap leaping systems. Ultimately, and unsurprisingly, such complexity is consistent with the view that the key driver of Loop Current dynamics is the integrated vorticity budget of a fluid parcel as it traverses the Loop Current. Thus, key unknowns and under-observed Loop Current physics are related to vorticity forcing, redistribution and dissipation.

The Interaction of West Florida Shelf Anticyclones (WFAs) with the Gulf of Mexico Mesoscale Activity

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In an effort to contribute to the understanding of Loop Current (LC) dynamics, we identify anticyclonic features, the West Florida Shelf Anticyclones (WFAs), that have not been fully investigated before, which shed from the LC when it impinges on the West Florida Shelf. Because of their northward, along-shelf propagation, the WFAs are indicators of connectivity between the southeastern and northern Gulf of Mexico (GoM), as well as of exchange and transport of properties between the deep GoM waters and the West Florida Shelf. We investigate their impact on the overall LC system variability using high resolution numerical simulations employing the Hybrid Coordinate Ocean Model (HYCOM) for specific events of WFA presence in a 6-year period (2010-2016). Favorable conditions for WFA formation are

* Student presenter

identified and connected to cyclonic eddy activity (LCFES), and the LC and Florida Current (FC) extensions. Focusing on a quantitative analysis of the interaction between the LC and shelf waters, results from targeted particle experiments will be shown for certain periods of WFA formation and release. The particle simulations are analyzed to quantify the coherence of these anticyclonic eddies, as well as the amount of LC waters that is transferred onto the shelf and other mesoscale features, such as LCEs and LCFEs. The addition of the WFAs to the already established mesoscale features that encompass the GoM variability, improves the understanding of the shelf dynamics of the basin under the presence of a predominant mesoscale current.

Ageostrophic Flow Observed in the Loop Current System

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The Loop Current (LC) complex is well-known to be energetic and dynamic, yet due to its high complexity, the forecast of this system remains a challenge. Aiming to elucidate the dominant forcings in the system, a momentum budget analysis was conducted using temperature and total velocity from a mooring array, and temperature and salinity from an oceanographic survey mission on the NOAA WP-3D. Each term of the momentum budget was calculated for the 2009-2011 period. The results indicate that the pressure gradient and the Coriolis forces have the same magnitude and are in balance, except for some specific cases. During periods of interaction between the LC and Frontal Eddies, the nonlinear term becomes larger and appears to be equally important as the pressure gradient to balance the Coriolis force. During these periods, the geostrophic balance then no longer holds and the ageostrophic component accelerates the flow. The increase of the ageostrophic flow is due to the merging and squeezing of the LC and the Frontal Eddies boundaries and leads to the intensification of the LC front. Thus, the results show that the ageostrophic component of the flow also plays a fundamental role in the Loop Current variability, in particular during unstable events such as the interactions between the LC and its eddies, and therefore cannot be neglected when studying the LC system.

Instabilities and Multiscale Interactions Underlying the Loop Current Eddy Shedding in the Gulf of Mexico

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A recently developed tool, the multiscale window transform (MWT) along with the theory of canonical energy transfer are used to investigate the roles of multiscale interactions and instabilities in the Gulf of Mexico Loop Current (LC) eddy shedding. A three-scale energetics framework is employed, in which the LC system is reconstructed onto a background flow window, a mesoscale eddy window, and a high-frequency eddy window. The canonical energy transfer between the background flow and the mesoscale windows plays an important role in LC eddy shedding. Barotropic instability contributes to the generation/intensification of the mesoscale eddies over the eastern continental slope of the Campeche Bank. Baroclinic instability favors the growth of the mesoscale eddies that propagate downstream to the northeastern portion of the well-extended LC, eventually causing the shedding by cutting through the neck of the LC. These upper mesoscale eddies lose their kinetic energy back to the background LC through inverse cascade processes in the neck region. The deep eddies obtain energy

* Student presenter

primarily from the upper layer through vertical pressure work and secondarily from baroclinic instability in the deep layer. In contrast, the canonical energy transfer between the mesoscale and the high-frequency frontal eddy windows accounts for only a small fraction in the mesoscale eddy energy balance, and this generally acts as a damping mechanism for the mesoscale eddies. A budget analysis reveals that the mesoscale eddy energy gained through the instabilities is balanced by horizontal advection, pressure work and dissipation.

Observed Loop Current Warm Core Eddy Interactions During Hurricanes Nate and Michael from Floats

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During the passages of hurricanes Nate and Michael, GoMRI sponsored APEX-EM floats measured the ocean responses in Loop Current warm eddies in 2017 and 2018. These float measurements were complemented with atmosphere-ocean profilers deployed from NOAA and the USAF aircraft. In the case of Nate, five floats were located in the northern Gulf with two on the right side of Nate's track. One of the floats was located in a warm core eddy and another along the shelf break. The velocity response along the periphery of this warm eddy sharpened the horizontal gradients of ocean structure between the Gulf Common Water and the Loop Current. Vertical shears were enhanced in the upper ocean, but were insufficient to significantly cool the warm eddy by more than 1^{o}C. In October 2018, six hurricane Michael aircraft missions on the NOAA WP-3D deployed expendable oceanic and atmospheric profilers across the eastern Gulf of Mexico. Additionally, APEX-EM floats were deployed from the USAF WC-130J across 26^{o}N. This ocean measurement domain included the Loop Current, a "cool pool", and a warm eddy underneath Michael's track to assess the oceanic impact on his intensity changes. These floats released ahead of Michael measured more than 650 profiles of evolving temperature, salinity, current structure in a "cool pool" of water separating a retracting Loop Current and a previously shed warm core eddy. These measurements revealed a barrier layer where a strong salinity gradient was evident within the ocean mixed layer. As Michael encountered these frontal regimes, minimal SST cooling was observed during a rapid intensity event, as the ageostrophic current shears across the mixed layer base were insufficient to lower the Richardson numbers to below critical values. This salinity gradient allowed for a sustained air-sea flux to the hurricane along the warm eddy frontal boundary. A second rapid intensity change was observed prior to landfall as Michael reached category five status, which occurred over a warm eddy filament extending to the shelf break and over the shelf. Thus, direct ocean current and shear measurements are crucial to the improving the prediction of Loop Current and warm eddy shedding events and assessing its potential impact on major weather events.

Understanding Multiscale Variability of the Loop Current and Its Impact on Hurricane and Oil Spill Predictions

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The Loop Current (LC) and its associated oceanic eddies, known as the Loop Current System (LCS), are the most dynamic and dominant ocean features in the Gulf of Mexico (GoM). The LCS structure and variability affect not only the ocean circulation in the GoM, but also extreme weather events like hurricanes and some winter storms as well as coastal marine environment. It has a complex multiscale

variability from the diurnal to interannual time scales. Understanding the LCS and its temporal and spatial variability is critical for predicting the high-impact weather and environmental hazards in GoM. This study investigates the multiscale variability of the LCS from days to interannual time scales using surface drifter observations and a high-resolution, fully coupled atmosphere-wave-ocean model. We present two results from this study: 1) year-to-year variability of LCS has a significant influence on forecasting of potential oil spill in GoM, and 2) structure and strength of the LC has a major impact on hurricane intensity forecast on shorter time scales.

Observational and coupled model simulations have shown a large year-to-year variability from 2015-2017. The unusually strong LCS activity in 2015 is in contrast to the LCS in 2016 as observed by more than 500 surface drifters deployed during the LASER field campaign. The coupled model simulations show that the variation of the LC northern extent in 2015-2017 can produce a significantly different areal coverage and evolution of a potential oil spill in the distinct conditions in GoM. Hurricane Michael (2018) went through a rapid intensification over the southern GoM before making landfall in Florida as a Category 5 storm. We conduct a number of coupled model experiments by varying the ocean conditions associated with the LCS in the model. The representation of LCS in our coupled atmosphere-wave-ocean model had a major effect on the model forecasts of the rapid intensification and storm impacts in the coastal regions at the landfall.

The West Florida Shelf Pressure Point Control on Shelf Ecology and Loop Current Penetration into the Gulf of Mexico

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The southwest corner of the West Florida Continental Shelf is a region where isobaths converge as they wrap around the Dry Tortugas, the westernmost islets of the Florida Keys chain. When the Gulf of Mexico Loop Current contacts the shelf slope at this pressure point region, it sets the entire West Florida Shelf in an upwelling favorable motion. Prolonged pressure point contact thus brings new, upper continental slope water and material properties onto and across the West Florida Shelf, with important ecological consequences. Such Loop Current/shelf interactions, in turn, also affect the Loop Current evolution by anchoring the Loop Current in its direct inflow-outflow path configuration, facilitating prolonged upwelling. Farther northward penetration into the Gulf of Mexico occurs when such anchoring is released. Both observations and numerical circulation model simulations show how harmful algal blooms and reef fish recruitment are affected by the pressure point, an energetics analysis supports the anchoring argument, and satellite altimetry analyses using machine learning (Self-Organizing Map) illuminate these findings of importance for environmental resource management, offshore energy operations and coastal community well-being.

Gulf of Mexico Loop Current and Eddy Observations from HF Radar Systems on Offshore Platforms

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This project is part of a larger effort, funded through the Gulf Research Program (GRP) of the National Academies of Sciences Engineering and Medicine (NASEM), to improve understanding and predictions of what causes the Loop Current to penetrate northward into the Gulf of Mexico and pinch-off eddies. CODAR SeaSonde High Frequency Radars (HFR) will be installed on the Shell URSA and Appomattox platforms in the Gulf of Mexico to measure surface currents over the region where eddy formation occurs. URSA is in 1200 m water depth about 89 km south of South Pass of the Mississippi River and the Appomattox platform is in 2200 m of water about 193 km due south of the main pass of Mobile Bay. These SeaSondes operate at close to 5 MHz and have a range of about 200 km, which could put coverage as far south as 26.3 N, covering the region where loop current eddies pinch off. In order to avoid problems that have plagued previous deployments of SeaSondes on offshore platforms, a robust data management plan with enhanced quality control and quality assurance procedures for the unique offshore environment will be implemented, an AIS antenna response pattern package will be added to the systems, agreed upon procedures for maintenance and repair have been made between the parties, and an extensive validation effort will be carried out. The team is part of the LOOP Consortium that also includes University of South Florida, University of Miami and Texas A&M University, the members of which were funded in 3 groups to install and operate new HFR stations at three critical areas defined by the NASEM LC study: Yucatan Straits inflow region; offshore platforms on the northwest escarpment; and the Florida Straits outflow region. The goal of the LOOP Consortium is to provide the scientific community with the highest quality HFR data possible. One way that goal is being accomplished is by having a unified data management program led by Rutgers.

Session 005: Gulf Restoration: Planning, Tools, and Collaboration

Managing One of the Largest Restoration Initiatives in Modern History: The Need for Research and Scientific Tools to Help Assess Progress and Inform Directions

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The environment of the Gulf Coast region was significantly injured by the Deepwater Horizon oil spill, as well as from chronic and acute harm caused by other past and on-going human actions. Impacts of natural events are also intensifying in association with climate change. As a result of the Deepwater Horizon spill several restoration programs were stood up to address the acute injury from oiling impacts, including the NRDA Trustee Council, the National Fish and Wildlife Foundation Gulf Environment Benefit Fund (NFWF GEBF) and the RESTORE Council, which is uniquely also able to address chronic degradation that has occurred in the region for decades. Restoring the Gulf ecosystem and its related economy is a grand challenge for these restoration programs. Inter-governmental coordination, engagement, and transparency are essential for ensuring that the available funding is used in the most effective and efficient way possible. The scale of these restoration programs is unprecedented. In most cases the restoration goals and objectives overlap or are naturally integrated by the ecological interactions within the ecosystem. Given that the restoration programs have an overarching goal for comprehensive ecosystem restoration, it is important that the cumulative effects or interactions across restoration projects and related stressors are measured and accounted for to assess the benefits of the diverse suite of restoration actions across programs. Restoration assessment is presented here as a challenge to the research community, to help develop tools and methods for not only understanding the state of the ecosystem and the multitude of restoration targets comprised within, but also understanding the many

benefits and interrelated nature of all restoration projects on the landscape/seascape of the Gulf of Mexico. It is fundamental that Gulf ecosystem science link scientific results to ecosystem restoration and management, as well as to social, economic and resiliency factors, so this wealth of restoration derived information and research can inform regional management and policy. There remains a need for science to provide these tools to inform strategic guidance that will help the RESTORE Council, NRDA Trustee Council and NFWF GEBF to more effectively address these complex and critical challenges.

Strategic Planning for Monitoring and Adaptive Management within the Deepwater Horizon Open Ocean Trustee Implementation Group

E. Weissberger
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The Open Ocean Trustee Implementation Group (OO TIG) is responsible for performing restoration for natural resources damaged by the Deepwater Horizon oil spill within the open ocean restoration area. Under the 2016 settlement agreement with BP, the Open Ocean TIG was allocated $200 million for monitoring and adaptive management (MAM) to collect information needed to plan, evaluate, and adaptively manage its restoration work. The TIG has funded three MAM activities, two addressing Gulf sturgeon populations and habitat, and a third addressing the effects of multiple stressors on whales and dolphins. In addition to these programmatic efforts, the TIG is also monitoring each of its restoration projects. The TIG also developed an Open Ocean MAM Strategy that lays out a process for prioritizing needs so that funds are spent to address critical needs for restoration work, allow for ecosystem level planning and evaluation, and increase data collection efficiency. In 2019, two outreach events were held to get input on monitoring and adaptive management needs for OO TIG restoration: a workshop at the GoMOSES meeting and a meeting held in conjunction with the release of the OO TIG's second restoration plan. The OO TIG then identified information needed to support restoration for specific resources, common needs among resources, and needs addressing ecosystem-level issues. The OO TIG's criteria for prioritizing MAM needs include relevance to the open ocean resources and ecosystem; importance for restoration planning, implementation, and programmatic evaluation; feasibility of obtaining data in a timely fashion; urgency of the need; and likelihood of meeting the need. The OO TIG's MAM priorities will be released to the public as part of its MAM Strategy and will guide development of activities to gather information needed to support restoration. Priorities will be updated as needed during the restoration program.

RESTORE Council Monitoring and Assessment Program Inventory of Monitoring Networks in the Gulf of Mexico

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Approved as a Gulf-wide investment in the 2015 Initial Funded Priority List, the Council Monitoring and Assessment Program (CMAP) is administered jointly by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS). Funded activities include the development of basic, foundational components for Gulf-wide monitoring to measure beneficial impacts of investments in Gulf restoration by the Council. The program, in coordination with the Gulf of Mexico Alliance (GOMA) and through collaboration with the Gulf States, Federal and local partners, academia,

non-governmental organizations, and business and industry, has leveraged existing resources, capacities, and expertise and build on existing monitoring data and programs. Specifically, the foundational components revolve around a comprehensive metadata inventory of Gulf of Mexico monitoring programs for water quality, habitat and mapping and a catalog of assessments that can be used as baseline or reference points for future monitoring, restoration, or response activities. Overall, 544 monitoring programs and 300 assessments met criteria for inclusion in a database that will be discoverable through a user-friendly web-tool (demonstrated at Tools Café!). CMAP will highlight techniques that identify core monitoring parameters and methods for 20 habitat types and how they may aggregate to inform multi-scale questions. CMAP will present work done to date, techniques developed to identify core parameters for specific habitats, and an approach to examine monitoring gaps in a watershed framework.

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

Cross Trustee Implementation Group Monitoring and Adaptive Management Work Group[1], A. C. Hijuelos[2], **N. Martin**[3]
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The Deepwater Horizon Trustees selected a comprehensive, integrated ecosystem approach to restoration in the Gulf of Mexico, as presented in the Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (PDARP/PEIS). One of the programmatic goals in the PDARP/PEIS is "Provide for Monitoring, Adaptive Management and Administrative Oversight to Support Restoration Implementation" to ensure that the portfolio of restoration projects provides long-term benefits to the resources and services injured by the spill. On behalf of the Trustees, the Cross-Trustee Implementation Group (Cross-TIG) Monitoring and Adaptive Management (MAM) Work Group developed a MAM Procedures and Guidelines Manual (MAM Manual) Version 1.0 to guide MAM efforts conducted by the Trustees. Since release of Version 1.0 of the MAM Manual in January 2018, the Cross-TIG MAM Work Group has been working to develop additional monitoring guidance for restoration approaches and in 2019, released new guidance for oyster and submerged aquatic vegetation restoration projects, as well as land conservation and protection projects. Similar to the guidance in Version 1.0, the additional monitoring guidance provide examples of project-level restoration objectives, drivers of restoration outcomes, and potential uncertainties associated with each Restoration Approach. The guidance also include 1) a suite of core and objective-specific monitoring parameters for each Restoration Approach, 2) monitoring methods applicable to each core parameter, and 3) suggestions for additional monitoring parameters to consider for adaptive management or validation of function and services. With the MAM Manual project-level monitoring guidance currently in place, the Trustees are now beginning to look at how project-level information can be aggregated, analyzed, and synthesized along with other relevant information to evaluate progress towards the restoration goals described in the PDARP/PEIS.

Coastal Marsh, Dune, and Shoreline Restoration: Case Studies from the U.S. and Europe

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* Student presenter

This paper describes the successful long-term implementation of soft engineering techniques used to stabilize coastal marshes, dunes, and shoreline projects in the Northeast, Texas Gulf Coast, and in Europe over the past 20 years. We will describe the success of several of these projects which have withstood Tropical Storms and Hurricanes. Coastal dunes have been stabilized in New England, Texas, and in Spain using innovative sand-stabilization and planting techniques including the creation temporary sand-trapping devices and wind barriers. Several projects have been monitored for over 20 years and have demonstrated excellent resiliency and stability. Eroding coastal banks have been stabilized and protected using biodegradable coir logs and native plantings, and these have been monitored showing long-term resiliency through severe storms and hurricanes. This paper describes design and installation techniques used to ensure the long-term success of coir in coastal restoration. Additional case studies for the restoration of salt marshes and eel grass beds are described, including the planting techniques and implementation methods for the restoration and protection of plantings. The techniques described in this paper are transferable for other living shoreline projects and coastal restoration projects in the Gulf Coast.

The Strategic Conservation Assessment of Gulf Coast Landscapes: Land Conservation Planning Tools Using a Co-Production Science Approach

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A persistent challenge in any land conservation planning endeavor is identifying optimal opportunities for land conservation that address ecological and socioeconomic priorities of stakeholders. The Strategic Conservation Assessment of Gulf Coast Landscapes (SCA) project is an effort underway to integrate comprehensive, multi-state priorities to assist Gulf stakeholders in identifying co-benefits of proposed areas for land conservation relative to RESTORE Council goals. We used an iterative co-production scientific approach to develop a suite of conservation planning support tools that 1) coalesced land conservation priorities in the U.S. Gulf of Mexico Coastal Region (GCR); 2) incorporated priorities and best available science into an online Conservation Prioritization Tool (CPT) to assess relative co-benefits of proposed projects; and 3) developed a comprehensive geospatial framework to aid users in identification of land conservation opportunities given varying conservation priorities. We worked iteratively with 176 individuals representing 120 agencies and organizations in to identify Gulf stakeholder priorities for land conservation under the framework of RESTORE goals emphasizing habitat, water quality/quantity, living coastal and marine resources, coastal resilience, and Gulf economy. This feedback provided the basis for our online toolkit that utilizes underlying geospatial data that reflect a suite of priority attribute measures aggregated across the GCR. Our CPT tool was vetted in a series of stakeholder meetings, incorporating feedback from 126 individuals representing 70 agencies and organizations across the five Gulf states. We specifically highlight lessons learned from our work to identify shared stakeholder priorities for land conservation in the Gulf Coast region and the process of incorporating those priorities into an iterative analytical framework using best available scientific data.

* Student presenter

Ecosystem Service Logic Models and Metrics for Gulf Restoration: Linking Project Outcomes to Economic, Health, and Wellbeing Benefits for People

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Billions of dollars will be spent on large-scale restoration of Gulf ecosystems over the coming decades, but there is no shared platform to guide assessment and reporting of restoration progress and effectiveness for the broad set of environmental, social, and economic goals. The diversity of these goals—including habitat restoration, water quality improvement, marine resource protection, community resilience, and economic revitalization—means a variety of metrics are needed to fully evaluate the effectiveness of restoration projects. A set of common restoration models and metrics relevant across projects, programs, and locations can facilitate effective project planning, evaluation, and measurement of success. This project will advance standardized metrics of restoration success by developing ecosystem service logic models with stakeholders from the five Gulf states, relevant federal agencies, and technical experts. Ecosystem service logic models trace the effects of restoration actions as they influence ecological and social systems to create important outcomes to people. In addition, evidence that accompanies these models can be used to clarify uncertainties that need to be considered and to identify critical research gaps. With local stakeholders and experts in each of the five Gulf states, we will develop site-specific ecosystem service logic models for restoration approaches commonly implemented across the Gulf. These will then be integrated into regional unified models that reflect the priorities of the local models. Using these regional models, priority metrics that effectively capture the outcomes of these restoration approaches will be identified. We will also assess the extent to which these metrics are already being monitored in the Gulf and where gaps in monitoring exist. This project can help inform investments in restoration so they will have the greatest possible positive impact on the Gulf economy, people, and ecosystems.

Integrating Messy Data: A Case Study

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The Data Integration, Visualization, Exploration and Reporting (DIVER) Portal serves as the central repository for Deepwater Horizon damage assessment and restoration monitoring data collected by NRDA Trustees. Within DIVER, standardized data are housed in the Environmental Database, and data templates and planning tools have been developed to facilitate data integration. The goal of data integration is to facilitate evaluation of restoration performance and progress across projects with similar objectives. To identify issues involved in data integration and to develop solutions, we attempted to prepare monitoring data from Deepwater Horizon early restoration for integration into DIVER. We chose early restoration data for this exercise because a structure did not yet exist within DIVER for restoration project monitoring data at the time the projects were implemented and standards for monitoring data were in the process of being developed. Therefore, these data do not conform to a single standardized format, structure, or parameter set, presenting challenges to integration related to reading and importing the data files, relating parameters in each dataset to those in DIVER's schema, aggregating related parameters, and converting or scaling units. Those challenges were exacerbated by

loss of institutional memory which resulted in difficulty locating and accessing raw data; incomplete or missing metadata; and procedural gaps. Based on our experience with the early restoration data, we provide recommendations and tools that may be generally applicable to large, long-term restoration programs, including a generalized process flow and templates for data management planning, simplifying requirements for standardized metadata, and standardizing data structure and format using generic templates.

Improving Oyster Resources Monitoring in the Gulf of Mexico Using Remotely-Sensed Data and Object-Based Image Analysis Techniques

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Eastern oysters (*Crassostrea virginica*) are arguably the most important living coastal resource actively managed in the Gulf of Mexico. Oysters reefs provide a range of essential ecosystem services, such as shoreline protection and water filtration, and have cultural and economic importance as they are exploited both recreationally and commercially. However, these benefits are threatened by a variety of factors including climate change, habitat loss, and resource over-consumption; there has been an estimated 66% decline in oyster reef area along the Big Bend Coast of Florida since 1982. This situation calls for more frequent, effective, and comprehensive mapping and monitoring. However, most current sampling methods do not capture the full extent of reefs and are not robust nor consistent in estimating reef health, meaning that we often lack baseline data against which to measure growth and restoration success.

This paper introduces a multiscale framework combining multiple remote sensing technologies (*e.g.*, microwave radar, optical, and acoustic technologies) to provide a comprehensive and detailed assessment of oyster resources. Our approach uses microwave radar and multispectral satellite imagery to locate and delineate intertidal oyster reefs at a regional scale, and multispectral imagery from unmanned aerial systems to map and collect detailed information at a more local scale. Subtidal reefs can be mapped using a combination of satellite-derived bathymetry and multibeam echosounders. Our preliminary results highlight our ability to differentiate and automatically delineate intertidal oyster reefs from salt marshes, mud, and sand flats using object-based image analysis at the scale of an estuary. Statistics on reef extent can then be computed from the extracted objects. With the increasing availability of remote sensing data, our approach provides a relatively inexpensive method to study oyster reef coverage and health.

Assessing Reef Fish Habitat Restoration and Recreational Fishing Enhancement Efforts Using Fisheries Dependent Monitoring Methods

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Florida's Artificial Reef Program is one of the most active in the Gulf of Mexico region. To date, 2,421 patch reefs have been deployed in Florida's Gulf waters. The NRDA Phase III Florida Artificial Reef Creation and Restoration project is a collaborative effort between FL FWC and FL DEP to provide enhanced reef fish habitat and long-term recreational fishing opportunities in the northwestern

panhandle of Florida. In addition, the program requires post-construction monitoring to assess how well habit enhancement efforts are meeting intended objectives. Monitoring the recreational fishing component of an artificial reef program is necessary to understand how large-scale artificial reef projects influence recreational fishing behavior, catch-per-unit-effort (CPUE), and overall landings of managed reef fish species.

To achieve monitoring requirements, we utilized a specialized recreational fishing survey that was implemented in Florida during 2015 with funding through the NFWF Gulf Environmental Benefit Fund. The Gulf Reef Fish Survey (GRFS) was designed to improve recreational fishing statistics for reef fish stocks in the eastern Gulf following the Deep Horizon oil spill. In 2016, new questions were added to quantify recreational fishing trips that utilize artificial reefs. In addition, we conducted separate surveys at major inlets in the panhandle to assess artificial reef use during two recreational fishing seasons for Red Snapper in 2017 and 2019. Here we summarize trends in recreational fishing effort and catch from artificial reefs across the west coast of Florida, compare artificial reef angler trip estimates in the panhandle region generated from two separate surveys, and provide discussion on assessment of project objectives and the use of artificial reefs in marine fisheries management.

Milestones Reached Using Fishery Enforcement Tools to Aid in Implementation and Compliance Within the Oceanic Fish Restoration Project

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Novel tools and collaboration used by The National Oceanic and Atmospheric Administration Fisheries Office of Law Enforcement (NOAA OLE) are aiding project implementation and compliance in a Deepwater Horizon early restoration project. The Phase IV Early Restoration Oceanic Fish Restoration Project (OFRP) involves a unique collaboration and partnership with multiple entities. NOAA Fisheries, the National Fish and Wildlife Foundation, as well as industry and community members have worked closely together on the OFRP since 2015. One of the goals of the project is to restore pelagic fish by reducing fishing mortality within the Gulf of Mexico commercial pelagic longline fleet. NOAA OLE uses the participants' Vessel Monitoring Systems to monitor their fishing effort and can relate it to overall effort within the Gulf of Mexico pelagic longline fleet after the oil spill through the implementation of the OFRP. Outreach and communication conducted by NOAA OLE with project partners and participants, as well as utilizing monitoring tools typically used for regulatory purposes, will be discussed to highlight change in pelagic longline effort within the Gulf of Mexico and restoration goals attained specific to the OFRP.

Analysis of the Restoration of Fish Populations as Part of the Deepwater Horizon Oceanic Fish Restoration Project

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The Oceanic Fish Restoration Project is a voluntary, temporary, and non-regulatory restoration initiative that aims to restore pelagic fish populations injured by the 2010 Deepwater Horizon oil spill by reducing fishing mortality in the Gulf of Mexico pelagic longline (PLL) fishery. The project includes two separate,

* Student presenter

but complementary components: (1) a repose period, and (2) use of alternative fishing gear. During the voluntary repose, participating vessels are compensated to stop using PLL gear for six months in order to reduce discards in the fishery, thereby restoring biomass. For the alternative gear component, fishers are able to continue fishing during the repose with non-PLL gear provided by the project (greenstick, buoy gear, and deep-drop rod-and-reel), with the goal of minimizing economic impacts to the vessel owners, fishers, and shoreside support industries caused by reduced catches of target species. Performance criteria used to monitor the restoration objectives include annual number of participants, average biomass of dead discards avoided, and net profit of alternative gears. Seven PLL vessels participated in the project in 2017 and ten participated in 2018. A standardized catch per unit effort was created to compare catch rates of gear types across the project period. Using data collected from the project and the NOAA Pelagic Observer Program, the average species composition of PLL and alternate gear catches was determined. A baseline rate of PLL catches was used to estimate the amount of bycatch avoided during repose periods. Results of this study will reveal information on the restoration process in fish stocks and allow us to better understand opportunities for fishers to target highly migratory species in the Gulf of Mexico.

Session 006: Evolution and Development of Spatially Related Response and Restoration Data Collection, Use, and Retrieval Tools

The Environmental Response Management Application (ERMA): A Good COP

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The Environmental Response Management Application (ERMA®) is a web-based geographic information system (GIS) tool that helps emergency responders and environmental resource managers deal with incidents that may adversely impact the environment. ERMA combines real-time and static data to display a single interactive map that makes it easy for users to visualize an active environmental situation, damage assessment or long-term restoration monitoring. Recent ERMA development includes the United States Coast Guard's adoption of ERMA as the Common Operational Picture (COP) for functional exercises and response incidents for the government. This solidifies the ability of NOAA and ERMA to support data sharing and systems interoperability across the Unified Command (government and Responsible Party) as well as across the entire response community. User enhancements have provided users greater access to data for use within ERMA or as electronic data services provided out from ERMA. Remote sensing data ingest and visualization has been enhanced for surface and subsurface oil characterization. Animated NOAA Trajectory Forecasts and time enabled data are supported. Users can also add data for their specific use. These and additional developments expand the functionality of ERMA for incident and natural disaster response as well as for damage assessment and long-term restoration monitoring. ERMA facilitates the integration and synthesis of various types of information. It provides situational awareness via the COP to all individuals involved in a response on-scene or remote. It improves communication and coordination among responders and stakeholders. ERMA gives resource managers the information they need to make informed decisions when dealing with an incident.

Use of GIS Results from Oil Spill Modeling in Support of Oil Spill Response Drills

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Determining the movement and behavior of oil releases from vessels and facilities is an essential part of emergency response planning. Safely and effectively responding to a release requires knowledge of where the product may be transported, the timing of that movement, the weathering and behavior of the released product, and the potential effects on the environment under varying conditions. The most effective planning requires complex numerical models to assess the movement and behavior of released products on land, in rivers, and into coastal and offshore environments. The results of these models must be coupled with Geographic Information System (GIS) based outputs and visualization tools in order to aid operators and responders with gaining a clear understanding of the model results. These modeling results can be displayed in a multitude of formats, including video, static and interactive maps, and tables. Oil spill response planners can use these products during contingency and exercise planning to inform the placement and timing of response countermeasures for full-scale exercises and actual events. Using GIS capabilities, these results can be created quickly with the most useful time-enabled information in order to easily share this data with field responders and the Incident Management Team at the Incident Command Post. Results can additionally be used by operators and responders to prepare Geographic Response Strategies, Oil Spill Response Plans, and Area Contingency Plans. This presentation will provide example outputs and visualization tools from actual modeling results to illustrate to the audience the possibilities of this technology.

Using Machine Learning Techniques for Near Real-Time Assessment of Marine Biogeochemistry

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A rapid and informed response to an extreme event or disturbance is crucial to mitigation efforts. Responders and decision-makers do not necessarily have access to continuously running “nowcast” ecological simulation models nor do they have the time to spin-up such models to inform their initial response. The Adaptive Ecosystem Climatology (AEC) uses machine learning to integrate the latest satellite ocean color and sea-surface temperature data (Earth Observations- EO) into a 3D representation of marine biogeochemical properties.

The foundations of the system are Earth observation and numerical model climatologies. EO data from the Moderate Resolution Imaging Spectroradiometer (MODIS) were processed for the Gulf of Mexico for each day spanning 2003 (initial launch) to 2013. Each day of the 366-day climatological year is composed of a five-day rolling mean, centered on that day, for all 11 years. Therefore, each pixel in a climatological day image is a mean of up to 55 individual values (valid, cloud-free pixels). Anomalous values derived from high viewing angles, algorithm failures, cloud edges, etc. were eliminated. Simultaneously, a 33-year simulation (1980-2012) was used to produce a climatological year from a coupled NCOM-COSiNE physical-biogeochemical model. Next, the AEC optimal interpolator (AEC-OI) system was developed and used to blend the 2D EO climatologies with the respective three-dimensional model climatological fields - chlorophyll and temperature. Subsequently, a Deep-Learning Neural Network (DNN) was trained using these climatologies. Operating on the latest 7 days of satellite imagery, to reduce missing data due to clouds, the DNN produces a 3D representation of the latest conditions for all of the model variables. This

product is available on-line and can be visualized using tools on the website. Additionally, the data are available for download and can be used as input or boundary conditions for other decision-support tools or simulation models.

Development of a Nearshore Wave Model Using a Spatially Robust Dataset

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Waves have a major impact on the movement of oils and sediment. Having a continuous spatial-temporal understanding of wave energy can provide a better understanding of the distribution and movement of oil spills. Hence, it is extremely important to analyze wave energy and its drivers in order to mitigate the impacts from oil spills. The aim of this study was to develop and validate a wave model for the Back Bay Biloxi, Mississippi in the northern Gulf of Mexico. The SWAN software (Simulating Waves Nearshore; Delft University of Technology) was used to simulate wave height and direction. SWAN input data includes: wind speed, wind direction, and a bathymetric mesh. Due to the complexity of the area, an unstructured bathymetric mesh was generated using SMS software (Surface-water Modeling System; US Army Corps of Engineers). One limitation in many wave modeling studies is the lack of spatially robust wave measurements that can be used for validation. This is due to the fact that installing a large number of wave gauges, in any one site, is usually cost prohibitive. In this this study we deployed 38 relatively cheap DIY wave gauges to comprehensively measure wave conditions in Back Biloxi Bay. Wave gauges were deployed three times between June and August 2019 for 7 days during each deployment. These data were used to validate the wave model. Consequently, this study provides a novel validation of a wave model by way of a spatially comprehensive wave measurement dataset.

Observation and Modeling of Low-Salinity Lenses off the Louisiana Coast

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River runoff on the Louisiana Coast produces relatively shallow, low-salinity lenses. These lenses create significant horizontal density gradients in the upper ocean and can spread as gravity currents. In this paper, we analyze the field and synthetic aperture radar (SAR) satellite measurements conducted off the Louisiana Coast during LASER and SPLASH field campaigns. We investigate dynamics of low-salinity lenses using computational fluid dynamics (CFD) tools. The CFD model reveals the so-called 'head' at the edge of the spreading lens, which is a distinctive feature of gravity currents. The upwind edge of the lens is destabilized by the wind-driven flow of higher salinity/density water over the lens's edge, which triggers the Kelvin-Helmholtz (KH) instability in the form of billows. The KH billows initiate strong mixing and large entrainment fluxes at the upwind edge of the lens. The downwind edge of the lens is stabilized by horizontal advection of the lower salinity (less dense) water. The model also develops spiraling coherent structures at the frontal edge of the spreading low-salinity lens, further intensifying mixing. These coherent structures resemble the 3D pattern of water motion in the leading edge of the gravity current and trailing fluid as reported by Özgökmen *et al*. (2004) and Soloviev *et al*. (2015). The model reproduces the main features of in situ and SAR observations of low-salinity lenses off the Louisiana

* Student presenter

Coast. The results of this work help to understand the effect of river runoff on oil spill propagation during the Deepwater Horizon disaster.

The Application of Integrated HF Radar Network Along the Texas Shelf to Improve Search and Rescue and Oil Spill Response

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An integrated high-frequency radar (HF-radar) network is built along the Texas coastline, which can provide ocean surface current data with an expected range up to 180 km and 6 km resolution, every 1 hour. HF-radar data is suited for many applications, especially in the enhancement of the immediacy and accuracy responses, such as search and rescue, oil spill mitigation, and ecosystem management.

In this project, we present a reliable particle trajectory toolbox by using the HF-radar dataset, which provides a rapid and informed response for decision-makers in search and rescue or oil spill scenarios. The toolbox offers two types of user-interface, including a user-friendly web app as the front-end and a python software package as the back-end. The user can simply use the back-end call to complete the mission of the particle tracking. The package dataset is stored at a remote THREDDS data server or at the local-end personal computer. In addition, we currently plan on extending the functions of this toolbox. The goal of the extension function is combining the observation from HF-radar with various levels (reanalysis, analysis, and forecast) of numerical simulation to 1.) fill up the missing spatial information, and 2.) enable the nowcast/forecast skills. The beta version of the particle trajectory toolbox is already published on GitHub.

Session 007: Tell Your Story: Making Your Data Clear, Understandable, and Usable

The Power of Beautiful Data

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With tens of millions of data points generated over the course of nearly a decade, it can be challenging just to sort it all, let alone create a clear visual representation of what the data means. But the impact of good data visualizations on your audience (whether that is scientists, decision-makers, stakeholders, students, or the public) can be extremely powerful. A strong, well thought out graphic or video can help you explain the results far better than that spreadsheet with a million lines. This presentation will feature select examples of data story telling successes, such as large-scale drifter releases presented in an animation, merging of multiple big data sets into one graphic, videos created for children, and a citizen science study told through an ArcGIS storymap. While each data set is unique and each has a different story to tell, we hope to share a spark of inspiration for when you're ready to tell your data's story.

* Student presenter

When the Numbers Don't Speak for Themselves: An Ocean Portal StoryMap

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There are a multitude of important components when it comes to storytelling—compelling narrative, conflict, and characters, to name a few. What about data? Millions of data points were collected by the Gulf of Mexico Research Initiative over the past ten years since the Deepwater Horizon oil spill. But data can only do so much. Context is necessary to share the stories behind the data and to make links to future solutions.

Using language, video, and imagery we are able to decode the information held by data into the universal language of storytelling to share with larger audiences. Information suddenly becomes more accessible and stories can be shaped and merged together. This presentation will discuss the process the Ocean Portal worked through in collaboration with GoMRI data managers, scientists, and other communicators to gather relevant data and package it into a story using the ArcGIS StoryMap platform. It will also include tips and tricks gleaned from the process to help you think about the best ways to use data to tell stories.

Beneath the Horizon: An Interactive Tour and Timeline of Oil Spills

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Beneath the Horizon (http://beneaththehorizon.org/) is an electronic tour of several oil spills that have occurred, with a particular focus on the Gulf of Mexico. Through user friendly map-based interactions, visitors to the site can locate a spill's epicenter and gain information on each spill from the associated profiles displayed on the map. These quick reference profiles contain the location, duration, type of incident causing release, date of incident, amount of oil released, and environmental persistence issues. However, more information-rich locations are linked to multimedia content such as timelines, podcasts, stories from those directly impacted, short films and other resources. Some of the more compelling "big picture" stories from the digital content include comparisons (1) between the Deepwater Horizon and Ixtoc 1 spills (a major component of C-IMAGE research), (2) between similar spills in regions around the world, and (3) between sites of similar fauna but experiencing varied oiling. For example, some mangrove coastlines were heavily impacted with a direct hit from Deepwater Horizon and some areas were only lightly oiled. How do these areas differ in terms of coastal erosion? Are the mangroves recovering in the lightly oiled area? What are the impacts given the larger role of mangroves in coastal resiliency? The website also compares mangroves impacted during the Ixtoc 1 spill with those in the northern Gulf. In the same way, the digital timeline also looks at the difference between the two spills in terms of their impact on marine resources such as oysters, shrimp as well as the impact on the local economies of the communities in coastal Louisiana and in the Campeche region of Mexico.

Visualizing the Twitter Record from Hurricane Irma in Florida to Investigate Coastal Storm Impacts

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University of North Carolina at Greensboro, Greensboro, NC

* Student presenter

Real-time impacts during extreme events are often reported on streaming social media services, but the volume of data generated requires additional processing to become usable by scientists, managers, and policymakers. Here we develop an analysis and visualization tool using a dataset of 54k geolocated tweets from Florida during Sept. 10-12, 2017 - this is a digital trace of the FL landfall of Hurricane Irma. We use a deep convolutional neural network to classify the 3k tweeted images in this dataset, and develop an interactive map and dashboard that can be used for resource managers, emergency managers, and scientists to sort and filter this data. Our work suggests that curating and interactively visualizing social media data allows scientists to test numerical models of storm forcing, and could allow policy makers and managers to further understand the impacts of extreme events in ways that are different from other synoptic surveys.

Online Information Flow and Fast-Paced Information Exchange in a Disaster Context: Characterizing Deepwater Horizon Oil Spill Tweets

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Every disaster in the past decade has triggered a complex network of fast-paced information exchange. Following the Deepwater Horizon oil spill (DHOS), information was widely broadcast through social media platforms like Facebook and Twitter. Based on Twitter's analysis, the DHOS was the top trend in 2010. We explored the tweets relevant to the oil spill using a combination of human coding and machine-classification to study the role of social media during the spill. Search filters were used to identify related tweets (*n*=826,298) within the first 4 months of the DHOS. A machine classifier for text analysis of the historical tweets was built through an iterative process of manual coding, validation, and accuracy testing. Application of the classifier yielded a set of 736,325 relevant tweets which was used for the analysis. Examination of the tweets revealed that the users initially focused on the explosion and the missing workers. In the following weeks, concerns about the sealing of the oil leak, harm to the environment and fishing community, the role of British Petroleum (BP) and politicians, legal implications, and compensation concerns were expressed. Community-based stakeholders mobilized online to help out and volunteer with the clean-up and connect resources to those seeking them. The narrative then shifted towards economic loss and health concerns. Our findings suggest that social media empowered community-based users, affording access to information, to federal agencies, BP officials, and other local power brokers, and potentially contributed to their resilience. Further study is needed to understand the participation of vulnerable groups on social media. Our approach and findings contribute to understanding online communications and coordination efforts to support disaster affected populations. Social media plays an important role during disasters, and stakeholders need to develop strategies to continuously evaluate online communications to counter rumors and disinformation.

DIVER Field Forms, Data Templates, and Guidelines — Integrating Data into DIVER for Future Access and Assessment

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The National Oceanic and Atmospheric Administration's Assessment and Restoration Division (ARD) creates tools to improve preparation for and implementation of Natural Resource Damage Assessment

* Student presenter

(NRDA) field efforts. Field and laboratory protocols, data templates, chain of custody, and field data collection forms to standardize data collection and intake are a key component of NOAA's efforts. Many of these materials are the genesis of field practices and lessons learned from the Deepwater Horizon oil spill, with recent refinement for on-going and future needs. These documents were developed for use within all regions of the United States.

NOAA provides these materials to partners and the public as part of ensuring consistency and best practices across different environmental assessments in all regions of the United States. This presentation reviews where to locate the forms and files, the types of templates available and the help resources. There are a variety of field forms and templates that represent past field sampling efforts by NOAA and partners. Templates are available for electronic deliverables including analytical chemistry, general field observations or field measurement data, biological and non-chemistry data, and Shoreline Cleanup Assessment Techniques (SCAT). This presentation will also highlight the next steps in DIVER templates development and how these templates help make data integration and usage smoother and more efficient.

Session 008: Taking Stock: Capacity Building and the Successes of Advanced Academic Scholarship, Professional Training, and Interdisciplinary Mentoring Through the Gulf of Mexico Research Initiative

Session Introduction and Review of GoMRI Graduate Student and Post-Graduate Capacity Building Survey Results

S. Gilbert[1], D. Hollander[1], K. Fillingham[2], L. Hotaling[1]
[1]University of South Florida, St. Petersburg, FL, [2]Consortium for Ocean Leadership, Washington, DC

One of the Gulf of Mexico Research Initiative's (GoMRI) important Legacy Goals is to build intellectual capacity through the training of future scientists and engineers. This includes training in disciplines associated with the basic, applied, health, and social sciences and through multidisciplinary/cross-disciplinary approaches. As the program reaches the end of its ten-year investment, in an effort to gain insight into the personnel capacity and professional achievement created through the graduate students and post-graduates who were trained on GoMRI-funded projects, a survey was distributed by the GoMRI Management Team to all current and former GoMRI-funded graduate students and current and former post-doctoral researchers. The survey recipients also included GoMRI-trained career professionals who are now employed in industry, federal/state agencies, and academia. This presentation will introduce the broader session, outline its goals, and discuss the results of the survey.

How to Get There from Here: The Not-So-Straight Career Path

D. Palandro
ExxonMobil Upstream Research Company, Houston, TX

An arc is the common geometric term used when educators speak about career paths. However, in practice the journey through academic education into the career ladder is rarely as smooth or predictable as the arc ⋯ it tends to be more akin to the line a pinball creates. In this invited talk, I will discuss my own career path experience, from academia to government to industry. Each of these jobs

* Student presenter

has required and provided a unique set of skills and experiences. In some instances, the skills acquired from the various ladder rungs provided adequate preparation, whereas other instances provided a steep learning curve, similar to drinking from a fire hose. However, over the years I have been fortunate enough have created a very particular set of skills, skills I have acquired over a moderately long career. From attending the GoMOSES conferences over the past few years, I have had the opportunity to interact with students and early career scientists at various stages in their pinball game. I will offer my perspectives, given my diverse job history, on what technical and personal skills are needed to be highly adaptable in the post-GoMRI world. I will also discuss the various, likely not aware of, opportunities that a career in industry holds.

Educational and Research Principles and Strategies Followed by CARTHE

T. Ozgokmen
University of Miami, Miami, FL

Deepwater Horizon event was the largest accidental oil spill in history, and the unprecedented amounts of funding devoted to its investigation created a special circumstance for oceanographic research. While the event was complex and rich enough to be able to sustain physical, biological and chemical investigations by thousands of researchers for a full decade, research had to be at a level only possible by large consortia, as opposed to comprising just a superposition of individual investigators. Thus, special strategies had to be developed to accomplish this goal for both research and graduate student education. The purpose of this talk is to provide a high-level perspective on how the research effort by CARTHE is designed to keep this large team focused and working efficiently for an extended period of time, and reflect on the skills attained, and opportunities encountered the graduate students within the GoMRI program.

[(26+23+(22+6)]PIs » [(7+15+8)PDoc] + [20+10+10)PhD] + [(14+8+5)MS] + [(26+50+13)UG] + [(8+10+7)REU)] = CWC-I+CWC-II+CWC-III = A LOT

N. N. Rabalais[1], B. J. Roberts[1], D. Justic[2], R. E. Turner[2], W. Morrison[1]
[1]Louisiana Universities Marine Consortium, Chauvin, LA, [2]Louisiana State University, Baton Rouge, LA

The Coastal Waters Consortium (CWC) stands proud with their mentoring of the next several decades of professionals and academicians for further studies of the Gulf of Mexico, or other regions, and research concerning the fate and effects of oil spills in coastal environments. The experience from the Deepwater Horizon oil spill provided an exposure of these students and postdoctoral associates to a massive, deep-water oil spill to which dispersants were added. Many of GoMRI's other mentees enjoyed the deep blue waters of the Gulf of Mexico and its megafauna or were in laboratories with clean techniques. Coastal Waters Consortium trainees, on the other hand, had to deal with mud, lots of mud, thunderstorms, waves in shallow bays, tedious measurements in the field, flies and mosquitos, heat and humidity, and further long hours in the laboratory, climate controlled-chambers or marsh mesocosms. They are so much better educated than their predecessors, and have provided a wealth of scientific expertise and background information for the "next one." This is due to the strong mentorship of the principal investigators who all worked with students and postdoctoral associates to make them an integral part of the Consortium's research program. Many who started as MS students, or PhD students, completed their MS and PhDs, moved on to other or postdoctoral positions, and some are now in Assistant Professor positions as Principal Investigators of the CWC and other research efforts. CWC worked to

direct their mentees into other research opportunities, or provided the accessibility of becoming CWC principal investigators. On the other hand, several senior CWC PIs have added 10 years of CWC research capabilities to their already long research careers. Some are moving on, some are hanging on, and others keep up the incredible pace. The blending of old and new can be a push-and-pull exercise, but overall the multiple contributions of all mentors and mentees are much greater than the parts.

Graduate Student Training in Collaborative Research

V. T. John
Tulane University, New Orleans, LA

The GoMRI experience has provided graduate students a unique opportunity to work in collaborative teams sharing data, learning new experimental and theoretical techniques and participating in joint intellectual progress with other students. We will discuss case studies where such collaborative research has been invaluable to the progress of the student and will describe possible methods to systematize the training that will lead to a significant enhancement in the student's scientific development. Most importantly, I will describe methods to inculcate the ethics of collaboration which goes far beyond the traditional rules of research conduct. I will describe aspects of collaboration that train a student to give credit to others, to be complimentary of the efforts of others in the team and to put oneself in a position of service to others in the team. These are ethical lessons that apply not only to research, but to living a good ethical life that will be richly rewarded by the respect of one's peers.

Developing Nanoparticle-Based, Concentration-Independent Dispersants: From Fundamental to Applied Science

K. Bentz, S. Walley, B. Barnes, S. Arencibia, C. Machado, **D. Savin**
University of Florida, Gainesville, FL

One of the legacy goals of the GoMRI is to, "build intellectual capacity by informing and training future scientists and engineers." Over five years, the Savin Group has trained five graduate and numerous undergraduate students on GoMRI-related projects, in collaboration with scientists at the University of Florida and Tulane University. By necessity, these future scientific leaders have been required to become adept in the areas of chemistry, physics, polymer science, and nanotoxicology. This talk will present some of the key scientific discoveries from five years of GoMRI funding. First, I will talk about some recent results on the fundamental properties of polymer brushes on nanoparticles. Second, I will present some work on a class of organogels that was discovered serendipitously, where we were able to explore the mechanical properties of these gels using shear and cavitation rheology. Finally, I will show some results on our final design of producing unimolecular micelles capable of encapsulating oil.

Introducing Engineers to Sea Butterflies: Lessons Learned in Interdisciplinary Research

D. Murphy
Department of Mechanical Engineering, University of South Florida, St. Petersburg, FL

As an engineering PhD student at Georgia Tech being co-advised by a biological oceanographer and an engineer and doing research on the fluid dynamics of plankton swimming, I was no stranger to interdisciplinary research. Thus, upon my graduation in 2012, I was eager to continue in this vein as a

postdoc at Johns Hopkins University with the GOMRI-supported DROPPS consortium. The DROPPS consortium allowed me to work with oceanographers, chemists, biologists, medical doctors, and public health professionals while providing a solid foundation in my home field of mechanical engineering. These experiences have well prepared me for my current assistant professor in mechanical engineering position at the University of South Florida, where I have active collaborations with a developmental biologist, an artist, and a biological oceanographer and, as a co-PI on a GOMRI-funded project, am learning to train my own PhD students to work across disciplines. Here I aim to share lessons learned in interdisciplinary research.

Training Through the Gulf of Mexico Research Initiative Funding

A. L. Dissanayake
RPS Ocean Science, South Kingtown, RI

Four years of my postdoctoral research was funded by the Gulf of Mexico Research Initiative. That includes three years associated with C-IMAGE consortia, developing a near-field oil and gas blowout plume model at Texas A&M university in College Station, Texas, with Dr. Scott Socolofsky and another year with Dr. Adrian Burd at University of Georgia in Athens, Georgia, developing a numerical model to simulate the interactions of marine snow and oil. Personally, Gulf of Mexico Research Initiative provided me many opportunities to build my knowledge, capacity and confidence and it was an excellent experience for a starting researcher. Apart from continuing with my own research, I had the privilege to interact with fellow researchers from other diverse backgrounds (chemistry, toxicology, biology, and oceanography etc.) from both academia and industry. Their studies focused on essential distinctive aspects of oil spills and their evolution. Hence it was a very valuable learning, knowledge sharing and networking opportunity. As a spill progresses through many different complex phases, it needs the expertise from these broad backgrounds to study and understand its behavior. Thus, I believe the cross-discipline knowledge sharing and critical discussions should be an essential part in oil spill research. The annual GoMOSES conference and the associated workshops were great occasions for intimate interactions between the research groups. Proposal writing workshops and conference session planning, organizing and convening opportunities were offered for researchers. Furthermore, the consortia directors and coordinators were always accessible, responsive and kept us in continuous communication and pointed out the opportunities available. At present I'm a research scientist at a consultancy company that has a focus on oil spill modeling with close interactions with oil and gas industry. This lets me to use the models that we developed and share the recent advances in oil spill science in academia at a more applied setting. The work is challenging and competitive. The knowledge and training gained, and the supportive oil spill expertise colleagues that I met over the years that I worked with the support of GoMRI funding will be immensely valuable and advantageous in confronting and responding to these challenges.

Early Career Advancement Through the Gulf of Mexico Research Initiative

P. Schwing
Eckerd College, St. Petersburg, FL

The Gulf of Mexico Research Initiative (GOMRI) and Center for Integrated Modeling and Analysis of Gulf Ecosystems (CIMAGE) have advanced my career through funding, mentoring, and provided professional development opportunities in three broad areas 1) Administrative and management capability, 2)

* Student presenter

Communication and Outreach and 3) Research development. GOMRI has enhanced my administrative and management capabilities by providing the opportunity to fund and mentor research staff (technicians, interns) and graduate students, refine data and sample collection, logging, organization and dissemination strategies, organize meetings (e.g. chairing sessions at the GOMOSES meeting, leading a portion of GOMRI synthesis efforts) and finally through the organization, planning and implementation of broad oceangoing and coastal field sampling efforts. My communication and outreach skills have also developed through refinement of my scientific writing approach in various arenas (proposals, book chapters and peer-reviewed literature), research reporting and presentations (e.g. GOMOSES and other international meetings), as well as participation in a host of media and outreach outlets including the Dispatches from the Gulf documentary series, local news media interviews, the Smithsonian Ocean Portal, National Geographic, Sea Grant, and multiple local science festivals. Most importantly, my scientific approach has also been refined during my experience with GOMRI through method development, expanded analytical capacity, and the development of a diverse network of science, agency and industry professionals. I plan to use these tools that I have developed for both teaching and research purposes throughout the remainder of my career. The samples and data collected through GOMRI will provide multiple lines of research for the generation of young scientists I am training in the classroom, field and laboratory. The time-series collections begun by GOMRI researchers are unprecedented in oceanographic research and will hopefully be continued through other funding sources. The GOMRI consortium funding structure challenged me to take on leadership roles and work with a diverse, interdisciplinary group of investigators to a degree that I would not likely have experienced through traditional funding avenues.

Insights into How My Training as a Postdoc in the DROPPS Consortium Prepared and Aided My Success as a Faculty Member

B. Gemmell
University of South Florida, St. Petersburg, FL

One of the priorities of the Gulf of Mexico Research Initiative (GoMRI) is to educate and train the next generation of professionals. Here, I will highlight a brief history of my time as a postdoctoral researcher and the beneficial interactions with an accomplished group of interdisciplinary scientists. I will discuss how these interactions aided and shaped my ability to compete on the job market at R1 research universities and ultimately improved my ability to advise my own group of students and postdocs who are working on oil spill related research.

Growing Up in GoMRI: Finding a Career in Passive Acoustics

K. Frasier
Scripps Institution of Oceanography, San Diego, CA

The 2010 Deepwater Horizon (DWH) oil spill generated intense interest in the use of passive acoustics to quantify oil spill impacts on megafauna populations at the scale of ocean basins. This task challenged nearly every aspect of the state of the art of passive acoustic monitoring, creating opportunities for students like myself at that time. Over half a petabyte of acoustic recordings have now been collected in the Gulf of Mexico by Scripps institution of Oceanography in collaboration with the C-IMAGE consortium. Extracting meaningful insights from this quantity of data has provided the impetus for my current research on unsupervised and deep learning for classifying underwater acoustic signals,

estimating acoustic signal detectability in a changing ocean, and methods for population distribution modeling with disparate datasets.

In addition to supporting groundbreaking research following DWH, the Gulf of Mexico Research Initiative's (GoMRI) program has provided extraordinary opportunities early in my academic career to serve on expert panels, participate in management working groups, join outreach efforts and lead research programs. GoMRI and its partners have held invaluable workshops on everything from interdisciplinary research and data management, to grant writing and media relations, providing a cohort of young scientists with skills to meet the many demands of a well-rounded research career. After nearly a decade of support and guidance from GoMRI, I find myself well-positioned to contribute expertise in the case of future oil spills in and beyond the Gulf. Anecdotally, it seems that peers who were not part of GoMRI have been less likely to find long-term research opportunities or to stay in scientific careers. By placing students at the center of its strategy, GOMRI has produced a group of early career researchers who feel a responsibility to continue what is now a tradition of cutting-edge inquiry in oil spill science.

Session 009: RESTORE Act Centers of Excellence Research Grant Programs – Filling Gaps in Gulf Research to Inform Policy and Management

Research and Results from the First Four Years of the Florida RESTORE Act Centers of Excellence Research Grants Program

L. Fetherston-Resch
Florida RESTORE Act Centers of Excellence Program, St. Petersburg, FL

At the close of 2020, the Florida RESTORE Act Centers of Excellence Program will have awarded a total of 18 Centers of Excellence nearly $6.8 million. FLRACEP has succeeded in funding interesting, innovative, applied, and appealing science. Yet, as a brand-new grants program serving as the facilitator of funds from a brand new federally managed Trust Fund, there have been a number of opportunities to learn and adapt. In this presentation, we will reflect on the research and results from the first years of the program, as well as the lessons learned and the path forward. While there are procedural and logistical challenges worth mentioning, ultimately the FLRACEP funding is an incredibly small amount of money to address the needs in all or any of the five eligible discipline. At the same time, it represents an unprecedented opportunity to advance our understanding of the human and ecological systems of the Gulf. To date, FLRACEP funding has been spread widely across three of the eligible disciplines, five different focal areas, numerous objectives, required and recommended criteria within those objectives, and has still left numerous important elements of coastal and marine science untouched. The challenge is a simple one, but important to get right: how to make the best use of the research dollars available to this program over the coming years? The FLRACEP Program Management Team will continue to weigh the benefits of large investments versus multiple investments, and going deep on an issue of importance versus examining the many worthy science questions in Florida's Gulf waters. In the changing climate that we are anticipating and already experiencing, every research dollar counts. FLRACEP will continue to contribute to this landscape in its selected eligible disciplines in the hope that the Florida Centers of Excellence will add far more than merely the sum of their awarded funds.

* Student presenter

Benthic Habitat Mapping in the Gulf: Integrating Data from Multiple Sources Is Essential for Comprehensive View of Seafloor

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While reef habitats on the West Florida shelf support numerous economically and ecologically important reef fishes, the distribution and composition of this critical habitat remains poorly understood. Several mapping approaches have been implemented to identify and quantify seafloor habitat, including a broad-scale, randomized mapping approach by the state of Florida that uses side scan sonar in support of a long-term, fishery-independent survey of reef fishes. Because these approaches vary substantially in the type and resolution of data provided, it is necessary to compare and calibrate habitat classifications to provide a unified map of reef habitat. Funding from the Florida Centers of Excellence Program supported a 2016 - 2018 study to compare habitat maps resulting from interpretation of side scan sonar and satellite imagery in nearshore waters of the West Florida shelf. Over 1,200 km^2 of seafloor (4 - 16 m) were mapped using available satellite imagery, of which 294 km^2 (25%) were characterized as hard bottom habitat. Within this area, 67 km^2 of side scan imagery was interpreted, of which 4 km^2 (6%) was identified as reef habitat. Large discrepancies in the estimated quantity of reef habitat may result from overly-conservative delineation of reef habitat with side scan imagery or, alternately, over-liberal delineation of reef habitat with the satellite data. Resolving this discrepancy would benefit from improved accuracy assessment within both areas of agreement and disagreement in future comparative efforts. Results of this project highlight the importance of overlapping efforts among different technologies across broad spatial-scales to accurately map benthic habitats. Such efforts would facilitate the integration of habitat maps across multiple surveys which would benefit ongoing reef fish surveys, marine spatial planning activities, artificial reef siting and evaluation of environmental perturbations such as hurricanes.

Overview of FLRACEP's SHELF Project: Spawning Habitat and Early-Life Linkages to Fisheries

E. Peebles
University of South Florida, St. Petersburg, FL

The SHELF project was designed to (1) create a monitoring program for fish eggs on the West Florida Shelf (WFS) that is based on DNA barcoding, (2) independently estimate stock sizes for WFS reef fishes using the Daily Egg Production Method (DEPM), and (3) characterize the individual habitat and trophic histories of fast-growing reef-fish survivors. In 2017, a pilot egg survey was conducted at 17 WFS stations, and DEPM was successfully demonstrated for vermilion snapper. Fast-growing survivors were found to be individuals that underwent steady, rather than irregular, increases in trophic position as they aged. Notably, the first two objectives were achieved using a synoptic sampling effort that was coordinated among two university research vessels and six commercial fishing vessels. In 2018, the results of the pilot SHELF project were reviewed and revised by FLRACEP's program management team, resulting in continued funding for the egg-monitoring component of the program, along with funding for special studies of targeted spawning habitats that will be conducted at smaller spatial scales. The egg-monitoring program was initiated in late summer of 2019 at 49 stations on the WFS. DNA barcoding of the eggs from these samples is currently underway.

* Student presenter

Supporting Scientific Discovery and Science-Based Guidance for Restoration and Management through the Mississippi Based RESTORE Act Center of Excellence (MBRACE)

K. Darnell, L. Bernard
University of Southern Mississippi, Ocean Springs, MS

The Mississippi Based RESTORE Act Center of Excellence (MBRACE) is a consortium of Mississippi's four research universities (Jackson State University [JSU], Mississippi State University [MSU], University of Mississippi [UM], and The University of Southern Mississippi [USM]), with USM serving as the lead institution. The mission of MBRACE is to seek sound comprehensive science-and technology-based understanding of the chronic and acute stressors on the dynamic and productive waters and ecosystems of the northern Gulf of Mexico, and to facilitate sustainable use of the Gulf's important resources. Since its' designation as Mississippi's Center of Excellence in September 2016, MBRACE has funded projects totaling $2.5M focused on understanding factors that influence oyster reefs and their sustainability. MBRACE will fund additional studies beginning in 2020 that focus on water quality and oyster reef sustainability. Research funded by MBRACE contributes to scientific discovery within the Gulf of Mexico and through the Center's close partnership with State managers, provides science-based guidance for State restoration and management priorities.

Surface Currents over the Oyster Reefs in the Western Mississippi Bight Measured from MBRACE High Frequency Radar

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[1]University of Southern Mississippi, Stennis Space Center, MS, [2]FNMOC, Stennis Space Center, MS

As part of the Mississippi Based RESTORE ACT Center of Excellence (MBRACE) 25 MHz CODAR SeaSonde High Frequency Radar (HFR) stations have been operated in the western Mississippi Bight at the Silver Slipper Casino in Waveland, MS and the Pass Christian Yacht Club in Pass Christian. The stations measure hourly surface currents over a portion of the western Mississippi Sound where commercially harvested oyster reefs are located. From the two-year data set monthly surface current climatologies have been constructed, the tidal circulation has been mapped, and wind driven currents determined. There is a clear seasonality to the surface currents, winds, river input and salinity. During the study period the Bonnet Carré Spillway was opened three times, including twice in 2019, resulting in very low salinities near the Silver Slipper Casino, during which that station has very little range. In this case the range of the radar can be related to the sea surface salinity (SSS) and serves as another measure of SSS.

Alabama's Center of Excellence: Ready for Kick-Off

J. Valentine
Dauphin Island Sea Lab, Dauphin Island, AL

Alabama's coastal waters are critical to its economic vitality and environmental health, and state and local leaders face major challenges as they seek to build more resilient coastal communities. Resource managers must better understand the many complex socio-environmental interactions that exist before they can implement policies that secure Alabama's economic and environmental health. Moreover, both business and government need access to the best available scientific knowledge about our coastal resources to assess risks and take advantage of opportunities for economic development and job

growth. To provide the needed scientific knowledge, the Marine Environmental Sciences Consortium (MESC, doing business as the Dauphin Island Sea Lab), in partnership with the Mobile Bay National Estuary Program (MBNEP) and Mississippi-Alabama Sea Grant Consortium (MSALSGC), are working together to address the needs articulated by the Alabama Gulf Coast Recovery Council (AGCRC) by operating Alabama's RESTORE Act-funded Alabama Center of Excellence (ACE). MESC is comprised of a broad cross-section of academic partners with experience in disciplines pertinent to coastal sustainability, restoration, and protection; fisheries and wildlife research; sustainable economic development; and comprehensive observation, monitoring, and mapping activities. To this end, ACE will develop a competitive grants program that will support innovative research in relevant focal areas and provide data-driven recommendations to decision makers. ACE will also improve ocean observation infrastructure and policy analysis aimed at providing AGCRC and other entities with recommendations for solving coastal problems. We will avoid duplication of efforts by coordinating ACE activities with other Centers of Excellence in the Gulf with organizations such as the Gulf of Mexico University Research Collaborative.

LA-COE: Funding Applied Research to Support the Implementation of Louisiana's Coastal Master Plan

M. Baustian[1], A. Dausman[1], C. Ramachandirane[1], A. Freeman[2], D. Lindquist[2], E. Haywood[2]
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The mission of the RESTORE Act Center of Excellence for Louisiana (LA-COE) is to support research that is directly relevant to implementing Louisiana's Coastal Master Plan by administering a competitive grants program. In doing so, the LA-COE provides the appropriate management, coordination and oversight to ensure that success metrics are tracked and achieved. The LA-COE is sponsored by the State of Louisiana's Coastal Protection and Restoration Authority (CPRA) and administered by The Water Institute of the Gulf. Thus far, one request for proposals (RFP1) was released and 13 research project awards were announced in June 2017 that totaled approximately $3 million. The funded research projects (two-year duration) are currently ongoing and include collaborative, research, and graduate studentship type awards and are associated with institutions from across the state of Louisiana, such as Louisiana State University, Nicholls State University, Tulane University, University of Louisiana at Lafayette, University of New Orleans, and Louisiana Tech University. The RFP1 funded research helps address knowledge gaps listed in the Research Needs document and includes disciplines from the natural and social sciences, field observations and numerical modeling of coastal conditions and processes. Researchers provide updates to LA-COE on a quarterly basis through webinars and short reports and on an annual basis via an All Hands Meeting. Important success metrics that measure the outcomes of this program include utilization of 100 percent of funded research to improve or support CPRA's implementation of the Coastal Master Plan.

Texas OneGulf: Building Regional Resilience Across Communities, Economies and Ecosystems

K. Wowk
Texas One Gulf, Corpus Christi, TX

* Student presenter

The Gulf of Mexico (GoM) has great impact on Texas citizens during both natural and man-made disasters. These events can affect citizens' health and well-being on significant economic and environmental scales. Episodic and chronic issues such as oil spills, coastal storms, dead zones, harmful algal blooms, inadequate freshwater inflows, and coastal community resiliency must be addressed to assure the long term environmental and economic health of Texas. To assist, OneGulf is using an interdisciplinary approach to advance RESTORE disciplines while advancing the co-production of knowledge with local communities. This process requires three steps: data collection; analysis, modeling, and integration; and, solutions focused on decision support.

Improving Adaptive Management in Louisiana: Louisiana Center of Excellence Contributions

A. Dausman
The Water Institute of the Gulf, Baton Rouge, LA

Adaptive management can be defined as asystematic process to incorporate new and existing knowledge into management decisions. It is a learning based, iterative process to improve management decisions, and actions, based on increasing understanding and feedback between this learning and subsequent decision making. While a great deal of thinking has gone into the theory of adaptive management, resulting in a large number of frameworks and terminologies, affecting practical change in day to day project and program implementation has proven challenging. Even when essential lessons learned, knowledge gaps, and research results are captured, they are rarely discoverable and searchable by those making restoration decisions. The result is that adaptive management remains an informal or social process, reliant on interpersonal communications with certain individuals that hold project implementation and research knowledge.

Louisiana has a long history of coastal management and restoration actions with multiple projects implementing common approaches. Louisiana has been working towards formalizing adaptive management through DWH funding from the Louisiana Trustee Implementation Group.

This presentation will include a description of adaptive management within a typical restoration program and project cycle, with a focus on key actions for either utilizing or capturing lessons learned, decision justification, or gained knowledge. A key factor in this adaptive management cycle is how the base of knowledge, including synthesis and applied research to resolve specific uncertainties at project, regional, or coastwide scales, is integrated into the process. The LA-COE is one of the active research programs directly relevant to implementation of Louisiana's Coastal Master Plan, as well as informing the key steps of adaptive management more widely. This presentation will also include how the LA-COE research informs the adaptive management cycle, the future development of targeted RFPs that address specific management questions, and the development of a formal tracking system to document when research findings are used in decision making.

* Student presenter

Session 010: Movement Ecology and Ecosystem-Based Management in the Gulf of Mexico: Lessons Learned and Solutions for Moving Forward

Integrative Tracking of Marine Fish in the Gulf of Mexico

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Recreational and commercial fisheries in the US Gulf of Mexico (GoM) support billion-dollar fisheries but face increasing stressors, including: habitat alteration, fishing pressure, discard mortality, spatially-explicit disturbances (i.e., oil spills and red tide blooms), and climate change. To ensure sustainable fishing under these conditions will take both new data sources and new approaches to assess population health. One such method is electronic tracking data, which is expected to grow exponentially in the next ten years. Although movement has always played an important role in fisheries science, recent integrative tracking approaches and technological advances make it possible to collect data on fish movement (and fishers' movements) in a way that wasn't previously possible. Integrative tracking increases the power of individual studies by taking a systems approach to understanding how movement affects spatially-explicit productivity and vulnerability at the LME scale. It is typically a platform for synthesizing tracks from multiple animals/species (PSAT/archival tags) or sharing data across arrays (acoustic telemetry). Examples of the power of integrative tracking to inform single species stock assessments and ecosystem-based management will be presented and challenges to operationalizing this at the Gulf scale reviewed. All presenters will be asked for input into how to develop the movement ecology science needed in the Gulf of Mexico before the next oil spill.

Predictive Movement Ecology: We Need to Act Fast to Catch Up to the Problems

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Representing how mobile organisms make behavioral movement decisions is needed for predictive modeling of spatial distributions and is critical for the assessment and management of fish and fisheries. A major response to climate change will be shifts in the spatial distributions of fish and the Deepwater Horizon oil spill illustrated the challenges in quantifying exposure of mobile fish to spatially and temporal-varying stressors. Ecosystem-based Management and Ecosystem-based Fisheries Management approaches rely heavily on spatially-explicit models that must realistically simulate the distributional responses of multiple species to environmental variation. Most analyses to date either assume the new spatial distributions or migration patterns are known, can be represented very simply using environmental-ecological correlations, or can be assumed to be the same as how habitat changes. I suggest that with recent parallel advances in movement modeling and in data collection of individual trajectories and habitat utilization patterns, the time is now to develop and test predictive models of behavioral movement. These models can be then used to generate spatially-resolved predictions of the changing spatial distributions, alone or as a module within population, food web, ecosystem, and end-to-end models. It is time to better integrate movement ecology, bioenergetics, modeling, and fisheries into a single coupled modeling system where growth, mortality, and reproduction are explicitly two-way linked to movement decision-making and the resulting energetics trade-offs. Such modeling offers an opportunity for prediction of the complexity of how individuals will respond to changing environmental conditions and will lead to better understanding of the processes that underlie stressor-environment-

habitat-organism relationships. I will present some examples that illustrate the recent advances in the exploding field of movement ecology modeling and offer some ideas for a path forward to capitalize on combining the emerging measurement methods with predictive modeling approaches.

Advances in Acoustic Telemetry: Unifying Data Systems and Developing New Technical Capabilities to Increase Research Relevance and Reach

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Acoustic telemetry has proved extremely useful at providing information linking animal distributions, abundances, and survival to environmental conditions. This information is used for management, policy development, and to guide sustainable development of the ocean. In acoustic telemetry, detection of tagged animals depends on the tagged individual approaching within range (typically < 1000 m) of a receiver at a known location where the time and data of passage are recorded. Movement paths and residence times are determined through sequential detections on different receivers as the animal moves from place to place. Deploying sufficient numbers of acoustic receivers to provide movement data at the necessary temporal and spatial scales remains a key challenge beyond the means of a single investigator, especially those monitoring highly migratory animals. However, there are many active telemetry groups using compatible equipment globally that can and do detect other group's tagged animals. The Ocean Tracking Network and its partners are working on a major innovation in telemetry by developing inter-linked, compatible, internationally-certified data systems that will greatly augment the capabilities of individual investigators to cost-effectively document their animal's movements. Additional efforts are focused on developing new ways to deploy acoustic receivers by fixing them to underwater autonomous vehicles, and by adding receiver capabilities to platforms of opportunity such as offshore oil and gas infrastructure. Work is also underway to develop future classes of receivers that can be deployed from fishing and other vessels that will detect tagged animals even at relatively high speeds, and to store information from tag environmental sensors on board the tags which would be downloaded whenever the tags are in range of an acoustic receiver. These next-generation technologies could significantly increase the relevance and usefulness of acoustic telemetry.

Application of 3-D Acoustic Telemetry to Estimate Reef Fish Discard Mortality and Evaluate the Benefit of Releasing Fish with Descender Devices

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Geopositioning underwater acoustic telemetry was used to test whether weighted return-to-depth (descender) devices reduced discard mortality of red snapper (*n* = 141) and gray triggerfish (*n* = 26) captured and released at 30-60 m depths at two 15 km^2 study sites in the northern Gulf of Mexico. Cox proportional hazards modeling indicated red snapper released with descender devices had significantly lower discard mortality within the first 2 days (95% CI = 18.8% - 41.8% for descender-released vs. 44.0% - 72.4% for surface-released, unvented fish), while there was no significant effect of descender devices on discard mortality of gray triggerfish. Predation by large pelagic predators was estimated to account for 83% of red snapper and 100% of gray triggerfish discard mortality. Discard mortality due to predation has likely been overlooked in previous mark-recapture, laboratory, and enclosure studies,

suggesting cryptic population losses due to predation on discards may be underestimated for red snapper and gray triggerfish. Large-area three-dimensional positioning acoustic telemetry arrays combined with collaboration and data sharing among acoustic telemetry researchers have the potential to advance our knowledge of the processes affecting discard mortality in reef fishes and other taxa.

Effects of Oil on Mahi-Mahi (*Coryphaena hippurus*)—Using Pop-Up Satellite Archival Tags to Reveal the Movement Ecology of Wild Fish

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The 2010 Deepwater Horizon blowout released nearly five million barrels of petroleum hydrocarbons into the Gulf of Mexico (GOM) and coincided spatially and temporally with the spawning window for mahi-mahi (*Coryphaena hippurus*, "mahi" in the following). The ecology of mahi is tied to their vertical movements, migrations, and spawning, which are poorly studied and may have been affected by oil exposure in the GOM. To better understand the 3D-habitat use and reproductive ecology of wild mahi, we used pop-up satellite archival tags (PSATs) to measure acceleration, depth, temperature, and light levels for geo-location modeling. We first tagged wild-caught captive mahi with PSATs to build models to estimate spawning in wild fish using known spawning times and PSAT acceleration data. Captive-based tagging experiments were followed with the deployment of PSATs on wild control mahi in the Florida Straits (n=17) and the GOM (n=2) between 2016 and 2018. In June 2019, we conducted a second study to directly examine the effects of brief oil-exposure on the movement and reproductive ecology of mahi in the GOM. Mahi were caught, tagged with PSATs, and incubated in onboard control or oil-exposure tanks for 12-24 hours (n=26 control, n=24 oil-exposed) before release. Our results provide new insights into the movement ecology of mahi and demonstrate that: 1) wild mahi tagged in the Florida Straits and the GOM are capable of large scale migrations of up to 100 km per day; 2) vertical habitat utilization and activity are driven by sea surface temperature, lunar illumination, and diel cycles; and 3) remotely transmitted accelerometer data can be used to predict spawning in wild marine teleosts. Further, while results are still preliminary, PSAT data from oil-exposed and control mahi released in the GOM will provide data on the effects of oil exposure in wild mahi. This research was made possible by a grant from the Gulf of Mexico Research Initiative.

Spatial Scales of Stock Dynamics, Fisher Behavior, and Governance Arrangements in the Gulf of Mexico's Coastal Sport Fisheries: A Case for Place-Based Management?

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Challenges to the sustainability of the Gulf of Mexico's diverse coastal sport fisheries and their ability to provide full benefits arise from anthropogenic habitat degradation, high and increasing fishing pressure, and environmental disturbances. Current fisheries management systems are not well set up to address many of these challenges which can vary at relatively small spatial scales and often involve impacts from outside the fisheries sector. Here we synthesize insights from multiple projects that have investigated the spatial scales of stock dynamics, fisher behavior and governance arrangements in the red drum (*Sciaenops ocellatus*) and snook (*Centropomus undecimalis*) fisheries. Both stocks show within-stock spatial variation in recruitment and life history characteristics and snook in particular are sensitive to

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bay-scale environmental disturbances. A majority of coastal fishers undertake most of their fishing activities within a limited 'home range' of 30 to 50 miles and often have deep first-hand knowledge of local environmental and fisheries management issues, combined with a strong sense of place attachment and stewardship of local resources. Place-based Fisheries Forums in Southwest Florida have shown that stakeholders can engage in sustained, place-based collective action where avid recreational fishers and fishing guides are present and basic logistic and facilitation support is available. Place-based Forums addressed a broad range of fisheries-related issues including habitat and environmental concerns and increased stakeholders' understanding of diverse and sometimes adversarial positions on the issues. In the light of these results we discuss the case for and against incorporating a place-based layer into Gulf's fisheries governance system.

Red Drum Recruitment: Spatial Scales and Implications for Management

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Recruitment processes are critical for sustainable exploitation of fish and wildlife, since they determine year-class strength, harvest potential, and ultimately population dynamics. However, spatial dynamics of recruitment of many estuarine fish populations remain poorly understood. To address this, we synthesized long-term, fisheries independent monitoring data from all Gulf of Mexico U.S. states to evaluate spatial linkages in time series trends in recruitment of *Sciaenops ocellatus* (red drum). Specifically, we used recent advances in understanding of fish body-size-based recruitment dynamics to create standardized recruitment trends throughout the Gulf of Mexico. We then analyzed trends using standard correlation analyses, as well as state-of-the-art time series approaches (Empirical Dynamic Modeling, EDM) that can separate correlation from causation and infer the extent to which recruitment in certain estuaries could depend on recruitment in others. Surprisingly, we found spatial proximity did not consistently drive spatial patterns—i.e. more proximate estuaries may not share recruitment patterns. The inference that red drum recruitment may be regulated at finer, estuary-specific spatial scales has implications for fisheries management and estuary restoration. We discuss these implications and note how approaches here may be applied to other estuary species.

Movements and Habitat Use Patterns of Whale Sharks (*Rhincodon typus*) Tagged in the Northern Gulf of Mexico

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Whale sharks (*Rhincodon typus*) are typically solitary animals; however, in the northern Gulf of Mexico they form large aggregations at continental shelf-edge banks during summer. While there is an understanding of their seasonal distribution in the region, knowledge of movements once they leave aggregation sites is limited. Here we report the movements of 42 whale sharks satellite tagged within the Gulf of Mexico from 2008-2015. Most sharks (66%) were tagged at Ewing Bank, an aggregation site off the coast of Louisiana. A Hidden Markov Model (HMM) was applied to tag geolocation data to

generate most probable tracks and used to analyze seasonal trends in movements. Sharks ranged from 4.5-12.0 m total length (*n* = 42 mean = 7.8 ± 0.3 m SE) with a male to female ratio of 5:1. Whale shark track duration ranged from 3 to 366 days (mean = 97 days ± 15 SE). All individuals remained within the Gulf of Mexico, with three sharks being tracked over one year. Overall, whale sharks utilized continental shelf edge and offshore waters, spending little time in neritic waters. In general, shark movements appeared random after tagging; however, there was a net movement southward during cooler months. There was no direct connection to a known whale shark aggregation site off the Yucatan, but several sharks migrated to the southwest Gulf of Mexico during fall and winter, suggesting this region could contain an aggregation site. The broad-scale GOM-wide movements observed in this study demonstrate multi-national, cooperative efforts will be needed to improve management of whale sharks in the western North Atlantic Ocean.

Seasonal Movement Patterns and Habitat Use of Blue Marlin and White Marlin in the Gulf of Mexico

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Highly migratory species (HMS), such as billfishes, tunas, and sharks are important predators in open ocean ecosystems, but their complex migratory behaviors often complicate their conservation and management. Time series data collected before (2007-2009) and immediately after (2010) the Deepwater Horizon Oil Spill documented potential shifts in adult distribution and declines in larval abundance for several billfish species associated with impacted areas of the northern Gulf of Mexico (GOM). Unfortunately, migratory patterns, habitat use, and residency of billfish in the northern Gulf of Mexico are poorly understood, limiting our ability to assess the impacts of oil spills and other environmental disasters on essential habitats and migratory pathways. In response, a multiyear satellite tagging study focused on long-term deployments was conducted on blue marlin and white marlin in the northern Gulf of Mexico to address these questions. Individual blue and white marlin were captured in recreational fisheries in the northern Gulf of Mexico offshore of Louisiana and Texas from 2008-2013 and fitted with satellite tags programmed for 1-year deployments. Tagged individuals of both blue and white marlin displayed a high degree of residency within the GOM, with a greater proportion of white marlin emigrating from the basin. Horizontal and vertical movement patterns for both species were linked to environmental conditions to identify and characterize essential habitats within the basin. Results provide critical information on billfish habitat in the GOM needed for ecosystem-based management plans.

The RAFOS Ocean Acoustic Monitoring (ROAM) Tag: A New Satellite Tag for Accurate Tracking of Pelagic Fishes in the Open Ocean

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The logistic challenges of tracking fish in a vast, largely opaque ocean have plagued marine ecologists for decades. Although recent advances in satellite telemetry techniques have yielded remarkable insight into vertical behavior and large-scale movements of marine species, our understanding of most aspects

of pelagic fish ecology remains constrained by our inability to accurately geolocate and track individuals. Current light-level geolocation techniques generally exhibit poor accuracy (+/- 100-200 km) even under best-case situations when movements are confined to shallow water (< 100 m) during daytime hours. The lack of accuracy of has, in turn, meant a paucity of mechanistic studies addressing the influence of mesoscale oceanographic features on at-sea habitat use by open ocean fishes. We are developing a new satellite archival tag that aims to provide accurate geolocations of fish throughout the water column across ocean basins. The **R**AFOS **O**cean **A**coustic **M**onitoring (ROAM) tag miniaturizes and re-purposes a proven oceanographic technology used to track subsurface drifters into a small animal-borne tag. The ROAM tag promises +/- 5 km accuracy using an onboard hydrophone and an array of moored low-frequency sound sources. Archival and satellite-enabled are tags currently being designed in collaboration with commercial tag companies. We hope that ROAM tags will provide new understanding of the links between open ocean features and fish movements, connections between the surface and deep ocean, and data needed for dynamic fisheries management in the future.

Moving On: An Evaluation of the Contribution of Movement Ecology-Related Research to Implementing Ecosystem-Based Fisheries Management in the Gulf of Mexico

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Ecosystem-based fisheries management (EBFM) has become the national and international policy goal for managing large marine ecosystems in recent decades. The need for an ecosystem approach to (fisheries) management has been well established, and a number of scientific tools have been developed to aid in the transition from single-species management to EBFM. Operationalizing this new management paradigm, however, remains a challenge. To help realize EBFM in the U.S., NOAA Fisheries has developed regional EBFM implementation plans. The Gulf of Mexico implementation plan describes progress made and research needs in the following seven theme areas: advancing stock assessments, tracking ecosystem trends, climate change, multi-species interactions, spatial scales and connectivity, habitat conservation, and human dimensions. In this study, we provide an overview for how movement ecology matters to addressing aspects of these theme areas and how movement knowledge gaps are hindering implementation of EBFM. We discuss the contribution of past and ongoing movement-related research to closing these knowledge gaps, identify where current approaches are falling short of addressing the need, and offer potential solutions for how movement-related research in the Gulf of Mexico can better support the path to EBFM moving forward.

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Session 011: Understanding the Drivers of Biological Patterns in the Pelagic Seascape of the Gulf of Mexico

Using a Coupled Ecosystem Modelling Approach to Evaluate Effects of Reductions in Nutrients and Hypoxia on Living Marine Resources

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Expansive hypoxia in the Northern Gulf of Mexico (NGOMEX) will continue to affect living resources, but the magnitude, predictability and even the direction of these effects are not well quantified. To evaluate effects of hypoxia on fish and fisheries, an Ecospace model was developed representing 60 groups of the NGOMEX food web. The model is coupled to a physical-biological model from which it receives dissolved oxygen (DO) and Chlorophyll *a* concentrations. After initial simulations emphasized the importance of (bottom-up) food web dynamics when evaluating effects of nutrient loading and hypoxia on NGOMEX living resources, our current focus is on simulating recommended nutrient reduction scenarios. The coupled model was calibrated using existing conditions from 2000-2016, after which scenarios for short-term and long-term hypoxia reduction were explored: The short-term goal of a 20% reduction in N and P load by 2025, and the long-term goal of reducing the hypoxic area to 5000 km^2 by 2035. Future modifications include the integration of 3D production potential models for selected species. The overarching goal of the coupled modelling approach is improving the capability to assess effects of alternative management strategies on ecosystem function, living resources, and fisheries revenue.

Impact of Diurnal Sea Breeze on the Ecological and Biogeochemical Processes in Mississippi Sound

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A circulation model based on the Coupled-Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modeling System, with coupled biogeochemical module, has been implemented for the Mississippi Bight and the adjacent estuarine waters. The model is forced with observed riverine inflows as well as hourly winds that resolve the diurnal sea breeze and passage of synoptic weather events. Highly resolved exchanges between nearshore lagoonal estuarine waters and the adjacent continental shelf provide new insight into how hydrologic and atmospheric forcing influences ecosystem function in the highly productive waters of the Mississippi Sound region of the Northern Gulf of Mexico. Twin experiments, implemented through application of a low-passed temporally filtered realization of the high-resolution atmospheric forcing, are performed to examine how the region's prevalent diurnal sea breeze impacts estuarine exchange, water quality, planktonic and larval advection, and hypoxia onset and intensity. Detailed insight into how shore to shelf connectivity influences these processes is revealed through dye and drifter release experiments. The along-track environmental conditions of the circulation model drifters are input to the Trophic Simulation model (TroSim) which is used to develop a habitat suitability index (HSI) to quantify oyster larvae condition from spawning to settlement. The influence of the diurnal sea breeze on advection pathways and residence times that control both larval and pollutant

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propagation will be presented. The HSI guidance obtained through this synthesis of modeling applications is providing critical insight used to inform resource management decisions relating to restoration of current oyster reefs and strategic investment with the objective to establish new reefs.

Are Pelagic Fish Embryos Really Floating at the Sea Surface?

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Pelagic fish embryos are generally assumed to be floating at or near the surface where external stressors are the highest. Yet, their actual fine scale vertical distribution, and therefore their exposure to surface stressors (e.g. heat and ultraviolet (UV) radiation) has rarely been tested. We focused on the mahi (*Coryphaena hippurus*), a highly valuable species present in the Gulf of Mexico (GoM) for which embryos have been demonstrated to display UV avoidance in laboratory experiments. We then addressed the ecological relevance of this seemingly adaptive response by developing a module for the Connectivity Modeling System (CMS, an open-source particle tracking model) to estimate the dose of solar radiations embryos receive while moving in the ocean. Calculations are based on the intensity of the surface irradiance, the coefficient of absorption of the wavelength considered, and the embryos' depth at each Lagrangian time step. In the model, embryos were released throughout the year, above the thermocline (0-30 m depth) based on adult spawning behavior in the GoM, and the laboratory hourly measurements of terminal velocity were used to determine embryo buoyancy through time. Each virtual embryo was tracked for 48 h, the maximum time to hatch based on the minimum surface water temperature in the GoM (*ca*. 20°C). The model shows that embryos drifting passively at the surface would experience sublethal to lethal UV doses. In contrast, considering the empirically-measured specific gravity in response to UV exposure enabled embryos to significantly reduce UV dose, even in the clear waters of the GoM. Our results therefore show that mahi embryos are unlikely to drift at the surface. Under climate change scenarios, combined knowledge of the very fine scale vertical distribution of embryos and solar radiation variability will become even more critical to understand the patterns of dispersal and survival. Funded by the RECOVER grant from The Gulf of Mexico Research Initiative.

Pelagic Habitat Partitioning of Late-Larval and Juvenile Tuna in the Oceanic Gulf of Mexico

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Tunas are ecologically important in pelagic ecosystems, but due to their high economic value, most species are overfished. Declines in fishery landings of large-bodied tuna species in the Gulf are expected to increase fishing pressures on unmanaged, small-bodied tuna species, whose life history traits are less known. While predicting spawning stocks and recruitment success typically focuses on estimates of larval abundances, juveniles may provide a better estimate of future adult stock sizes, as they are more likely to survive to adulthood. However, distributional studies on juveniles are rare, leading to a gap in our understanding of tuna ecology. In the present study, tuna early life stages were collected across the Gulf between 2010-2011 (NRDA ONSAP) and between 2015-2018 (DEEPEND). The size class examined in this study, representing large larvae and small juveniles, is larger than that of previous larval tuna studies in the Gulf. In total, 11 of the 16 scombrid species inhabiting the Gulf were collected, with small-bodied tuna species (*Euthynnus alletteratus* [little tunny] and *Thunnus atlanticus* [blackfin tuna])

* Student presenter

dominating the assemblage. Generalized additive models and distributional plots indicated that early life stages of *E. alletteratus* were associated with productive continental shelf/slope environments (low salinity, high chlorophyll *a* concentrations, nearer to shelf break), while *T. atlanticus* juveniles were associated with oligotrophic habitats (high salinity, low chlorophyll *a* concentrations, further from shelf break). These results demonstrate that over a broad spatiotemporal domain, large larvae and juvenile tunas partition pelagic habitat on the mesoscale in addition to the temporal partitioning of adult spawning. These factors are important for spatially and temporally explicit modeling aimed at predicting tuna stock sizes, and for assessing the spatial vulnerability of small tunas to oil spill events.

The Interannual Variability of *Sargassum* in the Gulf of Mexico and the Driving Forces

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Pelagic *Sargassum* is critical marine habitat for various marine fauna in the Gulf of Mexico (GOM). Recent efforts have demonstrated the capacity of satellite observations to quantify the large-scale *Sargassum* distributions from space. The goals of this research are to understand the driving factors that lead to these past changes and to develop long-term prediction capacities on the future *Sargassum* abundance variations. To achieve these goals, we first analyzed the seasonality and inter-annual variations of *Sargassum* abundance in the GOM using twenty years' MODIS observations and observed strong inter-annual variability in the past twenty years. These monthly mean *Sargassum* distributions were then analyzed with several environmental variables, including the sea surface temperature, sea surface salinity, the light availability, and chlorophyll concentrations, etc. In these analyses, the environmental products were averaged to monthly means over the *Sargassum*-presented regions. The nutrient availability will be investigated from the Mississippi Rivers dynamics (the river discharge and nutrient content), the eddy activities, as well as from the indirect evidence of chlorophyll anomalies. With these data, we are expected to build a *Sargassum* abundance model to understand the environmental conditions driving the past variations and to prepare for the future blooms.

Exploring the Association of Gray Triggerfish (*Balistes capriscus*) with *Sargassum* Habitat in the Gulf of Mexico and Its Implication on Recruitment

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One of the most challenging goals when developing fisheries assessment models is to understand and predict recruitment variability. The challenge is to examine the processes affecting the abundance of the early life stages of fish and determine impacts to recruitment. In the Gulf of Mexico (GOM), one of the most abundant species present in *Sargassum* is the gray triggerfish. Although present during most of the year in the GOM, storms, currents, and other oceanographic factors constantly transport *Sargassum* habitat and limits its time over one area. Therefore, *Sargassum* provides a mobile and ephemeral nursery habitat which may affect year class strength and recruitment of gray triggerfish depending on the amount, temporal length, and distribution in the northern Gulf of Mexico. Two yearly *Sargassum* habit indices were derived using data from ship-board based sampling and remote sensing products. The first set of indices used ship-based measurements of *Sargassum* collected on Southeast Area Monitoring

and Assessment Program (SEAMAP) ichthyoplankton surveys. The index was generated utilizing a delta-log normal model which examined the effects of geographic region, water depth, wind speed, and wind direction on the annual estimates. Daily mean *Sargassum* biomass (0.5 degree by 0.5 degree grid) measured from remote sensing products during the corresponding ichthyoplankton surveys were utilized to derive a second habitat indices. Recruitment indices for age-0 gray triggerfish collected in SEAMAP trawl surveys were developed utilizing a delta-log normal model. Correlation analysis between the two habitat indices and gray triggerfish age-0 indices were carried out to examine the influence *Sargassum* has on the recruitment of gray triggerfish in the GOM. An established correlation between the *Sargassum* and age-0 gray triggerfish recruitment would provide much needed information to help account for annual variability in estimates of stock abundance.

Modeling the Deep: A Vertically Resolved, End-to-End ECOTRAN Model of the Oceanic Gulf of Mexico

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The importance of connectivity between the epipelagic, mesopelagic, and bathypelagic depth zones of the oceanic Gulf of Mexico is not well understood and greatly affects our ability to predict the impacts of perturbations to pelagic ecosystems. As evidenced by the Deepwater Horizon Oil Spill (DWHOS), the absence of baseline data—particularly in mesopelagic and bathypelagic depth zones—has contributed to the challenges of understanding ecosystem dynamics in the Gulf of Mexico. By applying an ECOTRAN end-to-end modeling approach, we have developed the Vertically-Integrated Oceanic GoMex ecological model. The objective of this model is to improve our knowledge and understanding of the ecosystem processes in the Gulf of Mexico. Our model estimates trophic energy transfer within and between the epipelagic, mesopelagic, and bathypelagic habitats by incorporating animal vertical migrations, passive particle sinking, and vertical mixing. Model parameterization incorporates observations of deep-pelagic molluscs, crustaceans, and mesopelagic fishes from the DEEPEND Consortium, observations of zooplankton from post-DWHOS Natural Resource Damage Assessment (NRDA) sampling, large pelagic fishes abundance and diet data compiled for a Gulf of Mexico ATLANTIS model (C. Ainsworth, U South Florida), and our own larval fish stomach content and stable isotope analyses. With this novel oceanic food web model, we will quantify trophic energy transfer within and between the Gulf of Mexico's oceanic depth zones. Static and dynamic scenario analysis will allow us to simulate the ecosystem-level effects and functional group sensitivity to climate change-related ocean warming, changes in fishery harvest rates, and perturbations such as oil spills at depths exceeding 1000 m.

Evaluating the Role of Trophic Vertical Exchange Processes Within the Oceanic Gulf of Mexico: GoMex-ECOTRAN

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Understanding of Gulf of Mexico ocean ecosystem dynamics is hampered by lack of quantitative estimates of connectivity between epipelagic, mesopelagic, and bathypelagic depth zones. Pathways of

vertical connectivity include migration of nekton and the sinking of detritus to be recycled at depth via microbial oxidation or consumption by zooplankton and nekton. In this GoMRI-sponsored research, we aim to quantify trophic connectivity within and between depth zones and produce a vertically resolved ecosystem model to estimate how perturbations to vertical exchange processes and to food web structure propagate throughout the water column. We apply the ECOTRAN end-to-end (physics-to-fisheries) model platform. Previous ECOTRAN analyses of diverse coastal ecosystems have shown that productivity and response to perturbation are highly dependent upon rates of nutrient and detritus recycling. GoMRI DEEPEND consortium observations of the deep-pelagic community, our own stomach content and stable isotope analyses, and independent estimates of the oceanic f-ratio are used to constrain food web structures, required subsidies of epipelagic production to mesopelagic and bathypelagic depth zones, and detritus recycling rates. In the analyses presented here, we use simple, idealized food webs within each depth zone to estimate the effects of alternate rates of detritus subsidies and export, detritus recycling, and trophic exchange via diel migration of nekton. Scenario metrics include: differences in production rates, response times following perturbations to epipelagic primary production, and the rate and intensity at which perturbations to consumer abundances within individual depth zones propagate throughout the water column. These idealized simulations are informative of error associated with the uncertainty in the strength of the various vertical connection pathways and rates of detritus recycling.

Environmental Drivers Structuring Horizontal and Vertical Distributions of Mesopelagic Larval Fishes in the Northern Gulf of Mexico

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Surveys of larval fish in the northern Gulf of Mexico (nGOM) rarely sample beyond the epipelagic (< 200 m), despite the essential contributions of mesopelagic (200 - 1000 m) larval fishes to pelagic food webs and oceanic carbon cycling. Here, we provide the first large-scale characterization of mesopelagic larval fish assemblages in the nGOM, utilizing samples collected during the Deepwater Horizon oil spill Natural Resource Damage Assessment on cruises targeting deep-pelagic plankton. These data contain ~150,000 identified ichthyoplankton specimens, encompassing six plankton cruises conducted in 2010 and 2011, sampling 48 stations in the nGOM with depth-discrete net tows (> 1000 m). We examined patterns in horizontal and vertical assemblage structure using multivariate regression trees, and applied generalized additive models to assess the environmental drivers of vertical distribution in the dominant mesopelagic families (Myctophidae, Gonostomatidae, Sternoptychidae, Phosichthyidae). The early life stages of mesopelagic fish taxa were common in the epipelagic during both day and night, and vertical migration was found to be strongly size-dependent, with movement into mesopelagic waters and patterns of diel movement not becoming apparent until individuals reached > 10 mm. Larval fish assemblage structure was largely explained by depth and temperature, with limited variation in communities associated with mesopelagic depths across the nGOM. However, mesopelagic taxa contributed to structuring within the epipelagic, with patterns of distribution further influenced by stratification and season. These analyses aim to fill gaps in knowledge about an understudied group of organisms that play a large role in the transfer of energy from mesopelagic to epipelagic food webs. Our results will be incorporated into a vertically-resolved nGOM ecosystem model to further examine the contributions of deep-pelagic functional groups to oceanic ecosystem dynamics.

* Student presenter

Temporal Changes in the Micronektonic Crustacean Assemblage in the Gulf of Mexico Since the Deepwater Horizon Oil Spill

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This talk will present data from a series of cruises conducted in 2011 (ONSAP), one year after the Deepwater Horizon oil spill, and cruises conducted in 2015-2017 (DEEPEND), five to seven years after the spill. This analysis includes the dominant taxa, in terms of both abundance and biomass, that make up the micronektonic crustacean assemblage in this area - the Euphausiacea (families Euphausiidae and Bentheuphausiidae) and the Decapoda (families Benthesicymidae, Sergestidae, Pandalidae and Oplophoridae). There has been a dramatic decrease in abundance for the assemblage as a whole between the ONSAP and DEEPEND cruises, with the Euphausiacea declining by 70-80% and the Decapoda declining by ~50%. There are no pre-spill data with which to compare these numbers to demonstrate a cause and effect, but the magnitude of the decline cannot be explained by measured natural variability. There are differences in vulnerabilities of the various families as indicated by differences in the magnitude of their declines, and differences in life histories and food preferences will be discussed as possible explanations for these observations.

To Stay or Go? Understanding the Behavioral Drivers of Diel Vertical Migration in Deep-Living Fishes

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particularly with regards to the movement of carbon and energy via the biological pump. The characteristic pattern of diel vertical migration (DVM) conducted by deep-living pelagic fauna involves remaining at mesopelagic depths (c. 200 - 1000 m) through daylight hours, then migrating to epipelagic depths (0 - 200 m) at night to feed. However, there is considerable variability in DVM patterns amongst migrants, with some species migrating every night (“obligate migrants”), and others migrating less frequently (“partial migrants”). While DVM amongst obligate migrants is likely driven by inherent biological requirements (e.g., circadian rhythms or energetic necessity), partial migrants appear to have more choice over whether or not to migrate. Here, we analyse an extensive, spatially and temporally explicit collection of >250,000 mesopelagic fishes from the northern Gulf of Mexico (2011 - 2017) to demonstrate a novel statistical method for quantifying DVM behavioural patterns within the 55 most-abundant species, and to examine biological (e.g., ontogenetic) and environmental (e.g., mesoscale hydrography) patterns of DVM behaviours within those species identified as “partial migrants.” We anticipate that the findings from this study will provide valuable insight into the behavioural rules governing DVM amongst mesopelagic fishes, and improving predictions of carbon flux through this poorly-known, but critical, component of the biological pump. These findings should also prove useful for resource management (modelling the connectivity of deep-living and shallower-living, commercially managed species) and future oil spill response and assessment (quantifying the active movement of the pelagic fauna through subsurface oil/dispersant plumes).

* Student presenter

Summer Hypoxia, Layering, and Dynamic Physical Features Alter Fine-Scale Abundances of Mesozooplankton and Marine Snow

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Summer stratification in the northern Gulf of Mexico (nGOM) shelf ecosystem generates habitat heterogeneity for planktonic organisms. Bottom water hypoxia (dissolved O_2 < 2.0 mg L^{-1}) and thin layers of marine snow and plankton that form at the hypoxic interface are widespread phenomena, yet the response of different zooplankton taxa and size classes is poorly characterized due to sampling limitations (e.g., coarse spatial resolution and taxonomic biases). The detailed distributions surrounding these features are necessary to understand plankton exposure rates to pollutants, such as spilled oil, and interactions within the plankton community that may cascade up to higher trophic levels. To address this knowledge gap, we towed a plankton imaging system through a shallow shelf region (~25 m water column) in the western Mississippi Bight in July 2016. Approximately half of the water column was hypoxic. The larval fish community was dominated by engraulids that aggregated near the surface during the day and moved to the mid water column during the night, with few individual larvae crossing into the hypoxic region. Shrimp tended to move in the opposite direction, aggregating within the hypoxic region during the day and moving up in the water column at night. Large marine snow particles tended to aggregate at the hypoxic interface, which is a general feature of the summer shelf waters, even in regions that are not hypoxic. During the night, we sampled an internal wave packet that was propagating northward and shifted the particle size distribution towards smaller sizes, which also corresponded to anomalously high abundances of larval fishes and shrimp. These results demonstrate that complex biological and physical interactions occurring on fine spatiotemporal scales must be taken into consideration for making predictions about ecological impacts of hypoxia on the nGOM shelf.

Session 012: Transport, Dispersal, and Connectivity in the Gulf of Mexico: Patterns, Processes, and Implications

Lagrangian Observations of Transport, Dispersal, and Connectivity Patterns Across Scales: A GOMRI Legacy

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Transport and dispersal processes in the Gulf of Mexico operate over space scales of meters to hundreds of kilometers and time scales from minutes to weeks. Moreover, they are anisotropic and inhomogeneous. Quantifying these processes comprehensively requires both new observational methods and new analysis methods that cover the enormous range of scales and account for anisotropy and inhomogeneity. GoMRI-supported field experiments have shown that massive deployments of Lagrangian probes can address the challenge of disparate spatial and temporal scales with different Lagrangian data sets targeting different scales. However, large Lagrangian data sets are new in

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oceanography. Thus, appropriate analysis paradigms are required to reveal transport pathways and dispersal and connectivity patterns. Two paradigms are discussed here: adaptations of dynamical systems theory and an extension of structure functions from classical turbulence theory to Lagrangian data. Application these methodologies to Lagrangian data combined with Eulerian observations from ships and satellites yields a new and unprecedented picture of transport and dispersal patterns in the Gulf of Mexico.

Influence of the Loop Current on the Connectivity and the Main Pathways of the Gulf of Mexico

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Using trajectories from drifters and floats datasets, we construct geographies of the Lagrangian circulation in the Gulf of Mexico at the surface and depth, respectively. A Lagrangian geography is composed of weakly communicating basins of attraction for almost invariant forward attracting sets revealed from a spectral analysis of discrete transfer operators (transition matrices) computed using the trajectory datasets. From the resulting geography, we will assess connectivity and forecast density evolution (such as oil particles, plastic debris and larvae). To evaluate seasonal variations of the Gulf of Mexico, we subset the datasets in function of the Loop Current state using a time series of its zonal and meridional extension (defined by the northernmost and westernmost positions). We then assess how the Loop Current extension affects the connectivity of regions near the Yucatan channel, the main pathways across the Gulf of Mexico and the forecast of oil spill and algae bloom such as red tide or sargassum.

Can Neural Networks Learn Realistic Ocean Trajectories?

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Artificial neural networks (ANNs) may be futuristic tools for predicting maritime oil dispersion, but only if they are capable of learning realistic particle trajectories in a turbulent ocean. We explore the predictability of 2D trajectories from a variety of flow regimes. After conducting proof-of-concept experiments consisting of simulated flows of increasing complexity, we generate realistic particle trajectories using modeled flow fields from a regional ocean general circulation model for the Gulf of Mexico. We chose as a test case of interacting scales of motion a mesoscale eddy surrounded by submesoscale dynamics. ANNs are developed to predict particles' future velocities based on their past observations. A rolling window training approach enables the ANNs to be continuously updated according to the most recent available data. ANNs are trained in two ways to predict velocity 6 hours in the future: first, a so-called "one-to-one ANN" uses only a particle's most recently observed velocity as input, and second, a "time series ANN" uses the past 24 hours' worth of velocity observations as input. We compare ANN output to rudimentary persistence predictions within a 24-hour forecast window and find that, for realistic trajectories, one-to-one networks offer little to no improvement over persistence while time series ANN forecast errors are at least half those of persistence. We complete the exploration by training time series ANNs on observed drifter trajectories from the Grand LAgrangian Deployment (GLAD) in the northern Gulf of Mexico. These networks again offer considerable improvement over persistence forecasts and the results imply that observed trajectories do contain some inherent

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learnability. By always testing the simplest possible ANN, our networks have much room for further development and performance enhancement. Our results suggest that ANNs are a promising new data-driven approach to forecasting material transport in the ocean.

Advances in Oil Transport and Fate Modeling for Deep-Sea Oil Spills Using the Oil Application of the Connectivity Modeling System (Oil-CMS)

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Modeling of large-scale oil spills resulting from deep-sea blowouts is particularly complex due to a high number of bio-chemo-geophysical interactions. Following the Deepwater Horizon accident in 2010, the largest oil spill disaster in the U.S. history, several new processes and interactions have been discovered. To improve our understanding of the oil transport, fate, and changes in mass-conserved petroleum hydrocarbons concentrations in 3-dimensions, such new scientific discoveries have to be implemented into numerical models. Here we report several novel capabilities of the oil application of the Lagrangian probabilistic framework of the Connectivity Modeling System (oil-CMS) developed over the past decade. Firstly, we improved the representativity of the oil droplet size distribution (DSD), one of the most critical parameters in oil transport and fate is the that drives the rising of the oil in the water column. We show that simulating DSD by selecting individual droplet sizes at random from a log-normal distribution changes significantly the amount of oil reaching the surface, yet showing high concentrations in a subsea oil plume that exhibits rotation. Secondly, we present a new implementation of a degassing parameterization in a two-phase approach with liquid oil and methane gas in the same droplet, and show the results with a log-normal distribution of the droplets at the release time similar to that in the classic multi-fraction droplet approach. Thirdly, the present the parameterization of pressure-dependent methane dissolution, including a minimum droplet diameter at which both degassing and dissolution processes are considered and a maximum diameter at which the degassing process dominates. With this series of experiments, we discuss the recent improvements in predicting the resulting oil concentrations, surface and sub-surface oil mass distributions, and droplet size evolution thanks to the implementation of these new modules. This research was made possible by a grant from the Gulf of Mexico Research Initiative (GoMRI), CIMAGE III.

Modeling the Effects of Mississippi River Diversions on Estuarine-Shelf Connectivity and Transport Pathways in the North-Central Gulf of Mexico

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River systems worldwide are increasingly influenced by flood control measures and river diversion operations. Yet, surprisingly little is known about the effects of river management on estuarine-shelf connectivity and associated nutrient and pollutant transport pathways. Freshwater diversions on the Lower Mississippi River 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 river diversion projects are being considered that would divert a third of the Lower Mississippi River into deltaic Louisiana estuaries. The effects of existing and proposed river diversions on nutrient and pollutant transport pathways were investigated using a high-resolution, three-dimensional, coupled hydrodynamic-

biogeochemical model (FVCOM-WASP-LATEX). The numerical model domain covers most of the Alabama-Mississippi-Louisiana-Texas continental shelf and includes high resolution (on the order of 20 meters) nested grids in Barataria and Breton Sound estuaries. The model was driven by tidal and subtidal forcing at the open Gulf of Mexico boundary, freshwater and nutrient loads from rivers and river diversions, and surface wind stress. A number of different diversion scenarios were assessed, including a concurrent operation of six river diversions with a combined flow of 6,500 cubic meters per second. Numerical modeling results indicate that, depending on the scenario considered, the proposed large-scale river diversions would have the potential to strongly influence estuarine-shelf exchanges and associated nutrient and pollutant transport pathways in the north-central Gulf of Mexico.

In-situ Measurements of Circulation Features Influencing Cross-Shelf Transport Around Northwest Cuba

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For decades, the ocean circulation near Cuba was under-studied, as almost no in situ observations were available to the international community. With a historical change in US-Cuba collaborations in 2015-2016, unprecedented research cruises took place in Cuban waters, during which physical and biological data were collected. Here, we present results from three NOAA cruises that took place along northwest Cuba in May 2015, May 2016, and May 2017, which provide detailed information about coastal processes and shelf exchanges in the southeastern Gulf of Mexico. The 2016 cruise sampled through a pair of mesoscale eddies: first, an anticyclonic eddy along the northern coast of Cuba that is typical of Cuba ANticyclones (CubAN), which were identified only recently; second, a cyclonic eddy just west of the anticyclonic one. Together, these eddies, under upwelling-favorable wind conditions, allowed the offshore advection of coastal waters, visible by satellite ocean color. Similar eddy features were also sampled with a Lagrangian surface drifter. Along the western tip of Cuba, all three cruises sampled shelf-break processes that appear to be strongly dependent on the Loop Current state. When the Loop Current is retracted, the offshore export of coastal waters is limited, and these waters can rapidly be transported to the Straits of Florida. When the Loop Current is extended, coastal waters can extend far offshore and be entrained with the Loop Current as it flows into the Gulf interior. Coastal processes along northwest Cuba thus offer new insights on connectivity pathways between Cuba and the rest of the Gulf. They are especially relevant to biological connectivity, as northwest Cuba hosts rich ecosystems and important Marine Protected Areas, and to the transport of pollutants, since this is also a region of potential oil exploration.

Cuban Eddy and Upwelling Processes Influencing Regional Gulf Stream Variability in the Gulf of Mexico

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The meandering of the Gulf Stream through the Straits of Florida is associated with eddy activity to the north (along the Florida Keys) and the south (along the Cuban coast). This study focuses on recently identified processes along the Cuban coast, namely anticyclonic eddies (Cuban ANticyclones: CubANs)

* Student presenter

and cyclonic activity characterized by cold-core eddies (cyclones) and coastal upwelling that enhances them. High-resolution, data-assimilated simulations, in tandem with a variety of observational data, are used during a period of 8 years (2010-2017) to describe the characteristics of the evolution of CubANs and their contribution to Gulf Stream variability and associated coastal to offshore interactions. It is shown that these processes are an important factor for the evolution of the Loop Current/Florida Current (LC/FC) system, the regional Gulf Stream branches. In particular, the Gulf Stream meandering inside the Straits (that is manifested as the position of the FC branch) is strongly related to CubANs either inside the retracted (closer to the Cuban coast) LC branch (CubAN "A") or outside the LC as independent eddies (CubAN "B"). Coastal upwelling processes may enhance the cyclonic activity along the Cuban coast and together with the anticyclonic eddies (CubANs) form a counter-rotating eddy dipole (cyclone and "B" anticyclone). The dipole-induced northward currents are the main mechanism of the offshore pathways of upwelled coastal waters. The long-term fate of these waters is strongly related to the meandering of the Gulf Stream/FC, as it moves eastward to northward, and the direct influence of the CubAN anticyclones that create opposing currents, which delay the export of Cuban coastal waters toward the eastern Florida shelf and the Atlantic Ocean along the Gulf Stream main front. These findings are important for connectivity pathways between U.S. and Cuban marine protected areas and between U.S. coasts and the main Cuban area of oil exploration.

Wind-Based Estimation of Ocean Surface Currents from Massive Clusters of Drifters in the Gulf of Mexico

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This study explores the contribution of the wind and waves on the entrainment of the 1000 surface CARTHE drifters released in the Langrangian Submesoscale Experiment (LASER) of winter 2016. The repeated storms resulting in 40% drifters losing their drogue allowed incidentally to document both the near surface (5 cm) and deeper (60 cm) flows, which are relevant to transport of oil spills, as well as marine debris. The surface Lagrangian current prediction is obtained by combining a state-of-the-art ocean forecast model (NCOM) with wind and wave data from a coupled atmosphere-wave-ocean model (UWIN-CM), via Lagrangian wind-based parameterizations. The parameterization is based either on Ekman dynamics, or direct addition of a fraction of the surface wind. The optimal performance of the wind-based parameterizations infer the wind and wave contribution in surface transport in the Gulf of Mexico under LASER weather conditions.

It is found that incorporation of wind and wave data into the ocean circulation model can lead to major prediction improvement, by reducing the average two-day separation from the modeled and real LASER trajectories by a factor ranging from 1.4 to 4.9. This is a significant improvement for applications, where a rapid deployment of assets is needed, such as oil spill response, or other tracking problems.

Drifter-Derived, Submesoscale Velocity Gradient Statistics in the DeSoto Canyon in Summer and Winter

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Details of the statistics of near-surface horizontal divergence, strain and vertical vorticity are obtained from four drifter release experiments conducted in the Northern Gulf Mexico during Summer 2012 and Winter 2016. The data density provided by the near-simultaneous deployments of large number of surface drifters in each case allows estimates of the scale dependence of velocity gradients in the submesoscale range. The robustness of the triplet-based estimates is confirmed by direct comparisons with available Eulerian measures of the surface velocity obtained from ship-based X-band radar surveys. Surveys of the near-surface vertical density structure show both distinct differences and some similarities between the four cases. The winter launches were both deployed above a relatively deep mixed layer, one in a region with nearly horizontally homogeneous density structure and the second in a region of strong surface density gradients associated with filaments of fresh MRO water. The summer launches occurred in a shallow mixed layer with one launched across a frontal jet separating regions of horizontally homogeneous density and the second, similar to one winter launch, in a region of relatively strong, submesoscale horizontal density gradients produced by shallow lenses of cold, fresh water. While both the magnitude of velocity fluctuations, and the widths of the distributions of surface vorticity and (especially) divergence, are higher in the winter observations, in terms of the structure of surface kinematic properties, differences due to spatial inhomogeneities between same-season launches are larger than seasonal differences. Unlike the eastern canyon launches where strain dominates vorticity distributions that are not heavily skewed, the launches in MRO water show strongly skewed vorticity distributions and large probabilities of observing cyclonic eddies where vorticity dominates strain.

Transport and Landfall of Marine Oil Spills: Laboratory and Field Observations

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The dynamics of crude oil and different surface ocean drifters were compared to study the physical processes that govern the transport and landfall of marine oil spills. In a wave-tank experiment, drifters with drogue did not follow oil slicks. However, patches of undrogued drifters and thin bamboo plates did spread at the same rate and in the same direction as the crude oil slicks. Then, the trajectories of the Deepwater Horizon oil spill and 1300 GPS-drifters released near the spill source were investigated using transition matrices. Undrogued drifters were transported twice as fast as drogued drifters across the isobaths. 25% of the undrogued drifters landed, versus about 5% of the drogued ones, for the most part on the same coastline locations where oil was found after the Deepwater Horizon spill. Results highlight the importance of near surface gradients in setting the cross-shelf transport and landing of surface material on the Gulf of Mexico's northern shores. Finally, we analyzed the convergence rate of hundreds of drone-tracked bamboo plates while they accumulated into windrows in the Louisiana bight. Observational tools and techniques presented here reproduced typical oil spills transport patterns observed at different scales. Results are aimed to be of practical interest for modelers and from an operational spill responder’s point of view.

* Student presenter

Session 013: Microbial Genomics to Improve Predictive Understanding of Disturbance in the Global Ocean System

The Oil Microbiome Webserver: An Interactive, Searchable Genome Repository Expanding the Catalogued Diversity of Crude Oil-Associated Microbes

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Oil spills can have pronounced impacts on natural ecosystems and the microbial community dynamics following such spills have only recently been documented, especially for the Deepwater Horizon (DWH) spill in the Gulf of Mexico, one of the largest marine oil spills. The microbial interactions that ultimately dictate the fate of oil are highly complex and remain poorly understood but genome-revolved metagenomics can help unravel these complex interactions. Public repositories host a plethora of sequence data from a diverse array of environments in the form of raw-reads or assembled MAGs (metagenome assembled genomes). However, lack of environmental context in the form of *in-situ* physicochemical data and comparative MAG analysis capabilities in these repositories have severely limited the interpretation of the data and progress. Here, we curated a comprehensive and searchable database documenting microbial populations that responded to accidental or natural oil spills across different ecosystems from around the world along with their underlying physicochemical data, geocoded via GIS to reveal their biogeographic distribution patterns. Analysis of the ~2000 MAGs available in the database revealed ecological niche specialization within specific habitats (e.g., specialization to coastal sediments vs. water-column vs. deep-sea sediments) as well as distinct biogeographic distribution of MAGs associated with the Deep Horizon spill. Over 95% of the recovered MAGs belonged to novel/uncultured taxa underscoring the limited representation of the oil-responding among cultured organisms. Whole genome comparisons identified a total of 1536 unique clades at the species level (>95% average nucleotide identity) among these MAGs, revealing an extensive species diversity. Our interactive metagenomics repository will help to provide a predictive understanding of the microbial response to oil perturbations and identify biomarkers that can universally predict ecosystem recovery.

Improved Metagenomic Methods to Monitor Meiofaunal Communities

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Meiofauna are microscopic animals that live almost ubiquitously across the earth's beaches and benthic habitats. They are diverse and abundant, encompassing at least twenty of the thirty-four recognized animal and are important contributors to ecosystem functioning through their roles in nutrient cycling, sediment stability, and food web interactions. Shifts in meiofaunal biodiversity may reflect environmental changes, which can be revealed almost instantly thanks to the organisms' short generation time and low dispersal capability. Therefore, surveying these communities is fundamental to the assessment of natural and anthropogenic stresses, restoration, pollution monitoring, and ecosystem health. Current molecular studies typically employ metagenetic sequence analyses, but are very limited

* Student presenter

due to a historically low representation of meiofaunal genomic data in public repositories and the lack of adequate genetic markers to capture population level changes. Here we report on an expanded set of reference genomes and discuss novel bioinformatics workflows to investigate meiofaunal communities. These new genomes encompass 170 individuals representing 77 unique taxa and primarily focus on Annelida, Nemertea, Platyhelminthes, Gastrotricha, and Nematoda. To test the influence of these new resources on metagenomic studies we conducted a comparative analysis with both mock meiofaunal communities and environmental sediment samples. We demonstrate that the expanded reference genomes improve the accuracy and breadth of sequence identification from metagenomic datasets. Furthermore, by utilizing a collection of 978 universal orthologous and a robust reference tree we place novel environmental sequences directly into phylogenetic perspective. These results allow us to evaluate the progress towards a more detailed description of meiofauna communities.

Metabolic Plasticity and Nutrient Acquisition Strategies of Hydrocarbon Degrading Isolates from the Deepwater Horizon Disaster

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Studies of the long-term effects of the Deepwater Horizon oil well blowout in the Gulf of Mexico have revealed how this disaster impacted the ecosystem, as well as how it responded. We used comparative genomics to study bacterial strains isolated from the Gulf of Mexico during the blowout, including: *Alcanivorax sp. TY-5, Alcanivorax sp. TK40, Cycloclasticus sp. TK-8, Halomonas sp. GOS-1, Marinobacter sp. TT-1, Marinobacter sp. TK-36, Pseudoalteromonas sp. TK105,* and *Thalassospira sp. TK-46(2)*. These isolates were obtained from either surface slicks or deepwater plumes, and showed prevalence of genes associated with oil degradation, as well as other intriguing metabolisms such as nitrate, methane, DMSP, ammonium, and trace metal metabolism. Many isolates exhibit metabolic plasticity, possessing metabolic machinery for aliphatic and aromatic hydrocarbon degradation and for degrading other forms of organic carbon. This plasticity allows for survival of organisms under many environmental conditions but they are well suited to respond to inputs of oil at varying levels. Interestingly, *Thalassospira sp. TK-46(2)* and *Marinobacter sp. TK-36*, which were both isolated from the surface slicks, encoded for genes involved in denitrification, suggesting that they may occupy low oxygen niches in the water column such as those associated with particles and/or marine snow. Observed spatial variations between deepwater plume vs. surface slick isolates highlight differences in metabolic capabilities that may reflect unique aspects of the source habitat.

Niche Partitioning Between Coastal and Offshore Shelf Waters Results in Differential Expression of Alkane and PAH Catabolic Pathways

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In the wake of the Deepwater Horizon oil spill, the taxonomic response of marine microbial communities to oil and dispersants has been extensively studied. However, the functional metabolic response of these communities remains comparatively underexplored. Moreover, although marine oil spills can simultaneously impact thousands of square kilometers of both coastal and offshore environments, little information currently exists on how these responses vary spatially between different oceanic biomes.

* Student presenter

Using a combination of analytical chemistry, 16S rRNA amplicon, and metatranscriptomic sequencing, we provide a broad, comparative overview of the specific functional and ecological response of hydrocarbon degrading bacteria in marine surface waters over time between two oceanic biomes. We find evidence for the existence of different ecotypes of *Alcanivorax*, *Marinobacter*, and *Cycloclasticus* which behave differentially in coastal and offshore shelf waters despite being exposed to similar concentrations of oil, dispersants, and nutrients. This resulted in the differential expression of catabolic pathways for n-alkanes and polycyclic aromatic hydrocarbons (PAH)—the two major categories of compounds found in crude oil—with preferential expression of n-alkane degradation genes in coastal waters while offshore microbial communities trended more towards the expression of PAH degradation genes. This was unexpected as it contrasts with the generally held view that n-alkanes, being more labile, are attacked before the more refractory PAHs. Collectively, these results provide evidence for the existence of niche boundaries for hydrocarbon degrading taxa between neighboring oceanic regions.

Bacterial Community Structure and Functional Potential in the Northeastern Chukchi Sea

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Microorganisms are critical to ecological function, thus baseline characterizations are important to understanding biogeochemical cycling and predicting impacts of disturbance. We performed a molecular microbial ecological analysis in the Arctic Ocean in order to characterize bacterial community structure and genetic potential for biogeochemical cycling and oil biodegradation in an oil lease area. Samples were collected from the surface, middle (20 m), and bottom (2-3 m above seafloor) of the water column during the open-water season of August and September 2012 at 17 different locations. We determined bacterial community structure with 16S rRNA gene sequencing and detected functional genes, including an array of oil biodegradation and biogeochemical cycling (carbon, nitrogen and phosphorus cycling) genes, using the GeoChip 5.0 microarray. We then correlated molecular data to contextual physical and biogeochemical factors. Bacterial community structure differed significantly by depth (surface water vs. bottom water) and between sampling dates (August vs. September). While the relative abundance of major functional gene categories did not differ with depth, the abundance of individual functional genes for carbon cycling, nitrogen cycling, organic contaminant remediation, phosphorus cycling, sulfur cycling, virulence, and viruses differed between surface and bottom seawater samples. Aerobic oil degradation genes and taxa known to include oil-degrading bacteria were found at all three depths. These findings support previous observations that two different water masses contribute to a stratified water column in the summer open-water season of the Burger lease area, but indicate that microbial functional potential is fairly similar with depth despite differences in temperature, water chemistry, bacterial community structure, and individual functional gene alleles. While oil biodegradation rates have been assessed for surface waters in this region, future studies comparing function throughout the water column would aid in more comprehensively predicting the fate of spilled oil in the Arctic marine environment.

* Student presenter

Laying a Foundation to Investigate the Role of Microbes in the Response of Corals to Oil Spills and Other Stressors: Discovery of Parasites, Chemoautotrophs, and Abundant Symbionts in Deep-Sea Corals

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The Deepwater Horizon oil spill acutely impacted deep-sea coral communities in the Gulf of Mexico however the full extent of this impact is not fully understood since many aspects of deep-sea coral biology remain understudied. A growing body of research has focused on shallow-water corals and has revealed that their associated microbial communities play an important role in coral biology and can affect the way in which corals respond to stressors such as bleaching due to thermal stress. To understand how the microbiome may influence the response of deep-sea corals to stressors such as oil spills we first conducted a large-scale survey to characterize their associated microbiomes. We collected samples from over 30 species, water, and sediment from across the Gulf of Mexico for 16S sequencing. Coral microbiomes were distinct from the water and sediment and differed between even closely related species. Single microbes often dominated the microbiomes of particular coral species and may be symbionts. One is an apicomplexan (eukaryote) that dominated *Leiopathes glaberrima* with a plastid genome that partially encoded chlorophyll biosynthesis. Closely related microbes were found in a variety of other coral species and this group is likely parasitic. We also found a novel bacterium of the Mollicutes in *Callogorgia delta*. This bacterium had a functionally and physically reduced genome suggesting a symbiotic lifestyle. FISH microscopy revealed large aggregates of bacteria within the mesoglea however specific probes were developed to confirm their identity. Finally, *Paramuricea* sp. B3 from a site with active cold seeps were dominated by *Thioglobus*, a close relative of the sulfide-oxidizing endosymbionts of *Bathymodiolus* spp. This bacterium was not present in the surrounding water, sediment, or co-occurring scleractinian corals. Its genome revealed the potential to oxidize reduced sulfur compounds and fix carbon via the Calvin cycle and we confirmed that these pathways were transcriptionally active. Furthermore, its relative abundance in the coral was correlated with the depletion of carbon-13 and nitrogen-15 in coral tissue and therefore incorporation of chemoautotrophic primary production into the coral holobiont. This suggests that *Paramuricea* sp. B3 has a diet that may be supplemented with chemoautotrophy by a *Thioglobus* symbiont. Altogether, this work has laid a foundation to understand the roles of microbes in deep-sea corals which is a necessary first step to investigate the roles that these microbes may play in the response of corals to stressors such as oil spills.

Investigating the Immunosuppressive Effects of Oil Exposure on the Dermal Microbiome of Red Snapper (*Lutjanus campechanus*)

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Following the Deepwater Horizon (DWH) oil spill, reports of red snapper (*Lutjanus campechanus*) with visible skin lesions were widespread and seemed to correlate with temporal and spatial spill exposure. Functional impairments to fish immune systems and the natural dermal microbiome resulting in susceptibility to disease need to be understood in the context of the synergy of oil exposure. One proposed mechanism for immunotoxicity (immunosuppression) is oxidative stress from over expression of the systems responding to xenobiotics. In oil compromised red snapper, exposure to the pathogenic bacterium *Vibrio anguillarum* may suppress the immune response and alter the normal dermal microbiome (dysbiosis), which could result in the generation of external skin lesions. To investigate the

* Student presenter

consequences of oil exposure in the natural environment, a series of controlled exposures of the commercially important GOM species, red snapper, to DWH oil, Corexit 9500 dispersant, and the pathogenic bacterium *V. anguillarum* were carried out for 30 days. External mucosal microbiome samples were collected after 14 days for control and dispersed oil treatments and after 28 days from all treatments. Water, whole body, and liver samples were sampled for polycyclic aromatic hydrocarbon (PAHs) analyses and livers were assessed for IgM at time points concurrent with microbiome sampling. Metagenomics data indicates a significant effect of dispersed oil on the fish external microbiome. Dispersed oil-exposed fish harbored dysbiotic microbiomes compared to control fish at both 14 and 28 days. Dispersed oil/bacteria exposed fish harbored higher abundances of potentially pathogenic groups. Lesions were documented in one fish from the dispersed oil/bacteria treatment, although the microbiome was not significantly different from other fish in the same treatment. Potential health implications associated with dysbiosis and comparisons between microbiome structure, PAHs, and IgM will be discussed.

Role of Micron-Scale Aggregates in Hydrocarbon Oxidation

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The Deepwater Horizon oil spill in April 2010 introduced an estimated 650,000-780,000m^3 of crude oil into the Gulf of Mexico (GoM). To mitigate the impact of this oil to the coastal environment, dispersant was applied to the surface oil slick, promoting the incorporation of oil droplets into the water column. During the spill, the formation of oil associated flocculants was observed within the contaminated surface waters which aggregated and sank over time, leading to the sedimentation of oil-rich marine snow. Mesocosm experiments were conducted to better understand the role of such microbial aggregates in hydrocarbon degradation and transport. Using GoM coastal water, three mesocosm treatments were set up consisting of a seawater only control, seawater amended with the water accommodated fraction of oil (WAF), and seawater with dispersed oil. It was observed that, in addition to the formation of marine oil snow, smaller micron-scale microbial aggregates were also present in all treatments. Visual inspection of these microaggregates revealed that within the WAF and dispersant amended treatments, ≥90% were associated with oil droplets. The abundance of these aggregates was greater in the WAF and dispersant treatments as compared to the control and their peak abundance occurred on day 3, followed by a gradual decline. This peak abundance coincided with the maximum rates of biological hydrocarbon oxidation as estimated by the mineralization of ^{14}C labeled hexadecane and naphthalene. To elucidate the potential of these microaggregates to serve as hotspots for hydrocarbon degradation, the microbial assemblages within the aggregates was characterized via 16S rRNA gene sequencing, revealing a large and diverse population of potential hydrocarbon degrading taxa. The presence of some of these taxa with the microaggregate structure was further validated using fluorescent in situ hybridization (FISH) while the genetic potential of the aggregate communities to degrade hydrocarbon compounds was accessed through metagenomic sequencing.

Crude Oil Disturbance Selects for Generalists, not Specialists, in a Beach Sand Microbial Community.

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The specialization-disturbance hypothesis predicts that in the event of a disturbance generalists are favored, while specialists are selected against. This hypothesis has not been adequately tested in microbial systems and it remains unclear to what extent it could explain microbial community responses to perturbations. Previous field observations of Pensacola beach sands that were impacted by the Deepwater Horizon oil spill provided evidence in support of the specialization-disturbance hypothesis. However, ecological drift as well as uncounted environmental fluctuations (e.g., storms) could not be ruled out as confounding factors driving these field results. In this study, the specialization-disturbance hypothesis was tested on beach sands, disturbed by crude oil, *ex-situ* in a closed laboratory-controlled system that simulated *in-situ* conditions. Advective-flow chambers that mimic *in-situ* pressure gradients in saturated beach sediments were enriched with weathered Macondo oil; un-enriched chambers served as controls. Shotgun metagenomic sequencing was performed on DNA extracted from several time points across the incubation period (2 months). Community structure and similarity were assessed using 16S rRNA gene-encoding short reads. Functional diversity was accessed by read assignment to a defined set of molecular function and biological process gene ontology terms. Microbial community composition and succession across the time series closely resembled field observations, with pronounced increases in the abundance of *Alphaproteobacteria* and *Gammaproteobacteria* in the oil enriched chambers. Functional diversity significantly increased while taxonomic diversity significantly decreased indicating a decrease in specialist taxa, and providing further evidence in support of the specialization-disturbance hypothesis in crude oil impacted beach sands.

Microbial Analysis of Sea Surface Microlayer Slicks in the Florida Keys in Coordination with Synthetic Aperture Radar Imagery

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The sea surface microlayer (SML) is the boundary layer at the surface of the ocean, distinct from the water below and highly variable in space and time. Biogeochemical processes between the atmosphere and the ocean occur across this boundary layer. The SML is influenced by organisms that produce surface active agents (surfactants), which accumulate at the surface and can create slicks. Slicks are the result of surfactants dampening capillary waves, which can be seen in synthetic aperture radar (SAR) satellite imagery due to the smooth surface reflecting backscatter away from the receiving satellite. To investigate the presence and abundance of surfactant-associated bacteria in the SML above a coral reef area and in slicks above a coastal seagrass ecosystem, 220 SML and subsurface water (SSW) samples were collected during an experiment in the Florida Keys in July and August 2018. Samples were collected in both daytime and nighttime, some during SAR satellite overpasses. Samples were sequenced on the Illumina MiSeq. Increasing wind speed had a negative effect on abundance of these genera, with lower wind speeds showing a more habitable environment. The SAR images collected during the experiment indicated that slick features around the coastal seagrass area provided a more habitable SML for surfactant-associated bacteria, compared to the coral reef area. The ratio of abundance of surfactant-associated bacteria between the SML and SSW was affected by the diurnal cycle. This work supports the importance of using SAR in coordination with *in-situ* work. This project successfully combined SAR, to remotely sense the surface features of the ocean in productive areas such as corals reefs and seagrass areas, with next-generation sequencing.

* Student presenter

Session 014: Science to Action: Co-Production of Science to Support Resource Management in the Gulf of Mexico

What Indicators Should We Use to Track Progress Towards Ecosystem Restoration Goals in Southeast Louisiana?

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Much of the applied research in the Gulf of Mexico in the last decade has focused on developing the science and tools necessary to implement environmental restoration technologies. These technologies have the potential to stem and even reverse the devastating effects of land loss, due to subsidence, sea-level rise, and landscape fragmentation as a result of oil & gas exploration and damage from oil spills and tropical storms. However, restoration does not happen in a socio-ecological vacuum. The communities of southeast Louisiana are often close-knit communities, of a diverse and unique cultural background who have learned to live in a changing and often challenging environment. How will environmental restoration change their livelihoods, and what will the short and long-term consequences be? What does restoration mean for the animal species that have adapted to an ecosystem that is deemed unbalanced today? NOAA's Gulf of Mexico Integrated Ecosystem Assessment (IEA) program has enlisted the help of numerous experts from various disciplines to begin teasing out ways in which ecosystem restoration could be expanded conceptually to integrate societal concerns along with the environmental ones. Our team has used these goals to further decide on how these goals could be accomplished and what are some of the ways in which progress towards these goals should be measured. We use a series of socio-ecological indicators to evaluate the status, natural variability, and long-term trends of the Barataria Basin in Southeast Louisiana to present the state of the Barataria Basin before the implementation of any significant restoration projects. We focus particularly on those indicators that can inform policy-makers on the ways restoration influences human well-being; we also highlight important data gaps.

Improved Data to Better Inform Management: The Gulf Fishery Independent Survey of Habitat and Ecosystem Resources (G-FISHER) Program

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Reef fish assemblages in the Gulf are structured by a complex interaction among drivers at multiple scales, including habitat availability, episodic events, and fisheries management among others. Nevertheless, the nature of these interactions, and how drivers may ultimately influence the productivity and sustainability of fisheries resources, are not well known. Entities responsible for the assessment and management of reef-fish populations throughout the Gulf have identified a general lack

of high-quality fishery-independent survey data collected at appropriate spatio-temporal scales as a major impediment to an improved understanding of population dynamics and the underlying processes that drive them. Through the G-FISHER program, we are addressing these critical needs by integrating three regional reef fish surveys (involving habitat mapping and underwater video surveys) and expanding the spatial coverage and intensity of annual sampling effort. As part of these efforts, an optimized survey design is being developed that incorporates an integrated spatial-habitat stratification scheme to increase sampling efficiency and improve the precision of estimates of relative abundance and size composition. By expanding survey efforts Gulf-wide and incorporating the full spectrum of artificial and natural reef habitats available to reef-fish populations, the data products provided by this project will represent the most comprehensive and representative characterization of reef-fish abundance, size composition, assemblage structure, and habitat dynamics yet available in the Gulf. Novel approaches to integrate historical and newly collected data will greatly advance our understanding of interannual variability in reef-fish population dynamics and assemblage structure and how they relate to key environmental drivers at multiple spatial and temporal scales, greatly improving assessment and management capabilities in the region.

Scientific Decision Support for Deliberations of the Flower Garden Banks National Marine Sanctuary Boundary Expansion

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In order to support the Flower Grander Banks National Marine Sanctuary Boundary Expansion effort, we were called upon to integrate, analyze and synthesize the relevant scientific information in a way which would enable place-based decision making for expanding the boundaries of a national marine sanctuary. This work included engagement with the Boundary Expansion Working Group. Through a series of 12 meetings, we led representatives from various stakeholder groups through a biogeographic assessment process. During this process we integrated information on both the biology/ecology and human uses for a series of banks in the northern Gulf of Mexico. We integrated biological observations from over 550 survey dives using submersibles or remotely operated vehicles (ROVs) along with information on potential conflicts, such as fishing, shipping, or oil & gas extraction. We applied a geospatial decision support tool called Marxan and then conducted a participatory GIS process. This process enabled us to review biological and ecological features along with potential conflicts in a geographic context and to draw lines on the map to create a proposal for expanding the sanctuary boundaries. The Boundary Expansion Working Group ultimately adopted and advanced a proposal which expands the existing sanctuary to 14 additional banks and expands the area to be four times greater than the current sanctuary.

Understanding Habitat Use to Conserve Migratory Landbirds Along the Northern Gulf of Mexico Coast

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In order to implement sound and effective conservation strategies for migratory landbirds, we need an understanding of their population status and how they respond to the different habitat patches they

encounter *en route*. However, this basic information to inform conservation during the migratory period is limited, despite many migratory species are in decline and mortality during migration can be substantial. It is imperative to gain information along the Gulf of Mexico, where birds must negotiate a crossing of this large ecological feature while contending with the normal challenges of migration. Moreover, it is especially critical to understand individuals in close proximity to the Gulf given the rapid urban development of coastal habitats. Towards this end, and specifically to understand the function (rest or refuel) of stopover habitat for migratory birds at multiple spatial scales along the northern coast of the Gulf of Mexico, we established six landbird migration monitoring stations in southern Alabama and Louisiana in habitats that differ in their patch size, distance from the coast, and surrounding habitat matrix. We collected information on bird abundance and changes in physiological condition as birds use habitat, as well as resource availability and habitat structure and composition. We found that birds use habitats differently between spring and autumn, which can influence seasonal management of different habitat types. Additionally, bird density detected by weather surveillance radar corroborated some of the local patterns, illustrating a potential tool for broad scale conservation and management moving forward. By continuing our studies of bird habitat use at multiple spatial and temporal scales and expanding our scope with technological advancements, our data can prioritize conservation areas and identify knowledge gaps to implement successful conservation practices within the Gulf of Mexico region.

A Conceptual Framework for Assessing Ecosystem Health

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Over the past century, the environment of the Gulf of Mexico has been significantly altered and impaired by extensive human activities. A national commitment to restore the Gulf was finally initiated in response to the unprecedented Deepwater Horizon oil spill in 2010. Consequently, there is a critical need for an assessment framework and associated set of indicators that can characterize the health and sustainability of an ecosystem having the scale and complexity of the Gulf. This Drivers-Pressures-Stressors-Condition-Responses (DPSCR4) conceptual framework presented here is a comprehensive conceptual model of the coupled human-ecological system. It was developed as an integration of previous ecological risk- and environmental management-based frameworks for assessing ecosystem health. It was designed to identify the natural and anthropogenic drivers, pressures, and stressors impinging on ecosystems and ecosystem services, and the ecological conditions that result, manifested as effects on valued ecosystem components. Four types of societal and ecological responses are identified: reduction of pressures and stressors, remediation of existing stressors, active ecosystem restoration, and natural ecological recovery. From this conceptual framework are derived the specific indicators to characterize ecological condition and progress toward achieving defined ecological health and sustainability goals. Additionally, the framework incorporates a hierarchical structure to communicate results to a diversity of audiences, from research scientists to environmental managers and decision makers, with the level of detail or aggregation appropriate for each targeted audience. Two proof-of-concept studies were conducted to test this integrated assessment and decision framework, a prototype Texas Coastal Ecosystems Report Card, and a pilot study on enhancing rookery islands in the Mission-Aransas Reserve, Texas, USA. Although very different in scale and focus, the DPSCR4 conceptual framework was successfully used in both. Much like its predecessor, the ecological risk assessment

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framework, DPSCR4 can be tailored to different scales of complexity, different ecosystem types with different stress regimes, and different environmental settings.

The Development of the Living Shoreline Decision Support Tool for the Gulf of Mexico

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The current trend in the Gulf of Mexico is to install hard structures, such as, bulkheads, groins, or revetment on shorelines to protect waterfront coastal properties from erosion. In Alabama over 26% of the state's tidal shoreline has been armored, 40% of Tampa Bay's shoreline has been armored, and 20% of tidal marshes in Galveston Bay have been lost as a result of armoring. Hard structures are reducing critical habitat needed for wildlife, nutrient recycling, and sustainable fisheries. Based on discussions from the greater Gulf of Mexico scientific community more decision support tools need to be created to assist with the site assessment and to promote the use of "Living Shorelines." The presenters will discuss the creation, implementation, and use of the Gulf of Mexico Living Shorelines Decision Support Tool that is being funded by the NOAA RESTORE Science Program. The presenters will discuss the interactive interface questions associated with the decision support tool that are answered by the user to generate a natural shoreline erosion control best management practice. The best management practices could include, enhance or create marsh, plant marsh with sill, maintain beach or install offshore breakwaters with beach nourishment, remove failing structure and replace with an integrated buffer, remove structure grade bank if possible and plant marsh with sill, remove bulkhead and replace with revetment, or consider a bulkhead enhancement project. Additionally, survey results will be discussed to determine the types of stakeholders using the model, opinions on the usability, suggestions for future improvements of the model and additional ways to promote this product.

Estimating Historical Oyster Body Sizes from Paleoecological Records to Address an Information Gap for Habitat Management in Florida

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The Statewide Ecosystem Assessment of Coastal and Aquatic Resources (SEACAR) project is a Florida Coastal Management Program-funded project being undertaken by the Florida Department of Environmental Protection's Office of Resilience and Coastal Protection (RCP). The five-year project aims to aggregate several types of indicator data collected within RCP managed areas around the state to assess status and trends of five priority submerged habitats: coastal wetlands, seagrass beds, oyster reefs, coral reefs and the water column. An additional goal of the SEACAR project is to identify information gaps in the assessment's indicators so that they can ultimately be addressed.

One information gap that was identified early in the SEACAR project was a relative scarcity of monitoring records of oyster body size, one of the indicators chosen for the assessment of oyster reef habitats. Although body size is recognized as an important variable for monitoring oyster habitats today, monitoring records in Florida are relatively scarce prior to the 2000s. There are limited options for filling such historical information gaps, but RCP staff collaborated with paleontologists from the

Paleontological Research Institution (PRI) to design a project to estimate historical oyster body sizes by using the dead, buried oyster remains entombed within living oyster reefs as a historical record. The project design involved RCP managers and researchers from RCP and PRI to ensure that data produced would be useful from a research perspective as well as for the SEACAR project and habitat management. The project has documented oyster body sizes dating back at least 50 years for 31 oyster reefs around the state. We will discuss the collaborative process that led to this project, its results and how they will be integrated with the SEACAR project, as well as how they might influence RCP's future oyster monitoring and management practices.

Designing Climate Model Projections for Puerto Rico: Co-Production by Scientists and Resource Managers

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Climate projections are widely used to explore potential impacts and assess risks to resource management. However, climate projections are rarely designed specifically for such purposes; they are instead usually designed by scientists as experiments to answer climate science questions. In order to develop a set of climate projections that could be used by natural resource managers and ecosystem scientists, USGS's Southeast Climate Adaptation Science Center engaged a community of researchers and practitioners in the US Caribbean to design downscaled climate model projects that would meet a range of needs and applications. This approach to co-production provided unique insights to common and unique needs and approaches of participants. The resulting data better meets the needs of a large group of potential users of climate projections in the region. Post-project community engagement has also demonstrated the challenges of this approach for producers and users of such climate projections.

Session 015: Lessons Learned from Implementing Oil Spill Science Outreach and Education Programs: Reflections 10 Years After a Major Oil Spill

Inviting Learners to the DEEPEND: A Team Approach to Successful Outreach and Education

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The DEEPEND Consortium has taken a three-pronged approach to outreach during its 5-year tenure: 1) informal and formal science education (e.g., curriculum development, 'virtual' expeditions, educator training); 2) public outreach (e.g., aquarium, zoo, and natural history museum partnerships); and 3) shareholder outreach (e.g., presentations at fisheries management meetings, focused webinars, and scientific conferences). The multi-faceted approach allowed us to introduce DEEPEND research and discoveries to different types of audiences and age groups. Lessons we learned include the need for

original imagery, publicizing the research, and the enthusiastic support and participation of science team members in outreach and education endeavors. An initial lesson learned was the importance of showing audiences something they have not seen before. In our case that involved craning a lab-van-turned-studio onto the bow of the ship for use by a dedicated and experienced photographer on every cruise. Photos and videos lead to the second lesson, make the images available as educational tools and promotional materials. Audiences formed important connections to the deep sea and the interest of editors was more likely to be piqued with exciting image accompanying the story. The third lesson was to share the research as broadly as possible. Incorporating multiple outlets at all levels to share the teams' science proved particularly effective. The final lesson, all science team members are an essential and integral part of outreach and education. There was no shortage of ideas or DEEPEND Team Members willing to lead the charge for this important component of the DEEPEND mission. Their participation helped engage audiences and create a connection to the research, researchers, and ecosystem. Session discussion will focus on what we have learned through this endeavor, the lessons learned on our path to successful E/O initiatives, and how to engage a science team thoroughly at the outset.

Engaging Audiences: CIMAGE's Recipes for Success

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The Center for the Integrated Modeling and Analysis of Gulf Ecosystems (C-IMAGE) employed a multi-pronged strategy to engage various communities with our research initiatives. To reach the K-12 students, we incorporated teacher involvement through the Teacher at Sea/Adventures at Sea program during our Mud and Blood cruises, our GLOBE Training sessions and our SENSE IT workshops. We were able to engage students directly, using the research vessels as remote classrooms. C-IMAGE's ongoing involvement with the St. Pete Science Festival provided additional hands-on opportunities for young people, as well as its partnership with the locally coordinated Pint of Science events. Gaining the attention of the general public required the development of more strategic products due to the limitless nature of passive social media practices. C-IMAGE enlisted expertise from Mind Open Media on our podcast series "The Loop," collaboration with WUSF (local NPR radio station) to produce several episodes of "Florida Matters," features on several national NPR/PRX shows, our StoryCollider shows, our Audio Slideshows, and our interactive website Beneath the Horizon which profiles both the Deepwater Horizon and Ixtoc 1 oil spills as well as other major spills in the Gulf of Mexico. Our more scientific products include a special issue of the Marine Technology Society Journal, our TechSurge Workshop and our two-book series from Springer. C-IMAGE values its investment in the future work force and organized Early Career Scientists Professional Development Workshops that offered lessons for better communication skills and provided them with knowledge on locating and identifying funding sources and proposal writing.

Experiential Learning Activities for the Classroom: Lessons Learned Developing Standards-Aligned Science Curricula for Middle and High School Students

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* Student presenter

Experiential learning strategies are pervasive in STEM education, in part because they allow students to apply newly acquired knowledge or skills and to see the effects of their actions immediately. Studies have shown that this increases student performance and the likelihood that that participants will retain the new knowledge. An experiential learning approach also generates more positive attitudes toward the subject matter on the part of the students. Thus, for many educators, it is the preferred teaching practice in regular classrooms, particularly for complex topics such as science, technology, engineering, and math.

With this in mind, the development and incorporation of experiential learning activities has been a key objective of the GoMRI-funded Deep-C (Deep Sea to Coast Connectivity in the Eastern Gulf of Mexico) Consortium and the Consortium for Simulation of Oil-Microbial Interactions in the Ocean (CSOMIO) public education and outreach initiatives. This included creation of two ocean science curriculum - a Deep-C curriculum geared toward high school science and a CSOMIO curriculum geared toward middle school. The goal of both curricula is to use the scientific research being conducted by consortia sciences to help students make connections between theory and real-world applications.

Implementation of these initiatives resulted in numerous fruitful interactions, some entertaining flops, and many, many lessons learned. This presentation will provide an account of these as well as a practical, step-by-step process for creating a research-based curriculum, including the strategies used to integrate ocean literacy principles and the Next Generation Sunshine State teaching standards prescribed by the state of Florida. It will break the process down - from planning to implementation - and discuss the importance of seeking teacher input, prototyping activities, and undertaking participant evaluation.

RECOVER Virtual Lab — A Virtual Lab Application to Disseminate and Communicate Oil Spill Science for Educators

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The RECOVER Consortium developed a web-based interactive educational website and application to effectively disseminate oil spill science and research to students - ranging from elementary to collegiate levels - and the general public. The RECOVER Virtual Lab application allows users to conduct virtual experiments on the impacts of oil on fish physiology, similar to those of RECOVER researchers. By using the Virtual Lab, students, teachers, and the general public are able to understand the real-world applications of data, experimental designs, and results generated by RECOVER researchers. The virtual lab includes a Teacher's Workbook, and explanations from the researcher themselves, that have been used in classrooms throughout the United States. Both Virtual Lab lessons utilize data produced by GoMRI scientists which are made available to students and the public to expand the reach of the oil spill science to individuals that may not otherwise have access to oil spill science and data. From the launch of the first virtual lab lesson, feedback from the educators utilizing the RECOVER Virtual Lab were incorporated so that student choice and engagement were maintained while learning and conducting challenging virtual experiments. As of today, from the debut of the RECOVER Virtual Lab lessons, there have been over 1,000 student users from 143 schools throughout at least 10 states. This research was made possible by a grant from The Gulf of Mexico Research Initiative. Grant No: SA-1520; Name: Relationship of Effects of Cardiac Outcomes in fish for Validation of Ecological Risk (RECOVER). Data are

* Student presenter

publicly available through the Gulf of Mexico Research Initiative Information & Data Cooperative (GRIIDC) at https://data.gulfresearchinitiative.org.

Ten Years of Sharing Oil Spill Science Accurately and Interestingly via the GoMRI Website

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Coastal communities faced many challenges and uncertainties after the Deepwater Horizon incident, and one of those uncertainties included skepticism about the plethora of information that followed. The complex relationship between the public and trustworthy science became apparent as the spill unfolded, emphasizing the need for credible, accurate, and easily-accessible scientific information related to the oil spill. Following the Deepwater Horizon incident in April 2010, BP committed $500M over a ten-year period to create an independent research program to study the effect and the potential associated impact of hydrocarbon releases on the environment and public health as well as to improve spill mitigation, oil detection, and characterization and remediation technology. The Gulf of Mexico Research Initiative (GoMRI) was established to carry out that research. Dr. Rita Colwell, the GoMRI Research Board Chair, appointed board members to the Communication and Outreach Committee who established communication guidelines, including 1) a non-advocacy and non-sensational approach supported by science and facts and 2) coordination with GoMRI-funded researchers for their review and approval of communications about their work. This was no small task, given that the GoMRI research community has published over 1,264 peer-reviewed journal articles (and counting) as a result of 267 funded projects that involved over 3,600 people representing 42 U.S. states and 17 countries. This presentation summarizes the breadth and depth of over 600 original-content stories featured on the GoMRI website over the past ten years, covering summaries of peer-reviewed publications, highlights of scientists and students, and descriptions of research and education and outreach activities. We will describe our approach in identifying and selecting stories and the process used to develop them. This decade of work also represents a history of the GoMRI program and, as such, provides a valuable resource for developing products and resources beyond website content. Survey feedback from members of the GoMRI community describes outcomes from story postings and provides information about what worked well and lessons learned from communicating GoMRI-funded oil spill research.

Integrating Outreach and Research: Recommendations from the Gulf of Mexico Research Initiative Consortia

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The Gulf of Mexico Research Initiative (GoMRI) dedicated significant resources to outreach. GoMRI-funded research consortia in particular were required to include education and outreach (E&O) programs; importantly, proposed E&O activities were part of the proposal evaluation process. Over the past nearly nine years, a robust and varied outreach effort through the GoMRI-funded consortia has developed, with each consortium having had their own unique approach with respect to audiences, tools, teams, and strategies. Workshops and other collaborative activities provided the consortia outreach coordinators several opportunities to share ideas and best practices about E&O program

development and implementation. Their lessons learned were distilled into seven recommendations based on their collective experiences, which are: 1) involve outreach expertise as early as possible, preferably during proposal development; 2) be strategic when developing the outreach plan; 3) clearly identify audience(s) and determine the most effective ways to reach them; 4) capitalize on unique areas of research, team members skills, and relationships; 5) make sure the budget is reflective of the strategic outreach plan; 6) determine evaluation metrics as the outreach plan is developed; and 7) communicate regularly within the team and identify opportunities to communicate and collaborate with other outreach professionals. As funding organizations continue to incorporate broader impacts into research funding requirements, these recommendations can serve as a resource to scientists and outreach professionals seeking to initiate or expand outreach efforts in their projects or programs. In addition to discussing the recommendations, examples from the GoMRI experience will be shared.

Outreach and Engagement Strategies for a Proposed Gulf of Mexico Community Health Observing System

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Based on lessons learned from other health studies, a proposed Gulf of Mexico Community Health Observing System (GoM CHOS) includes a robust engagement strategy. The CHOS will kick-off with a broad advertising effort involving the Gulf Sea Grant programs, public media, healthcare provider organizations, community health workers (CHWs), social media, primary care physicians and nurses, community organizations, pharmacies, and other outlets to provide information and encourage participation. After participants are recruited, routine two-way communication with each member and distribution of newsletters, and other notices via mail, email, text, social media, and video, as well as regular updates through the formal news media will be used to sustain interest and promote retention. CHWs are expected to play important roles in sustaining contacts, and a participant liaison will be available to assist as needed. Participants will be contacted 6, 3 and 1 months in advance of planned sampling intervals. Encrypted web-portals will allow full-time data access for participants, public health officials, and approved researchers, and a public-facing web page will provide general information. On occasion, participants will be polled to solicit opinions and criticisms or suggestions for improvements. Mobile phones, email addresses, emergency or family contact information, social media, and Social Security numbers will be used as appropriate to follow-up with participants with whom contact may have been lost or who may have moved away. The CHOS will offer annual workshops, special-topic webinars, annual workshops, publications in scientific and popular media, and regular, plain-language reports to each participant about the information they provide, what it means, and what is being done with it. An Institutional Review Board to ensure appropriate treatment of human subjects and data derived from them and Community and Scientific Advisory Committees will be established.

Community-Researcher Partnerships, Dissemination, And Outreach in a Gulf Coast Disaster Resilience and Preparedness Survey Project

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This case study analyzes the community-researcher partnerships, and outreach and dissemination efforts for a disaster resilience and preparedness study of the GoMRI-funded Consortium for Resilient Gulf Communities (CRGC). The CRGC partnered researchers with community-based organizations in three Gulf Coast communities in Louisiana and Alabama to carry out an in-person survey assessing the continuing impact of the Deepwater Horizon Oil Spill on psychosocial resilience, social networks, and disaster preparedness. Community partners hosted survey administration, provided advice about recruiting participants, and worked with CRGC researchers to plan and carry out dissemination of survey results to community members. After data collection was complete, CRGC researchers interviewed staff at community partner organizations to evaluate the project's community outreach. Input from community partners stressed the importance of engaging with local community brokers to enhance trust in research; researcher-partner communication; and researcher interaction with community residents that respects local knowledge and culture. The partners indicated that even communities that have often been the subjects of post-disaster studies are receptive to research participation, especially when the effects of disasters are long-term and ongoing. Recommendations include using research methodologies that are congruent with post-disaster community characteristics such as educational attainment; collaborating with community partners to disseminate research findings; and incorporating theories and practices that center critical reflection and consider power dynamics when working with communities that have experienced disaster and trauma. CRGC researchers shared survey results with residents in the three communities where the survey was administered, and this case study also presents recommendations for effective dialogue between and information-sharing between researchers and community members.

Adapting Oil Spill-Related Extension and Outreach Programming to Meet End-Users' Dynamic Needs

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In 2010, the four Gulf of Mexico Sea Grant College programs responded to the Deepwater Horizon (DWH) Oil Spill in a variety of ways, providing extension, outreach, and education programming to diverse targeted audiences, including people directly impacted by the spill. By 2014, many questions remained. To address this need, the four Gulf of Mexico Sea Grant programs partnered with the Gulf of Mexico Research Initiative to formalize a Gulf-wide oil spill science outreach program. This program consists of a team of Sea Grant extension and communications professionals who identify the oil spill science questions and needs of people whose livelihoods depended on a healthy Gulf of Mexico. The team works to find published, peer-reviewed research that helps address those questions and needs. They synthesize and translate the science and use a variety of methods to deliver the information to target audiences. Oil spill science has been delivered through writing outreach publications, organizing and facilitating science seminars, developing a science on a sphere module, delivering presentations at meetings held by target audiences, and other extension-related methods. The program has adapted its approach over time as oil spill-related research discoveries continue but target audience concerns change the further time passes from the DWH spill. This presentation will highlight lessons learned and emerging challenges related to implementing a regional outreach program. A brief discussion about the Sea Grant/GoMRI-supported program’s approach to evaluation will also be included.

* Student presenter

The Role of Engagement in Developing Shared Knowledge Among Local Communities, Researchers, and the GoMRI User Community

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When the Deepwater Horizon Oil spill occurred in 2010, it became clear to those responding that researchers and local communities generally were unfamiliar with the robust oil spill preparedness and response system in the US especially the requirements for use of response strategies like mechanical oil recovery, dispersant application and in-situ burning (ISB). Because no two oil spills are identical, oil spill planners and responders, who have been referred to as GoMRI's "user community," are accustomed to dealing with uncertainty and incomplete science when they manage the incident and make decisions in real-time. Considering uncertainty in decision making and the involvement of stakeholders in complex policy decisions has been studied extensively by researchers as early as the 1970s, and some government agencies in the Netherlands and US have acted to apply that research. During the 1990s in the US, knowledge production and relationship building among agency and industry oil spill planners and responders during pre-spill activities contributed to the development of regional preauthorization policies for chemical countermeasures and ISB. Consensus among authorities was sought and achieved in regional polices. Yet among the full range of oil spill stakeholders, including those who infrequently participate in oil spill preparedness activities, developing a shared sustainable understanding about dispersants remains a significant challenge in oil spill contingency. Opportunities to further this effort among stakeholders, ideally refreshing them at the local and regional levels (U.S. Area Committees and Regional Response Teams), are important components of spill preparedness and response activities. Funded by the Coastal Waters Consortium, this presentation presents results from two engagement efforts in the Gulf of Mexico and coastal Virginia among oil spill planners, responders, researchers and local communities to produce shared knowledge about the use of dispersants.

Meeting Educators' Needs After a Disaster in a Timely and Cost-Effective Manner Through the Use of Video Conferencing Technology

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Addressing current events is an integral part of an educator's activities: students look to educators to provide information and answers to their questions. There is a need, as well as an opportunity, to provide credible information to educators to address misinformation and misconceptions in a timely fashion after an event such as the Deepwater Horizon (DWH) oil spill. With funding from NOAA's Office of Education, partners in 4 Gulf of Mexico states provided simultaneous professional development to 416 K-12 teachers and informal educators on 2 separate dates (April 2011, Jan 2012) at 10 locations after the DWH event using video-conferencing technology. Each video conference included remote presentations by 4 researchers actively studying various aspects of the oil spill and a question and answer session between audience and researchers. At each of the 10 locations, geographically spread across gulf states to include northern, central and coastal areas, facilitators from partner organizations led attendees through activities suitable for the classroom and relevant to the workshop content. Pre

and post-testing and attitudinal evaluations were conducted online following the workshop. Participants demonstrated significant change in content knowledge. Importantly, 91% of the participants rated the experience valuable or very valuable. Low evaluation scores were associated with presentations by researchers that included few or no graphics. The few technical difficulties did not affect participant valuation: more than half of the participants had never attended a workshop using video-conferencing technology, but 80% indicated that they would attend another. By sending individual facilitators to locations and not asking participants to convene at a single location, credible, high quality professional development was delivered to a large audience in a timely and cost-effective manner, addressing the knowledge gap present in the early days of the DWH oil spill.

Session 016: Human Health Effects of Oil Spills and Other Disasters: What Do We Know, What Don't We Know, What Do We Need to Know, and How Can We Get There?

Quantified Videotaped Exposure Activities for 122 Children from Beach Play

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As a part of the BEACHES study funded through GoMRI, video-footage was collected for 122 children (aged 1 yr. to 7 yrs.) at four beaches in Miami and in Texas to evaluate children exposure related activities, that may potentially be linked to contact with oil spill chemicals. Videotaping by research teams positioned at some distance from families occurred as children and parents engaged in normal play for approximately 1 hour. A tailored video-translation software program (i.e., VideoTraq) was used to code data to analyzable lines of activity data with details by second activity time elements. At the previous 2019 GoMRI conference, researcher presented data on activity (i.e., running, swimming, and digging) and location (e.g., water, berm, and foreshore) metrics across the 122 children. This presentation will cover activity, location metrics, along with contact activities for the right hand, left hand and mouth where researcher are particularly interested in relevant objects and surfaces contacted (e.g., seaweed, sand, play toys, shells). Statistical work will therefore overlap locations, activities and objects/surfaces to evaluate associations (via chi-square test, two sample t-test, and simple linear and multiple regressions: significance at alpha 0.05) between all three and other independent variables (i.e., race, age, sex, geographical beach location). Children spent most the time in Seawater (47.9%), followed by the Dune Ridge Area (18.8%), while they spent the most time contacting nothing (24.2%), plastic toys (25.8%) and seawater (18.6%) with the right hand (with similar findings for the left hand). The majority of the time, the mouth was not in contact with anything, however on occasions children ate on the beach (approx. 3 % of time). On occasions, they also put items such as toys, sand or seaweed in their mouths. These detailed contact and time-spent activities improve the accuracy of estimates for dermal, inhalation and ingestion exposures to oil spill chemicals found at beaches by telling a story of how children chose to play based on beach profile and how they contact surfaces in beach microenvironments that may be contaminated. The overall BEACHES project looks at health risk assessment for young children

* Student presenter

Skin-Sediment Adherence Estimated from Hand Press and Body Rinses for Children at Beaches Relevant for Exposure Estimates

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Skin contact at oil impacted beaches can contribute significantly to overall exposures and health risk. The skin-sand adherence metric can play a critical role in the estimate for dermal exposure where children's contact activities with this media is typically more intimate and intense during beach play. There were 122 children that participated in hand press trials upon arrival to the beach and body rinses following videotaping sessions conducted at four different beaches in Miami, FL and Galveston, TX USA. Hand press trials target maximum sediment loading on the palms of the hand and body rinses address total body sediment loadings. This presentation will focus on the results for both sediment adherence to the hands and the body and the relationship between the two, given the influence of grain size. Results showed that the average sand adherence for both hands across the 96 children was 36.09 mg/cm^2 (std. 42.14 mg/cm^2), with boys (40.90 mg/cm^2) showing slightly higher means than girls (32.02 mg/cm^2); however these differences were not significant ($p = 0.31$). The mean of body adherence based on full coverage was much lower at 9.08 mg/cm^2, where there was a statistically significant difference in the mean between boys (10.60 mg/cm^2) and girls (7.80 mg/cm^2) ($p=0.04$). The analysis of variance tests showed no linear relationship between hand and body adherences using regression model ($F=0.3215$); however nonlinear regression model showed statistically significant regression between hand and body adherence ($p < 0.0001$). Further studies using linear regression model show that prediction probability of hand adherence using grain size is statistically significant ($p < 0.0001$), where R-square values indicate that 24% of the variance of hand adherence can be predicted from average ambient sediment grain size. Other fit statistics using linear regression indicates that although full body adherence can be statistically predicted using ambient sediment grain size ($p=0.02$), only 4-5% of its variance can be predicted. Presented also will be the influence of other variables on both hand and body adherence values along with observed body coverage and clothing worn, and a discussion of intermittent loading with play activities. Overall results from this study can be used to evaluate health risk to oils spill chemicals.

Impact of Dispersant on Aerosolization of Crude Oil Content of the Airborne Fine and Ultrafine Particulate Matter

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We have shown that the application of chemical dispersant onto a crude oil slick increases the concentration of airborne fine and ultrafine particulate matter ($PM_{2.5}$ and UFPs) aerosolized due to the natural oceanic processes. Finer PM generally intensifies the health impacts due to effective penetration and larger surface area interactions with alveolar region of the human respiratory system, but a complete toxicity assessment of the exposure should consider the chemical composition of the PM. In this study, we determined the impact of adding Corexit 9500A at dispersant to oil ratios of 1:25 and 1:100 on crude oil content of $PM_{2.5}$ and UFPs aerosolized from a 0.5-mm crude oil slick in a bubble bursting tank. Gravimetric and chemical analysis of $PM_{2.5}$ were performed using a personal micro-environmental aerosol speciation sampler. Chemical analysis of the UFPs was studied using a low-

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pressure Anderson cascade impactor that facilitated chemical detection of the markers separately for particle cut sizes of 1.4, 0.9, 0.52, 0.23 µm. The chemical analysis was conducted through development of a gas chromatography and mass spectrometry technique to efficiently extract oily PM from quartz filters via n-pentane solvent. Dodecane and 1-(-2-butoxy-1-methylethoxy)-2-propanol (BMEP) were identified as markers for crude oil and dispersant, respectively. The highest $PM_{2.5}$ concentration (20.83 $\mu g/m^3$) is related to the case with a slick at DOR 1:25. This concentration is 8.83× greater than the case with pure crude oil. The average crude oil content of $PM_{2.5}$ from the slick of DOR 1:25 and DOR 1:100 were 1.90 and 0.94 $\mu g/m^3$ that are >0.77 $\mu g/m^3$ associated with the slick of pure crude oil. For particles <230 nm, the crude oil concentration was estimated to be 0.99 and 0.44 $\mu g/m^3$ at DOR 1:25 and 1:100 that are >0.11 $\mu g/m^3$ from the slick of pure crude oil. The considerable increase in crude oil content of $PM_{2.5}$ at DOR cases is attributed to UFPs, which is a health concern due to their most effective pulmonary deposition.

Application of Risk Assessment Modeling for Chemicals Found in Shoreline Contamination from an Oil Spill

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Offshore oil spills have the potential to contaminate shorelines and create widespread and lasting impact on ecosystems and communities. Studies have investigated the impacts to ecosystems through the application of ecological risk assessments; however, risk assessments estimating the human health effects associated with exposure to oil spill chemicals (OSCs) are limited. In addition, existing risk assessment differs in the selection of chemicals, along with chosen values for behavioral variables. A major objective of the Beach Exposure And Child HEalth Study (BEACHES) is to assess the potential adverse health risks among young children (walking to six years of age) to OSCs after recreational beach activity following an oil spill event. Data gathered from field observations and family surveys on beach play behavior from 122 children from two beaches each in Miami, FL and Galveston, TX, as well as modeled concentration and distribution data for various OSCs in nearshore environments, were used to generate risk ranges for oral, dermal and inhalation exposures. Computed risks were aggregated to estimate cumulative risk for both cancer and non-cancer from several compounds, including metals, dispersants, polycyclic aromatic hydrocarbons, BTEX chemicals, and saturated hydrocarbons. Hundreds of compounds can be found in crude oil, and several more are formed when crude oil contacts the water and air environments; through the risk assessment process, we identified key factors that inform which chemicals should be included in the model, as well as which chemical-specific variables have the greatest impact on overall risk estimates. These analyses will provide information on current gaps in data and inform future research.

DOSS Studies Towards Optimizing GOM Residents Preparation for and Recovery from Future Disasters

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Dioctyl sodium sulfosuccinate (DOSS) is a principle component of COREXIT dispersants, of which upwards of 2 million gallons were used in remediation of the Deepwater Horizon oil spill and which still remain detectable today in oil spill sediments. DOSS is also an emulsifier in processed food, drink, cosmetic, personal care and medicinal products. Published research on mice demonstrate that physiologically relevant maternal-specific dosing of DOSS leads to a syndrome of disorders in offspring, including increased body weight and adiposity, decreased bone density, inflammation and aberrant lipid/sugar metabolism. Such a pattern of disorders raises the question of whether DOSS exposure also contributes to compromised mental health of disaster traumatized populations. To this end, we ran multiple behavioral tests on adult offspring, including Fear Conditioning, Novel Object Recognition and Elevated Plus Maze to measure cognitive deficits and levels of anxiety. Early results indicate that anxiety disorder is significantly linked to developmental DOSS exposure, and that nutritional and microbiome states can exacerbate anxiety disorder. There are several remaining questions related to DOSS, including but not limited to those related to how maternal exposure leads to poorer lifelong health trajectories in offspring, and those related to dosing and what makes certain people more susceptible to the effects of DOSS exposure. To answer these questions will require more animal testing and dosing/outcome assessments in people. For example, we see that women who took DOSS-containing stool softener during pregnancy have significantly higher levels of DOSS in their breast milks and have damaged milk fat globules, the primary source of proper neonatal nutrition. The simple answer to better preparing GOM residents for, and promoting their recovery from future disasters is to reduce exposure to DOSS and improve key elements of nutrition. The heavy lifting part of this will involve sample testing to identify at-risk populations and changes in legislation to make transparent to the public the presence and prevalence of DOSS in products to be avoided.

Characterization of the Incidence of Children Presenting With, and Acquiring New Skin Abrasions During the BEACHES Study

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Recreational activities among visitors to beaches commonly involve playing in the sand and swimming or splashing in the water, especially among young children. While certain risks associated with these activities, such as sunburns or minor injuries, are usually recognized by families, less recognized may be the risks posed by exposure to potential contaminants found within the sand and water. Chemical pollutants, including those such as from oil spills and their clean-up products, or microbial contaminants, may present a health risk either by accidental ingestion or through dermal exposure. The presence of abrasions or open sores on the skin during activities increases the risk of exposure. The BEACHES project (Beach Exposure And Child Health Study), during the summer of 2018, took place on four beaches, two in Miami, Florida, and two in Galveston, Texas. Families with children were recruited in order to observe various behaviors among the children while playing at a beach. Prior to their play activities, all children had basic biometrics taken, and were examined for the presence of abrasions on exposed skin. At the end of their assigned beach time, children were once again examined for any new abrasion or increased injury to existing abrasions. Of the 122 children who completed the study, 39 in Miami, and 32 in Galveston (58.2% of total), presented with pre-existing abrasions. During beach play, 3 children in Miami and 7 in Galveston (8.2% of total) acquired new abrasions on exposed skin. More females than males

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originally presented with abrasions, and both presenting and acquired abrasions were most commonly found on the legs and knees. Beach play location and behavior may be correlated with risk of acquiring new abrasions. Understanding and recognition of the potential risks associated with the presence or acquisition of skin abrasions during beach going recreational activities may allow families to make more informed decisions.

Deepwater Horizon Oil Spill Exposure and Child Health: A Longitudinal Cohort Analysis

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The BP Deepwater Horizon oil spill (DHOS) raised widespread concern about threats to health among residents of the Louisiana Gulf Coast. This study uses data from the Resilient Children, Youth, and Communities (RCYC) study—a longitudinal cohort survey of households with children in DHOS-affected areas of South Louisiana—to consider the effect of DHOS exposure on health trajectories of children, an especially vulnerable population subgroup. Results from latent linear growth curve models show that although DHOS exposure via physical contact and job/income loss both negatively influenced initial child health, the effects of physical exposure dissipated over time while the effects of job/income loss persisted. This pattern holds for both general child health and the number of recent physical health problems children have experienced. These findings help to bridge research on socioeconomic resources as a fundamental cause of health disparities with research on disasters, resilience/vulnerability, and health.

Understanding Cultural Relationships with Water

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We explore two ways in which humans engage with water through the seafood industry and how cultural practices influence their use of water. This project is part of a larger ethnographic study conducted with Cambodian and Laotian refugee families living along the US Gulf of Mexico. We conducted 10, 1-hour in-depth interviews focused on engagement with water. Using extensive participant-observation that included trips into the Gulf of Mexico and meetings at participants' homes, semi-structured in-depth interviews, and analysis of transcribed data and fieldnotes, we found trends that encapsulate their relationship with water using aspects of culture and lifestyle brought with them from the native countries.

First, we report on the lives of these fisherfolk, how they relate to the natural environment, and how they adapt to natural and technological changes that impact the environment. Narratives reveal how they view changes in water and habitat quality and how that affects the seafood industry as their main source of livelihood. Although only a small portion of this community are boat owners, with most working in seafood processing or other support industries, we also explore the interaction of those boat owners with their prey and the environment. We identified patterns and perspectives that are linked to freedom and liberty. Second, we explore cultural retention in their relationship with water infrastructure, especially in how water is gathered, used and stored — patterns that are seen more broadly throughout the community. For example, gardens and produce serve as an economical means for monetary returns, subsistence, or as cooperative endeavors among members of the community in

* Student presenter

ways that resemble “old” ways of living. Overall, we show how fisherfolk in this community are affected by changes in the environment, how they express their freedom via fishing practices, and how they engage with water in such a way that holds explicit economic and cultural meanings.

Oil Spills and Human Health: Contributions of the Gulf of Mexico Research Initiative

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The Gulf of Mexico Research Initiative (GoMRI) was established in 2010 with $500 million in funding provided by British Petroleum over a ten-year period to support research on the impacts of the Deepwater Horizon oil spill and recovery. Contributions of the GoMRI program to date focused on human health are presented in more than 32 peer-reviewed papers published between 2011 and May 2019. Primary findings from review of these papers are: (i) the large quantity of dispersants used in the oil cleanup have been associated with human health concerns, including through obesogenicity, toxicity, and illnesses from aerosolization of the agents; (ii) oil contamination has been associated with potential for increases in harmful algal blooms and numbers of pathogenic *Vibrio* bacteria in oil-impacted waters; and (iii) members of Gulf communities who are heavily reliant upon natural resources for their livelihoods were found to be vulnerable to high levels of life disruptions and institutional distrust. Positive correlations include a finding that a high level of community attachment was beneficial for recovery in some cases. Actions taken to improve disaster response and reduce stress-associated health effects could lessen negative impacts of similar disasters in the future. Furthermore, GoMRI has supported annual conferences beginning in 2013 at which informative human health-related presentations have been made. Based on this review, it is recommended that the Oil Pollution Act of 1990 be updated to include enhanced funding for oil spill impacts to human health. Much remains to be done in the future to integrate environmental and human impact studies and especially fund research on human health impacts of oil spills. If similar funding opportunities following disasters occur in the future, additional efforts should be made to engage the public health and biomedical communities early in the development of research plans and funding opportunities.

Communication, Preparation, and Response: Environmental Threats Affect Health and Behaviors

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Unprecedented sea-level rise and extreme storm events increasingly threaten coastal communities. This environmental change renders U.S. coastal communities vulnerable to flooding, mold, air pollution, and chemical spills, as well as to property loss and displacement. This confluence of interrelated disaster events challenges people’s ability to adapt, with a profound impact on mental and physical health. This prospective longitudinal study of 1,879 Florida and Texas residents investigates the role of hurricanes and other stressors on trajectories of individual resilience. In this study, we assessed individual level factors including risk perceptions, distress (among other psychosocial measures), media exposure, and evacuation behavior and experience among residents in the days and hours before hurricanes made landfall and/or after. We also assessed exposure to environmental parameters during storm events, including wind speed, storm surge, and air temperature; as well as assessed the aftermath of storm events for individuals, including proximity to infrastructure damage and flooding. Since 2017, we have

repeatedly assessed our residents' mental health, physical health, and protective behaviors as their lives have been punctuated by hurricanes, their aftermath, and other stressors. In this talk, I'll present some initial findings regarding the mental health impacts of flooding after Hurricane Harvey on Texas residents. I will conclude with thoughts on the importance of longitudinal designs for understanding resilience, as well as policy recommendations for improving public health outcomes in the face of hazards and disasters in U.S. coastal communities.

How Disasters Drive Media Channel Preferences: Tracing News Consumption Before, During, and After Hurricane Harvey

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Understanding public media channel preferences can inform preparedness plans, response strategies, and long-term recovery. Questions remain about how media consumption changes across pre-crisis, crisis, and post-crisis phases. Preferences may change due to a range of factors, such as perceptions of quality, access costs, and a range of contextual factors. This paper takes advantage of a survey fielded to Texas residents soon after Hurricane Harvey, longitudinally following individuals from an earlier survey of Gulf Coast residents' regarding the Deepwater Horizon oil spill. Here we ask: (1) What media channels are most prominent in each crisis phase? and (2) Does a crisis like Hurricane Harvey influence media channel preferences for affected residents? Specifically, respondents were asked for their main news sources as the hurricane approached, during the hurricane, and once rain and flooding ended. As seen elsewhere, results show that television was a dominant media channel chosen by respondents, although some respondents reported preferences for the internet, social media, and word-of-mouth sources. By and large, media preferences did not change much across crisis phases. For example, most respondents (56%) never wavered from television. However, minor shifting occurred when entering the crisis phase, such as respondents turning to radio (8%, up from 3%) and about one third of internet users who gravitated towards television. This stability of media channel preferences is contradictory to existing mass media theories that predict greater variability in information seeking throughout the crisis lifecycle. The findings also offer considerations for emergency response, primarily that some individuals originate and remain in certain media "lanes." For example, simply prioritizing television during a crisis might leave out factions of audiences who consistently choose to seek information elsewhere.

A Conceptual Framework for a Community Environmental Health Observing System in the Gulf of Mexico Region

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A common limitation of human health studies after recent disasters in the Gulf of Mexico (GoM) was the lack of baseline health information, highlighting the need to establish sustained human health observations to improve disaster preparedness. The Research Board of the Gulf of Mexico Research Initiative, acknowledging that no such system exists, commissioned our work. We describe a Community Health Observing System framework consisting of 6 data domains: (1) existing, large-scale national surveys: the National Health and Nutrition Examination Survey (NHANES), Behavioral Risk Factor

Surveillance System (BRFSS), and National Health Interview Survey (NHIS); (2) a proposed new Augmented BRFSS survey specific to Gulf states; (3) relevant data from the NIH All of Us national longitudinal study; (4) a proposed new Large GoM longitudinal environmental epidemiologic cohort study; (5) a proposed new Small GoM longitudinal cohort study; and (6) a proposed new Disaster-Specific longitudinal cohort study. Domains 1-3 will serve as reference data nationally and for the Gulf's populations. Domain 4 is intended to serve as an inter-disaster baseline, currently lacking for the GoM. Domain 5 is nested in domain 4 and would allow for more in-depth data collection including biomarker assessments, while the domain 6 study will commence immediately post-disaster. Domain 6 will include participants from domains 4 and 5 as appropriate, but will also target the most vulnerable populations, likely necessitating recruitment of new members based on disaster exposure. Domain 6 will also require rapid distribution of new data collection instruments, modified for a particular disaster. Details of the proposed new cohort studies and data collection efforts will be presented. Uniquely important characteristics of the framework are a commitment to continuous collection of health data before, during, and after disasters and the incorporation of Allostatic Load as a measure of stress health impacts.

Session 017: Application of Remote Sensing to Oil Spill Monitoring and Classification

Comparison of Aircraft L-Band SAR Imagery with *in-situ* Oil Spill Thickness Measurements

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Starting with the initial results using the L-band NASA-UAVSAR airborne SAR system over the Deepwater Water Horizon in 2010, we have examined whether or not this instrument can reliably detect thicker oil within an oil spill. This airborne sensor provides fine resolution, low noise radar imagery under all weather and solar conditions and is fully polarimetric, which enables multiple methods to clarify the separation of oil from water. The very low system noise of this instrument, considerably better than all satellite SAR instruments, enables a detailed examination of the zones of reduced backscatter caused by oil spreading over seawater. Our results show that the varying surface wave damping within an oil slick affects the radar response and appear to delineate thin, oil sheen from thicker, emulsified oil. In this study we use UAVSAR data acquired over the MC-20 Taylor Energy site in the Gulf of Mexico obtained in 2016 and compare the variations in radar backscatter returns to coincident in situ measurements of oil thickness obtained with varying methods. We also consider wind and wave conditions for these comparisons. In addition, we examine the sea surface temperature, coastal currents, and the Mississippi River plume in altering the varying radar responses to likely changes in the oil thickness caused by aggregation and short-period weathering.

This work was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

* Student presenter

Optical Interpretation of Oil Emulsions: From Laboratory Measurements to Remote Sensing Applications

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Water in oil (WO) and oil in water (OW) emulsions from marine oil spills have different physical properties, volume concentrations, and optical properties (spectral reflectance ($R_u(\lambda)$, sr^{-1}), and spectral absorption ($a(\lambda)$, m^{-1})). In this study, the optical properties of both types of oil emulsions with different volumetric concentrations are determined from carefully prepared oil emulsion samples, from which remote sensing applications are demonstrated. The concentrations of stable WO and OW emulsions range from 45% to 95% and from 0.025% to 3%, respectively. They exhibit different R_u spectral shapes in the near-infrared and shortwave-infrared bands, with five "-CH" molecular bonds evident in the WO emulsion spectra. Values of R_u (600 - 1400 nm) of OW emulsions increase with concentrations from 0% to 3.0%, but values of R_u (600 - 2400 nm) of WO emulsions decrease with concentrations from 45% to 100%. On the other hand, for a fixed concentration (80%), R_u (600 - 2400 nm) of WO emulsions increases monotonically with thicknesses of up to ~0.4 mm. The potentials of these findings in remote sensing applications are demonstrated using hyperspectral AVIRIS imagery and multi-spectral Landsat imagery collected over the Deepwater Horizon (DWH) oil spill in the Gulf of Mexico (GoM). False color RGB Landsat composite images (R: 1677 nm, G: 839 nm, B: 660 nm) are effective in differentiating WO and OW emulsions as they show reddish and greenish colors, respectively. A decision tree method is developed to classify oil type and quantify oil concentration for each type, with results partially validated through spectral analysis and spatial coherence test. The numerical mixing experiments using AVIRIS pixels further indicate that the SWIR bands (especially 1295 nm) may be used to develop linear unmixing models once the coarse-resolution oiled pixels are first classified to WO and OW types.

UAS Remote Sensing of Oil Spills for Operational Response and *in-situ* Characterization of Oil Detections Obtained by SAR and Optical Satellites

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We have developed a UAS system that collects multispectral data in order to characterize oil slick thicknesses and emulsification ratios. This system consists on a UAS that carries multiple cameras that integrate sensors ranging from Ultra-Violet (UV) to Long Wave Infrared (LW-IR). This system has been originally tested at OHMSETT, at the MC-20 site in the Gulf of Mexico, and at the natural seeps offshore from Santa Barbara, California. This UAS was put in operation during the Lake Washington Wellhead blowout in Louisiana. In here we present examples of how this operational tool allowed oil spill responders to efficiently deploy containments of the floating oil (booming) and to monitor the collection of the oil on real time. This system is capable of broadcasting real time video of thermal and visual cameras displaying the location of the UAS live on the internet. Moreover, using a rapid classification algorithm, the multispectral data collected by our UAS allowed us to make a detailed high-resolution classification of the oil detected for in-situ validation of satellite observations.

* Student presenter

Surface and Subsurface Data Integration, Visualization, and Decision-Making Support

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NOAA and BSEE have been collaborating to validate the ability of remote sensing to provide significant operational data and deliver it to decision makers in support of emergency response and damage assessment. The focus of this work has largely been on ocean slicks using satellite, manned and unmanned aircraft, however recently there has been renewed interest to define measures of oil in the water column using tethered as well as autonomous underwater vehicles (AUV) systems to further improve oil release estimates from incidents. As part of these most recent efforts and in partnership with EPA, WHOI, BSEE and the USCG we have deployed an AUV equipped with sensors for oil quantification, characterization and quantify oil in the water column. Utilizing the Santa Barbara natural seeps, we have worked to demonstrate how an AUV can provide rapid assessments of spilled oil at fine spatial and temporal resolutions that when combined with surface assessments result in more comprehensive assessments.

In addition, this project has the dependent goal to develop data collection, processing and delivery workflow(s) to provide these data to decision makers in an operational timeline. The Environmental Response Management Application (ERMA®) is a web-based mapping tool that helps support emergency responders and resource managers data driven decision making. ERMA combines near-real-time (satellite, UAS, AUV) and static data to display an interactive map that provides information in context. For this project ERMA has been leveraged to ingest processed data in real and near-real time from multiple sensors to provide an integrated picture for field responders, operations and for off-site situational awareness.

This presentation focuses on the use of these data in NOAA's common operational picture (COP) ERMA and the how the combination of data collection, delivery and visualization are critical for understand risk and effective response decision-making.

Remote Sensing Techniques for Oil Spill Monitoring and Storm Damage Assessment in an Operational Context

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NOAA is responsible for monitoring coastal US waters for accidental and deliberate oil spills, as well as for the emergency response and environmental assessment and restoration following such events. In addition, in the aftermath of severe storms, NOAA assesses the status of and potential damage to offshore platforms and pipelines, which are potential sources of significant oil leaks and marine debris. All-weather and high-resolution data from the enlarging set of spaceborne synthetic aperture radars (SARs) and high-resolution optical satellites offer an important opportunity for NOAA to exploit remote sensing for automated oil spill response and remediation and post-storm offshore infrastructure assessment.

* Student presenter

Here we have embarked on a multiple-institution NASA project to:

1. Develop and mature automated oil spill detection and thickness estimates from SAR and optical imagery, based on focused field testing combined with *in-situ* oil sampling, and incorporate new sensors (NISAR, Radarsat Constellation Mission, etc.) over the course of the project.
2. Improve post-storm assessment of offshore oil and gas production facilities and marine debris.
3. Implement these new algorithms and databases in a semi-automatic system that NOAA uses operationally to detect and assess oil spills and post-storm offshore damage and debris. These products will be delivered through NOAA to enable rapid situational assessment and an optimized deployment of rescue and oil remediation and recovery resources.

We will describe our efforts thus far and the approaches we intend to take to have an operationally ready oil thickness product the end of this four-year project.

Characterization of Sound Induced by Bubbles Released from Nozzles

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In an oil spill event, the leaked crude oil creates underwater sound through bubble oscillations and fluid jets. The sound can be used for early monitoring of the event. In this laboratory study, sound induced by bubbles in two types of oil leakage were simulated: a few bubbles and constant flow bubbles. We investigated sound emitted by bubbles released from nozzles, aiming to obtain the characteristics of the oil leakage from the recorded sound signals. For the few bubble case, the dependences of bubble size and frequency on the nozzle diameter were measured. A relation between the average size of bubble and acoustic frequency with the nozzle diameter was used to explain the measurements. In the case of constant flow bubbles, different flow rate was tested. The relation of acoustic energy with the flow rate was obtained from the experimental data. Bubble size distribution was obtained from the spectrum of recorded sound signals. The physical modeling of the bubble sound will be presented and discussed.
[Funded by the Gulf Research Program of the National Academy of Sciences]

Session 018: Impact of Multiple Stressors on Gulf Ecosystems After Oil Spills

Toxicity of Common Environmental Contaminants on Two Estuarine Species Following Multi-Stressor Impacts

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Laboratory testing was used to assess multi-stressor interactions with three common environmental contaminants: an insecticide, bifenthrin; a PAH, pyrene; and an antibacterial agent, triclosan. Bifenthrin is a synthetic pyrethroid applied to crops, turf, and residential structures for the control of insects. Pyrene is one of the polycyclic aromatic hydrocarbons found in coal-tar, crude oil, and gas. Triclosan is a chlorinated biphenyl ether found in a variety of consumer products as an antimicrobial compound. All three of these compounds can enter estuaries through sewage treatment, runoff, or chemical spills. These chemical mixtures can yield additive or synergistic impacts that may alter oil fate and effect

* Student presenter

models. Early life stages of estuarine crustaceans and fish are the most vulnerable to effects of contamination from these compounds. The toxicity of mixtures of bifenthrin, pyrene, and triclosan on the larval stages of an estuarine crustacean and fish will be assessed along with compounded effects of changing temperatures and salinities. The data will inform response and restoration methods with the goal of reducing the damage to salt marsh organisms and accelerating recovery time for these critical environments.

Effects of Polycyclic Aromatic Hydrocarbons and Abiotic Stressors on *Fundulus grandis* Transcriptomics

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Following the 2010 Deepwater Horizon oil spill, extensive research has been conducted on the toxicity of oil and polycyclic aromatic hydrocarbons (PAHs) in the aquatic environment. Many studies have identified the toxicological effects of PAHs in estuarine and marine fishes; however, only recently has work begun to identify the combinatorial effect of PAHs and abiotic environmental factors such as hypoxia, salinity, and temperature. This study aims to characterize the combined effects of abiotic stressors and PAH exposure on the transcriptomes of developing *Fundulus grandis* larvae. *F. grandis* is a common estuarine species that is regularly exposed to fluctuations in water temperature, salinity, and dissolved oxygen levels, making it an ideal candidate for investigations into the effects of combined stressors in the estuarine environment. In this study, *F. grandis* larvae were exposed to varying environmental conditions (dissolved oxygen (DO) 2, 6 ppm; temperature 20, 30°C; and salinity 3, 30 ppt) as well as a low dose high energy water accommodated fraction (HEWAF) (∑PAHs 15ppb). Whole larvae were sampled for RNA and transcriptional changes were quantified using RNA-Seq. Expression analysis revealed that multiple genes associated with cardiac and hepatic function were differentially expressed in larvae exposed to PAHs as well as those exposed to hypoxic conditions. Larvae exposed to PAHs also showed an upregulation in genes involved in xenobiotic metabolism. Results of this study will provide a holistic view of impacts of PAHs and common environmental stressors on early life stage estuarine species.

Sex Change and Reproductive Development of the Hermaphroditic *Centropristis philadelphica* In and Around the Gulf of Mexico Hypoxic Zone

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Hypoxia, waters with low levels of dissolved oxygen, is a rapidly growing problem in the Gulf of Mexico (GOMEX). Nutrient pollution fueling increased algal biomass and the subsequent decomposition of this algal biomass by bacteria is responsible for the low levels of dissolved oxygen observed annually across large portions of the shallow GOMEX. Hypoxic conditions are not confined to the northern GOMEX as bacterial respiration has the potential to deplete the dissolved oxygen in many different situations, such as in the breakdown of hydrocarbons by aerobic bacteria, either naturally or in the context of remediation. Hypoxic conditions are known to have various ecological and physiological effects on marine life, with one of the most potentially disruptive physiological effects being ovarian masculinization and reproductive impairment. Studies have shown a clear link between hypoxia exposure and ovarian masculinization in the gonochoristic Atlantic croaker, *Micropogonias undulatus*

(Thomas and Rahman 2011). The molecular pathway responsible for ovarian masculinization in *M. undulatus* is similar to the molecular pathway utilized by protogynous groupers to transition from female to male in the normal course of their reproductive development. Using the closely related protogynous *Centropristis philadelphica* as a proxy for larger and harder to sample grouper we examined and compared the reproductive health, sex determination, and gonadal structure of *C. philadelphica* sampled from hypoxic sites with those sampled from normoxic sites in order to determine if hypoxic conditions alter the reproductive development *C. philadelphica*. Results on *C. philadelphica* can then be applied to protogenous grouper in order to better inform future research, sampling, and monitoring efforts. The potential of large-scale alteration of the reproductive biology of a group of fishes as commercially, recreationally, and culturally important as groupers needs to be investigated to the fullest extent. Our work is designed to be an early step in this important line of questioning

The Relative Toxicity to Fish Embryos of PAHs and Photo-Products in Weathered Oil Residues

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Many studies on the toxicity of oil spilled into the marine environment focus on the well-known adverse biological effects of non-polar polycyclic aromatic hydrocarbons (PAHs). Increasing evidence suggests polar compounds formed during weathering also can contribute to toxic effects. This study was designed to quantify the relative toxicity of non-polar and polar oil compounds in seawater contaminated with weathered oil residues. For this purpose, water accommodated fraction (WAFs) were produced with a weathered slick oil collected during the Deepwater Horizon response ("Juniper" oil), which was subject to photo-oxidation on the sea surface. Oil constituents were extracted from the WAF and separated into a polar and non-polar fraction using silica gel column chromatography. The whole, polar and non-polar fractions were diluted back into seawater for testing. Toxicity was assessed using developing embryos of a well-studied marine fish, the Atlantic killifish (*F. heteroclitus*). Survival and deformities were measured at mid-development (10 days post-fertilization, dpf). At tested concentrations, the non-polar fraction was minimally toxic, while the whole and polar fractions were completely lethal to killifish from a pollution-sensitive population, and only slightly less toxic to killifish from a pollution-tolerant population. Chemical analysis revealed a variety of oil photo-products, including oxygenated PAHs, n-alkanoic acids, and 2-alkanones, present in the whole and polar WAF extract. Biomimetic extraction using solid phase microextraction (SPME) served as a proxy for the bioavailability of compounds into embryos, and provided a basis to infer the contribution of these compounds to the observed toxicity. Together, SPME and toxicity results suggested that compounds in the polar WAF fraction may contribute more to toxicity than compounds in the PAH-containing non-polar fraction. Overall, our results imply that oil photo-products are potentially responsible for some of the observed toxic effects in fish embryos.

Fates of Petroleum Hydrocarbons in Louisiana Coastal Marshes Since the 2010 Deepwater Horizon Oil Spill

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* Student presenter

The blowout of the Macondo oil well 50+ miles off the coastal shoreline of the Mississippi River's delta in the Spring and Summer of 2010 resulted in a significant portion (~15%) of tidally affected marsh to be contaminated with liquid oil from this spill. However, the release was of "live oil" in mile deep waters, and the liquid oil that reached the Gulf's surface had been weathered by extensive dissolution during the oil's transit to the surface. Additionally, after surfacing, the oil was evaporatively and photochemically weathered with minor biodegradation during its transit to the shoreline. This presentation will describe the composition of oil that made it to Louisiana's impacted marshes and beaches, and describe the fates of the stranded petroleum hydrocarbons during the summer of 2010 and since as determined from GCMS analyses of over 2000 samples of coastal waters and sediments and from direct observations of the stranded oil residues. It will focus on degradative fates and residue concentrations of normal alkanes (C10 to C35,) two to six ringed PAH compounds and their respective C1 to C4 alkyl homologs, and the hopane and sterane petroleum biomarker compounds, and their persistence and compositional changes from 2010 to 2018.

Multiple Stressors and Marsh Shoreline Erosion Following the Deepwater Horizon Oil Spill

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Multiple peer-reviewed papers have been published on the effects of the Deepwater Horizon oil spill on marsh shoreline erosion rates, often concluding that marsh oiling accelerated erosion, at least in heavily oiled areas. However, a recent paper indicated that multiple disturbances should be considered when examining marsh erosion following oil spills, concluding that prior Hurricane Katrina effects on background erosion rates may have driven differences in marsh shoreline retreat in oiled versus reference areas, rather than or in addition to Deepwater Horizon oil spill effects. We have already published shorter-term data (2010-2012) on marsh erosion rates in a heavily oiled shoreline cleanup test area/field experiment and adjacent reference sites we monitored following Deepwater Horizon. We plan to examine and present for the first time our longer-term data over 2010-2016, coupled with examination of Hurricane Katrina influences on background erosion rates in our monitoring plots using historical aerial photography. We suspect that our study area may provide a good control for Hurricane Katrina effects, as fetch and wave exposure are relatively similar across our heavily oiled and reference plots, perhaps allowing a more direct examination of oiling effects. We also plan to examine other multiple influences on marsh shoreline erosion in our oiled study area, such as different shoreline cleanup activities, restoration planting, and perhaps post-Deepwater Horizon tropical storms.

The Role of Sulfur Functionality in the Production of Photogenerated Water-Soluble Compounds from Surrogate and MC252 Crude Oils

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Photo-oxidation of surface oil has been implicated as a critical weathering process in oil spills (e.g., Deepwater Horizon (DWH)) and has been shown to produce oil/water-soluble photo-transformation products. The conclusion was based on numerous laboratory microcosm studies to mimic petroleum

* Student presenter

weathering after spills. However, due to the low availability of unweathered Mississippi Canyon (MC) 252 well (from which the DWH spill occurred), many studies used a surrogate crude oil (of similar composition) that was collected from the Gulf of Mexico. Although chemically similar to the oil spilled in DWH, previous studies have revealed minor differences between surrogate and MC252 and suggest the production of different photo-oxidation products.[1] For example, one study observed differences in the carbon number range of photo-oxidized species, suggesting differences in boiling point. Our initial studies noted large differences in the relative abundance of sulfur-containing products; thus, we focus here on sulfur functionality. Although the sulfur content is low (<0.5%) in light sweet crude oils (e.g., surrogate and MC252), high abundances of SO_x species have been observed in the water-soluble fraction produced by irradiation of the surrogate oil. Furthermore, sulfur-containing polyaromatic hydrocarbons have been shown to photo-oxidize and become water-soluble,[2] however the role of sulfur-functionality in the production of water-solubles has not been studied. To reveal the role of sulfur functionality in the generation of photo-transformation products, surrogate and MC252 crude oil are separated into thiophene, sulfide, and thiol fractions,[3] that are subsequently irradiated in a solar simulator, and analyzed by ultrahigh resolution Fourier transform ion cyclotron resonance mass spectrometry to reveal the sulfur functionalities of the oil/water-soluble photo-oxidation products. The experiments facilitate direct comparison of surrogate and MC252 sulfur-containing products.
References: (1) Mar. Pollut. Bull. 2016, 104 (1-2), 262-268. (2) Environ. Sci. Technol. 2009, 43 (21), 8119-8125. (3) Energy Fuels 2015, 29 (10), 6177-6186.
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The Response of Indigenous Microbial Communities in Louisianan Saltmarshes to the Deepwater Horizon Oil Spill Over Time

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Microbial communities play a critical role in the biogeochemical cycles that regulate water quality, recycle nutrients and detoxify chemical pollutants in coastal saltmarshes. This study describes the time-series oiling impacts on indigenous microbial communities in salt marshes in Barataria Bay, LA over eight years. We established 21 saltmarsh sites, 7 for each category of reference, moderately oiled, and heavily oiled in 2011 based on the Shoreline Cleanup Assessment Technique ground survey, and collected soil microbial samples from these sites biannually from 2011 to 2018. We extracted DNA from the soils and employed 16S DNA amplicon sequencing to determine the changes of soil microbial communities under different oil pressures over time. Our results showed that oiling significantly decreased α-diversity and changed the structure of the microbial communities during the early oiled stage. Alphaproteobacteria and anaerobic bacteria related to nitrogen and sulfur cycles were enriched in heavily oiled sites. As oil concentrations decreased with time, microbial diversity increased, and potential hydrocarbon-degrading *Proteobacteria*, *Firmicutes* and *Bacteroidetes* were replaced with *Choroflexi*, *Chorobi*, *Acidobacteria* and *Planctomycetacia*. Further oil-degrading bacterial clone library analysis showed that PAH-RHDα GP genes became more diverse in 2018. Additionally, the co-occurrence patterns of soil microbiome revealed that hydrocarbons were degraded mainly through co-metabolism. Our study indicated that the bacterial communities at heavily oiled sites did not return to the primitive community structure of the reference sites eight years after the oil spill but have evolved into a new state.

* Student presenter

Environmental Factors Influencing the Recovery of Soil Microbial Communities in Heavily-Oiled Salt Marshes Eight Years After Deepwater Horizon

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In this study, we describe the long-term (8 year) effects of oiling on soil microbial communities in salt marshes in Barataria Bay, LA. We established 21 reference, moderately oiled, and heavily oiled salt marsh sites (7 for each category) in 2011 to document the long-term effects of oiling on the vegetation-soil-microbial system. We collected soil microbial samples from these sites biannually from 2011 to 2018 with concurrent collection of vegetation, soil properties, benthic infauna, and macroinvertebrate data. DNA was extracted from the soils and 16S amplicon DNA sequenced on an Illumina MiSeq instrument. Analysis of the sequences indicated that the soil microbial community composition was significantly different between heavily oiled and reference sites 8 years after the spill. The shifts were significantly correlated with total petroleum hydrocarbon concentrations in the soil and with quantities of live belowground plant biomass at the sites. We used a permutation-based dissimilarity analysis to determine which taxa significantly contributed to the oiling effect on microbial community composition. In May 2018 the difference in the soil microbial communities between reference and heavily oiled sites was driven by a greater abundance of a Myxococcales taxa at the reference. Communities in moderately oiled sites were primarily distinguished from the heavily oiled sites by a greater abundance of a nitrogen-fixing bacteria (family Rhodospirillaceae). We found no significant difference between moderately oiled and reference sites after 8 years. Our findings suggest that soil microbial communities in heavily oiled sites were significantly impacted over a longer duration and that the change in composition was indicative of shifts in the metabolic capabilities in the microbiota at the base of the food web. These results broaden the understanding of oil spill impacts on salt marshes and are important for decision making on restoration efforts in future oil spills.

The Influence of the *Spartina alterniflora* Microbiome on Removal of Oil from Marsh Soil

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Much of the work following the Deepwater Horizon oil spill focused on whether microbial communities enhanced biodegradation of oil in coastal and marine environments. In the salt marshes of the northern Gulf Coast, a natural extension of previous work is to ask how changes in microbial communities of the salt marshes influenced the resilience and functionality of salt-marsh macro-communities. The foundational salt-marsh grass *Spartina alterniflora* was found to be fairly resilient to the oiling it received in 2010, yet it is unclear if the resilience was enhanced by the plant's microbiome. Although several groups surveyed salt marshes for correspondence between oil decay rates and soil microbial community composition, no work has investigated how feedbacks between microbial communities and *S. alterniflora* influence oil decay. It is thought that the relationship between a plant and its microbiome is a reciprocal feedback in which the internal and external microbial communities are shaped by plant chemistry and the plant genetic expression is modulated by microbial processes. The stress-gradient hypothesis posits that during times of stress, interactions will shift to favor mutually beneficial results for the host and microbiome. Recent research has demonstrated that the many organisms can be dependent on interactions with their microbiome, particularly during times of stress. We hypothesized that *S. alterniflora* and its microbiome interact in an oiled environment to enhance each other's survival

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and productivity by biodegrading residual oil in the soil. We tested this hypothesis through a two-year greenhouse experiment in which we specifically examined how *S. alterniflora* and its soil, root, and leaf microbiome influenced each other and how that relationship changed in an oiled environment. We discuss results from this work and the implications for restoration efforts.

A Decade-Long Response and Recovery of Coastal Salt Marshes Following the Deepwater Horizon Oil Spill

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We conducted a decade-long field study to investigate effects of the Deepwater Horizon (DWH) oil spill on coastal salt marshes and their recovery following the spill. We established 21 field sampling stations that received heavy, moderate and no oiling in salt marshes along northern Barataria Bay, one of the most heavily oiled areas during the DWH oil spill. Concentrations of the surface soil total petroleum hydrocarbons were approximately 70 mg g^{-1} and 500 mg g^{-1} nine months after the spill in moderately and heavily oiled marshes, respectively, and were about 50 mg g^{-1} nine years after the spill in heavily oiled marshes. In moderately oiled marshes, dominant plant species, *Spartina alterniflora* and *Juncus roemerianus*, recovered within 1 and 3 years after the spill, respectively. In contrast, recovery of total live aboveground biomass of heavily oiled marshes was <50% nine years after the spill although live *Spartina* aboveground biomass recovered within 2-3 years after the spill; however, *Juncus* had not recovered nine years after the spill. In addition, live belowground biomass in heavily oiled marshes was significantly lower than that of the reference marshes. Heavy oiling still detrimentally affected marsh structure, function and sustainability a decade after the DWH oil spill.

Session 019: Fate of Dispersed Oil

Biodegradation of Chemically Dispersed Oil — Experiences from Lab Studies After the Deepwater Horizon Accident

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After the DWH oil spill, several projects have been conducted at SINTEF Ocean to study biodegradation of chemically dispersed oil and dispersant surfactants in natural seawater (SW). Studies in a flume basin at a temperature relevant for the GoM surface water showed that Corexit 9500A reduced oil droplet sizes of surface Macondo oil, when compared to physically dispersed oil, and faster alkane biotransformation was measured in chemically than physically dispersed oil, while PAH depletion was comparable between the dispersions. Experiments in a slowly rotating carousel system at low SW temperature, and with oil dispersions of defined droplet sizes, showed that hydrocarbon (HC) biotransformation was generally faster in a 10 µm than in a 30 µm dispersion, emphasizing the importance of oil droplet size for the biodegradation. Further studies with small oil-droplet dispersions from different crude oils (paraffinic, naphthenic, asphaltenic) at 13°C showed extensive nC10-*n*C36

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alkane and 2- to 4-ring PAH biotransformation with all oils. Experiments at different temperatures (-2°C to 20°C), and in different SW sources, showed substantial HC biotransformation, even at the lower temperatures, while the SW source seemed to have some influence on degradation rates. Microbial community analyses during all the experiments have shown successive patterns of typical alkane degrading bacteria abundant early in the degradation periods, followed by bacteria associated with degradation of aromatics, in line with the data from the chemical analyses, and in agreement with results from most other relevant studies. Comparison of HC degradation and microbial communities with and without dispersants did not show any inhibition of oil degradation or oil-degrading microbes by the dispersant, even at high dispersant-to-oil ratios. Recent experiments with chemically dispersed oil in the presence of biological (microalgae) and mineral particles have shown comparable biodegradation in the presence and absence of oil-related aggregates associated with the microalgae and mineral particles. Separate studies with dispersant surfactant degradation also demonstrated the biodegradability of these at low SW temperature.

The Role of Nutrient Availability in Regulating the Fate of Dispersed Oil—A Cross-Site Comparison

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Numerous studies have assessed the impact of the chemical dispersants on oil biodegradation and the results of this work are inconsistent and often contradictory. In some cases, chemical dispersants appear to stimulate oil biodegradation while in others, they either have no stimulatory effect or appear to impede biodegradation rates. A number of factors could contribute to these observed disparities, including, differences in microbial community composition, the type of oil, temperature, experimental procedures, etc. One experimental parameter that varies substantially between studies is whether samples were amended nutrients (N, P). We assessed the extent to which nutrients influenced the dispersant response by conducting experiments at three sites in the Gulf of Mexico (GC600, a deepwater natural oil seep; OC26, a deepwater site near the Macondo wellhead; and Taylor Energy, a more shallow anthropogenically impacted site), an oil slick off the coast of Santa Barbara, CA, and, surface water above a shallow (400m water depth) methane seep along the shelf off Cape Hatteras, NC. These sites provided a robust gradient in nutrient and oil exposure regimes. We conducted short experiments with surface water exposed to either nothing (control) or water accommodated fractions of oil (WAF), Corexit 9500® plus oil (CEWAF), or Corexit 9500® (DIS); we had separated a set of treatments with and without nutrient addition. Trends in bacterial production and potential hydrocarbon oxidation rates indicated that site nutrient status influenced the effect of Corexit on microbial communities and their ability to degrade oil. Nutrient stressed communities appear more likely to exhibit a negative response to dispersant addition while nutrient replete communities appear to be more immune to negative dispersant effects. The importance of nutrient status on Corexit-mediated impacts on oil biodegradation rates suggests that such information should be considered when implementing future oil spill response actions and when considering dispersant application scenarios.

* Student presenter

Role of Molecular Structure in the Production of Water-Soluble Species by Photo-Oxidation of Petroleum Compounds

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As global petroleum transportation is rising, oil spills are becoming a major threat to marine ecosystems. It is well known that evaporation is the major mechanism for mass loss in spills of light/medium oils, as they can lose between 40-75% of their spilled volume; however, heavy oils lose less than 10% to these processes. Nevertheless, after evaporation, the remnant material is enriched in the most refractory species, *asphaltenes*, known for a molecular structure enriched in polycyclic aromatic hydrocarbons (PAHs) and S-containing compounds. Therefore, understanding asphaltene weathering is critical for environmental science. This work focuses on the transformation of asphaltenes through irradiation in a solar simulator microcosm and the role of molecular motifs, single-core (*island*) and multi-core (*archipelago*), in the production of water-soluble species. Wyoming deposit (island-dominant) and Athabasca bitumen (archipelago-enriched) asphaltenes are photo-oxidized on artificial seawater. Molecular characterization of oil/water-soluble products, conducted by ultrahigh-resolution mass spectrometry, suggests that island motifs exhibit limited production of water-soluble species, and their oil-soluble products preserve the composition of the starting material. Conversely, archipelago motifs yield a water-soluble continuum of O_x and S_1O_x species that exhibit the typical chemistry of dissolved organic matter (DOM). The lower carbon number/aromaticity of the archipelago products suggests the occurrence of photo cracking. Furthermore, photo-oxidation of small PAHs from a distillation cut yields water-soluble compounds with carbon number and aromaticity 2-fold higher than the starting material, suggesting that polymerization has occurred. Collectively, the results highlight the importance of archipelago motifs and cracking/polymerization in the production of petrogenic DOM. Work supported by the National Science Foundation, Cooperative Agreement No. DMR-1644779 and the State of Florida.

Transformation of Macondo Oil Deposited on the Seafloor: Early (2010-2014) Temporal Compositional Changes Due to Weathering Using FTICR-MS Technology

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Spilled oil in the ocean is continuously undergoing composition changes due to several occurring weathering processes. An estimation of the long-term residual oil survival and its impact to the environment needs analytical capacities beyond gas chromatography-mass spectrometry (GC-MS) approaches, such as Fourier transform ion cyclotron resonance-mass spectrometry (FTICR-MS) to monitor the transformed polar oil constituents in the sediments. One hundred and twelve seafloor sediment samples were selected from the Natural Resource Damage Assessment (NOAA) sample repository (collected between 2010 and 2014) to best reflect the spatial expression of the Deepwater Horizon spill and the temporal dimension of the event; literature data (GC-MS based) assessing the likeliness of oil affected sediments was considered for the selection. The literature data comprised studies from various labs, therefore the first step was to re-analyse the sediments using GC-MS. The GC-MS data was used to determine the presence and abundance of hundreds of compounds typical of oil collected in seafloor sediments. This fingerprinting revealed that 20 sediment samples had a positive match, 9 probable match and 60 non-matching with Macondo oil (23 inconclusive). Based on these results, a subset of samples was analyzed by FTICR-MS in atmospheric pressure photoionization positive (APPI-P) and electrospray ionization negative (ESI-N) ion modes. FTICR-MS allows compounds of varying

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polarities to be analyzed along with high molecular weight aromatic compounds. This is beneficial to track transformation/alteration of oil constituents during weathering processes. The presentation will show that FTICR-MS data revealed additional confidence in oil matching assessment, extent of alteration, new insights into transformation processes and oil to common organic matter input.

Eight Year Evolution of Oil Transformation Compounds in Louisiana Salt Marsh Sediments Revealed by FT-ICR Mass Spectrometry

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The 2010 explosion of the Deepwater Horizon (DWH) drilling rig provides a unique opportunity to advance the understanding of the evolution of lingering oil in Louisiana salt marshes for nearly a decade after the initial spill. Preliminary analysis of saltmarsh sediments impacted by the DWH spill between 2010-2014 identifies highly polar oxygenated hydrocarbons with carboxylic acid functionalities. Here, we employ advanced analytical technologies such as targeted fractionation and isolation methods with Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) to document, and catalog oil transformation compounds detected in oiled saltmarsh sediments. Samples have been continuously collected from 21 previously established sampling stations located in northern Barataria Bay for the past ten years post-spill. The concentration of oil contamination from heavily and moderately oiled sites exceed non-oiled reference sites for years after the spill. Combining chromatographic fractionation, conventional GC MS, and ultrahigh-resolution FT-ICR Mass Spectrometry analyses, we identified tens-of-thousands of biotic and abiotic crude oil transformation products that remain persistent and keep evolving in the environment. Heavily oxygenated transformation products which are mostly only accessible by FT-ICR MS, span a wide range of chemical functionalities. Since chemical functionalities of these petrogenic contaminants dictate their toxicity, water-solubility, stable emulsion formation, and bioavailability, molecular level characterization is necessary for understanding the fate and long-term impact of these emerging environmental contaminants. The current study creates an eight-year-long assessment record, and a comprehensive understanding of petroleum compounds evolution and long-term recovery of oil-impacted wetlands ecosystem. Work supported by the NSF Division of Chemistry through DMR-164479, a grant from the Gulf of Mexico Research Initiative, and the State of Florida.

Oil Droplet and Particle Retention in Turbulent Vertical Flow

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A major pathway by which oil leaves the water column after a spill is though aggregation with solid particles, resulting in negatively buoyant oil-particle aggregates (OPAs). The production of OPAs requires positively buoyant oil droplets and negatively buoyant solid particles to be in close proximity and sufficient turbulent kinetic energy to force their interaction. Traditionally, this has been expected to occur mostly in the surf zone where breaking waves induce turbulence and sediment resuspension. However, recent observations have shown that, under the right conditions, Langmuir circulation can suspend sediment throughout the water column, possibly leading to formation of OPAs in much deeper water. The resuspended material accumulates in localized regions of turbulent vertical motion known as Stommel Retention Zones (SRZs).

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To understand the dynamics of multiple dispersed phases interacting in SRZs, a laboratory facility was designed to recreate regions of turbulent upwelling or downwelling. The experimental facility consists of a 1×0.2×0.5 m tank in which a shear stress is applied on the side walls using conveyor belts, resulting in a counterrotating vortex pair with either a central downwelling or upwelling region of variable mean velocity (0.05-0.2 m/s) and turbulent kinetic energy spanning two orders of magnitude. Planar particle image velocimetry (PIV) is used to characterize the flow patterns across the tank, and volumetric particle tracking velocimetry (PTV) is used to characterize the turbulence within the central upwelling or downwelling region. Particle fluorescence and optical filtering are used to distinguish between PIV/PTV particles and sediment particles or oil droplets in order to simultaneously measure flow fields and particle or droplet accumulation within certain regions. The resulting spatiotemporal distributions of sediment particles and oil droplets can reveal the potential for OPA formation.

Solar Induced Emulsification of Petroleum in Neat Films and Films on Water

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The impact of sunlight on the emulsion capabilities of Deepwater Horizon oil (Macondo well), surrogate oil from a nearby well, and heavy fuel oil (NIST standard 2717a) were evaluated following exposure to simulated sunlight for up to 12 days equivalent of sunlight. The selected oil types ranged from light-sweet to heavy-sour crude oil, and emulsification capabilities of sunlight exposed neat oil, oil over pure water, and oil over sea water were assessed via a bottle test. Dark controls and a heated (50 °C) neat control were compared to irradiated samples. For all exposures, qualitative measures revealed that emulsion stability was positively correlated with irradiation time. The time-dependent behavior of each oil was different, and as little as one hour of simulated sunlight exposure was enough to cause observable emulsification for some oils. Studies with varying oil volumes with fixed surface area demonstrated a concentration dependence of emulsification ability such that larger oil volumes resulted in poorer emulsification ability. Sea water had an inhibitory effect on emulsion capacity. These results indicate that sunlight is an important factor in the emulsification of oil spilled in aquatic systems, with factors such as irradiation time, oil type, oil thickness, and water type being important in controlling emulsification. Since the fate, transport, bioavailability, and toxicity of spilled oil are all impacted, it is important to better understand these factors.

Viscoelasticity of Polymeric Streamers Formed by Bacteria Over a Rising Oil Droplet

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Using *Ecology-on-a-chip* (*eChip*), we have demonstrated that polymeric aggregates can be formed around a rising oil micro-droplet by *Pseudomonas*. The EPS aggregate is initiated by forming trailing streamers with one end anchoring at the droplet surface and the other floating in the flow, which alters "wake" pressure field and consequently causes substantial drag on the drop. Experiments using *Alcarnivorex* and *Marinobacter* further reveal that although the formation of "streamers" is universal, its rheological characteristics vary significantly due to the EPS composition including polysaccharides, proteins, lipids and nucleic acids. To understand complex interactions of streamers and their surrounding shear flows, viscoelastic behavior of streamers must be understood. Here, we apply micro-

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rheology technique to quantify real-time viscoelasticity of streamers developed in a pinned oil droplet in *eChip*. Using high speed microscopy, filament strain is determined by tracking trapped bacteria in real-time and concurrently viscous stresses are measured using PIV-assisted PTV of freely suspended bacteria. Stress-strain shows hysteresis of viscoelastic materials.

Impacts of Particle Properties and Mixing Intensity on Oil-Particle Aggregates by Silica and Modified Kaolinite

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After oil spilled, dispersed oil droplets in the water column would interact with the sediments in near-seashore marine conditions, to form oil-particle aggregates (OPA) due to the particle density and mixing energy. Kaolinite and silica are normal hydrophilic particles in near-shore environment. The properties of particles and mixing intensity were compared in serial to better understand the interaction mechanisms between natural particles and oil droplets in near-shore environment. The hydrophobicity of kaolinite was modified by chitosan at various ratio (0.005~0.04) to obtain different particle-water-air contact angles. The original contact angle was changed from 28.8° to 37.7° at the ratio of 0.02; and 57.3°at the ratio of 0.04. The formation of OPA by modified kaolinite showed obvious difference when samples were collected and scanned by confocal microscope. Penetration happened in these cases and the penetration depth was different. By taking samples from different layers in the water column (surface, middle and bottom), oil trapping efficiency (evaluated based on the amount of oil trapped by particles) was found improved by the increasing of hydrophobicity but trapped oil distribution in the water column varied. Mixing time and shaking speed was changed to present various mixing intensities and the penetration depth and oil trapping efficiency were also compared. Kaolinite concentration was changed at 3 levels to have different oil/particle ration, to compare the oil trapping efficiency and the penetration depth. Silica comes in a different shape (spherical) compared with kaolinite (rod or plate), so their interaction with oil were also compared at the same particle concentration and mixing intensity. Also, silica sizes were changed at 3 microns and 9 microns to evaluate the particles size impacts. There was no penetration in OPAs formed by silica, and there was only small amount of OPAs settled on the bottom in all the mixing conditions.

Session 020: The Deep Gulf of Mexico: Knowns and Unknowns After the Deepwater Horizon Spill

Oil Spill Impacts to Seafloor Sediments on Monthly to Decadal Time Scales

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The 2010 Deepwater Horizon (DWH) oil spill resulted in a pulse of sediment deposited on the Northeastern Gulf of Mexico (NEGoM) seafloor in <5 months. The depositional process, known as

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MOSSFA, has been well documented, and is responsible for: 1) depositing a 1-2 cm thick sediment layer covering up to 35,000 km^2, 2) shoaling of the redox front within the sediment column, 3) severely decreasing abundance and diversity of benthic faunae, and 4) reducing bioturbation. Sedimentologically (texture, composition, sedimentation rates, source(s), transport and depositional mechanisms), much of the system appears to have recovered 1-2 years following the DWH event. Bioturbation started to return at some sites as early as 3 years following the event, but still (as of 2017) has not returned at other sites. The redox boundary reached a new equilibrium within 3 years after the initial impact of the sediment pulse. Benthic foraminifera abundance and diversity reached a steady state 3-5 years after the initial impact, but some assemblages remain significantly different than pre-event assemblages. Recent investigations show that there may be even longer-term impacts by the remobilization and transport of potentially-impacted sediments to down-slope depocenters by gravity flow processes. Sediments collected southeast of the DWH impacted area contain gravity flow deposits with sediments originating within the original DWH impacted zone, that have been transported >250 km to the SE. The response of the NEGoM sedimentary regime initially impacted by DWH can be described in three primary categories: 1) recovered to pre-event status within a few years, 2) has shown no recovery or change since initial impacts, or 3) has, or is in the process of, stabilizing to a new equilibrium. It could be years to decades before this can be fully characterized. It is imperative that all time scales be considered when investigating potential seafloor impacts of future oil spills.

Short-Term Sedimentary Processes Using $^{234}Th_{xs}$: Detecting Events and Developing New Baselines

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Natural and anthropogenic events can produce detectable impacts to sedimentary systems that are often defined by how and to what magnitude sedimentation is altered from pre-event/natural sedimentation patterns. For short-duration events such as oil spills, hurricanes, and sediment mass wasting events on slopes and canyons, high-resolution approaches to investigate sedimentary impacts are required. For the 2010 Deepwater Horizon (DwH) oil spill, high-resolution sampling of sediment cores (2mm resolution) allowed for the detection of increased sedimentation rates, fluxes of oil and contaminants to the seafloor in 2010/2011 and post-depositional chemical and benthic ecosystem impacts. This required defining pre-event/baselines for sedimentation patterns by using downcore (pre-event), as well as continued post-event sediment studies (annual core collection/time-series) using the same high-resolution sampling and analyses. Increased short-term (months) sedimentation rates (4-10 times higher than baseline) and lack of bioturbation, as defined by excess Thorium-234 ($^{234}Th_{xs}$) geochronology, characterized the major impacts of the DwH oil spill on sea-floor sedimentation and biological processes. This increase was validated by the post-event time series (2012-2017) indicating lower short-term (months) sedimentation rates defined by $^{234}Th_{xs}$ geochronology and site specific return of bioturbation at the same sites ~3 years following the spill. The construction of Gulf-wide baselines is underway for short-term sedimentation rates and mixing/bioturbation that can be used to define impacts of future events using measurements of $^{234}Th_{xs}$ associated with multiple studies in the Gulf of Mexico (Cuba, southern and northern GoM). These studies increase the understanding of the spatial and

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temporal variability of short time-scale sedimentary processes using $^{234}Th_{xs}$, including the strengths, limitations, and integration with $^{210}Pb_{xs}$ sediment dating to better understand sedimentation and accumulation patterns/variability on multiple time-scales (months, years, and decades).

Resuspension and Redistribution of Sediments in the Deep Gulf of Mexico — A Laboratory Sed-Flume Study

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A large percentage of the oil released during the 2010 Deepwater Horizon (DwH) oil spill was either chemically or naturally dispersed or settled below the sea surface. A large Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA) event removed most of all the material in the water column in a matter of weeks and with it transported a significant portion of the released oil to the sediments in a very short time. We are interested in the fate of this deposited material after it settled onto the seafloor. In a previous study, a large amount of data from a diverse selection of instruments were pooled to analyze some of the seafloor sediment resuspension events of different scales and magnitudes. Those analyses were based on the available limited amount of data of current speed near the sea floor and did not offer any insights into size specific sediment resuspension. Here we will discuss the laboratory study that focusses on the resuspension of sediment cores under controlled flow conditions. 27 cores were collected in the deep SE Gulf of Mexico using an Ocean Instruments multicorer. All cores were recovered with a nearly undisturbed sediment-water interface. These cores were analyzed in a SedFlume for size specific particle erosion of the surface layer over time under varying controlled turbulent flow conditions. Data of size specific resuspension of material and how it relates to the seafloor morphology and the depositional environment on the seafloor will be presented.

Grain Size Analysis of Resuspended Deep Gulf of Mexico Sediments

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Following the release of ~4.9 million barrels of oil into the Gulf of Mexico from the Macando wellhead, a vast area of the seafloor contained recently deposited, contaminated marine sediments. The initial deposition of these contaminated marine sediments was likely not the end of the journey for the particles. Events of increased current speed in the deep ocean setting can result in recently deposited sediments to resuspend and be moved laterally with the current flow. Understanding the process of resuspension and transport of recently deposited sediments provides information needed to estimate the extent of how much material might have been moved by the currents. Using flow modeling of the Gulf of Mexico, core sites were chosen to be in areas where erosion or deposition is thought to be the dominant local process. Erosion experiments are actively being performed with a Sedflume (McNeil, 1994) to analyze sediment cores from 27 locations collected in the southeastern Gulf of Mexico. Data collected from these flume experiments will provide the difference in the critical velocity needed to begin erosion in these different sedimentation environments. Using image data, size specific, grain size distribution analyses of the recently eroded sediments will be provided, with expectations of Hjulström like results. With larger particles being eroded first, this could support the idea that larger, recently

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deposited marine snow particles can be more easily transported than smaller surrounding particles. Comparing the data from the different sedimentation environments can show if there are erosion tendencies in the different environments. These results will offer a better understanding of the remobilization, transport, and ultimate fate of marine sediments the deep Gulf of Mexico. McNeil, J. 1994. “Measurements of the resuspension and erosion of sediments in rivers.” Ph.D. dissertation, Univ. of California at Santa Barbara, Calif.

Microbes Produce Copious Amounts of Exopolymeric Substances as Biosurfactants: What Happens to All the Excess Organic Carbon?

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Oil-degrading bacteria produce copious amounts of organic matter in the form of exopolymeric substances (EPS) that facilitate their access to oil. The fate of excess EPS from oil degradation is in part determined by activities of heterotrophic microbes capable of oxidizing EPS compounds (mainly carbohydrates and peptides). Oil-derived EPS production has the potential to stimulate microbial food webs and energy flow into higher trophic levels. Moreover, microbial transformation of complex organic matter may support primary oil degradation through (re-)cycling of inorganic nutrients. Despite their importance for microbial food web interactions during oil spills, little is known about microbial responses to oil degradation byproducts such as EPS. This presentation summarizes results from field observations and laboratory experiments on heterotrophic microbial activities in deep Gulf of Mexico environments during and after the DWH spill conducted within the ECOGIG consortium. Microbial enzymatic hydrolysis of carbohydrates and proteins were substantial in deep water oil plumes during the spill, surficial sediments affected by marine oil snow sedimentation, and in bottom waters affected by resuspended sediments near the DWH site after the spill. The results indicate the presence of highly active heterotrophic microbial communities in the deep Gulf of Mexico not involved in primary oil degradation. Secondary microbial activities need to be considered in future oil spills as sentinels for oil induced effects on microbial food web interactions and higher trophic levels.

Following the Flow—An Approach to Analyze the Rise of Particles Throughout the Water Column

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Over the past years the Hamburg Group has used the high-pressure laboratory to study the effects of the deep-water environment on the droplet formation directly at the entrance into the water-column. Using the laboratories Jet-Module a stream of “live” and “dead oil” was injected into seawater pressurized to 150 bar to analyze the droplet size distribution of outbursts occurring at depths of 1500m. This research has led to many new insights. However, as these oil-droplets are rising through the water column they encounter changing conditions and different influences. To study these resulting effects a different test-setup is required. Instead of simulating the inflow of oil into sea water at deep-sea pressures, a drop rise through the water column is simulated. The goal is to vertically stabilize a droplet using a counter-current while steadily controlling the surround environmental factors like pressure and temperature. Details to be analyzed are the influences of these environmental factors on the density, size and velocity of the droplet. Other aspects like possible degassing and hydrate formation

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might be analyzed as well. Simultaneously to the jet-experiments, the foundation to realize this test-setup was developed. While currently the rising-path module is being further improved, first results are expected to be available until February 2020. Besides these new results a brief overview over the pressure lab's other accomplishments of the past years will be given, accompanied by a view to known unknowns and possible future research. This research was made possible by a grant from the Gulf of Mexico Research Initiative (GoMRI), C-IMAGE III.

In-situ Lander Measurements of Methane Concentrations, Transport, and Oxidation in the Deep-Sea Benthic Boundary Layer

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In-situ time series measurements from benthic landers were used to quantify processes controlling methane concentrations, transport and microbial oxidation in deep waters of the northern Gulf of Mexico and Astoria Canyon off the Oregon Coast. In the northern Gulf, methane concentrations depended on current directions and speeds and were highest in bottom waters transported over near gas bubble seeps. Inertial wave motion apparently transmitted from surface storm activity created predicted oscillatory 26 hr periodicity observed during a long 46 day time series. Water transport from non seep areas generally revealed methane concentrations near equilibrium with the atmosphere. Aerobic methane oxidation rates (AMOR) measured in situ at 500 meters depth in Astoria Canyon off the Oregon coast using a new lander based incubation system ranged from 2.2 to 302 nM/day. In situ lander systems developed during the ECOGIG program are now deployable without ROV or submersible support and proven capable of quantifying methane sources, transport and sinks at upper slope and deeper sites in the northern Gulf and other deep-sea sites around the world.

Ocean Dumping of Chlorinated Hydrocarbons Under the Marine Protection, Research, and Sanctuaries Act of 1972

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Now that scientific assessments related to the Deepwater Horizon release are substantially complete, we need to look at data gaps. Baseline conditions were unknown in some cases, and the assessments did not fully evaluate cumulative effects from other stressors on the marine ecosystem.

A large waste drum disposal site is located 50 miles from the Deepwater Horizon site. Not much is known about the waste site, and it appears this question was not considered in the assessments. EPA permitted ocean disposal of drummed chemical waste in US waters during the period of 1973 to 1977 under Section 102 of the Marine Protection, Research and Sanctuaries Act (MPRSA) of 1972. While employed as a water quality subject matter expert and NEPA contributor at the Bureau of Ocean Energy Management (BOEM), the author requested all MPRSA permits from EPA via a Freedom of Information Act (FOIA) request. In May 2016, EPA provided the author with copies of Region 6 permits issued to four chemical companies with barging reports related to the permits. Permit #730D008, issued to Shell Chemical Company, allowed disposal of three waste streams, including chlorinated hydrocarbons. The number of waste drums disposed under Permit #730D008 was estimated by the author at 1,640,000 based on the number of barge trips and the permitted number of 8,000 drums per trip. The area of

Permit #730D008, now being developed by Shell Offshore, Inc., utilizes a Waste Barrel Avoidance and Release Response Plan which allows a minimum stand-off distance of 10 m (33 ft) between drilling equipment and any drums on the seafloor. The Plan states that the drums contain wastes from the manufacture of fungicides and herbicides, and many of the drums may have released their contents over time. The author continued to study the waste site after his retirement, and found information indicating that the waste includes byproduct from Agent Orange manufacture at Rocky Mountain Arsenal by Shell Chemical Company.

Based on these findings, it is suggested that target species in the Gulf of Mexico should be tested for a full suite of chlorinated hydrocarbons, including DDT, PCBs, and dioxin, to evaluate background conditions. These background conditions should be considered when evaluating residual health effects related to the Deepwater Horizon release.

Pleistocene Aged Terrestrial Sediments in the Northeast Gulf of Mexico at 1,800-3,000 Meters Water Depth

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We used radiocarbon to date Pleistocene aged terrestrial-like organic matter near the surface of 10 gravity/ piston cores collected in association with submarine channels located in the 1800-3000 meters water depth in the eastern Gulf of Mexico. The locations of these observations vary from the north-western side of the upper DeSoto Canyon to the flank of the Mississippi Fan at the base of the Florida Escarpment. These apparent terrestrial-sediments are found from 10 to 80 cm below the sediment surface as collected in gravity and piston cores. The characterization of terrestrial-like material is based on 1) a shift in $\delta^{13}C$ of the sedimentary organic matter from -21±1‰ to -26±1‰, a shift in the C/N ratio from 8±2 to 16±2, and a shift in $\delta^{15}N$ from 6±1‰ to 2±1‰. Other biomarkers are being employed to further test this hypothesis. The thickness of these deposits vary but they can be as thick as 2 meters. The channels are 5-10 meters deep, relative to the surrounding topography, and in the upper DeSoto Canyon the Pleistocene-terrestrial material is closer to the surface in the channels than it is outside of them, suggesting either higher Holocene depositional rates outside of the channel and or periodic erosion within the channels as they funnel sediments down-slope. The channels were apparently conduits for sediment flows in the past, and may be active today. Sedimentary structures throughout the cores indicate low density turbidity currents and slumps as the primary gravity flow processes. Sediment types and sources likely include siliciclastics from the NE GoM and carbonates from the adjacent Florida platform. The channels at the base of the escarpment appear to rest upon the seafloor rather than cutting down into it, yet the terrestrial-like sediments are still within a 50 to 80 cm of the surface of these cores.

Development of a Benthic Foraminifera Based Marine Biotic Index for the Gulf of Mexico

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The Gulf of Mexico (GoM) is an economically important region (e.g. oil and gas, fisheries) with diverse environmental stressors. This includes the expansion of oil drilling and potential for oil spills and well blowouts, more frequent and geographically expansive harmful algal bloom events, dead zones expansion, anthropogenic eutrophication events, contaminant loading and changing climatic conditions. It is important that the ecological quality statuses (EQS) of different localities in the Gulf are closely monitored. EQS, as implemented by the European Water Framework Directive, is a surveying tool effective for monitoring benthic ecological health and developing baselines. One such index used to define EQS is the AZTI Marine Biotic Index (AMBI), which pairs species abundance with environmental stressors. Benthic foraminifera are ideal specimens to populate the index due to their varying environmental sensitivities among species, preservation potential, and high diversity and abundance in nearly every marine environment. To calculate Foram-AMBI, species are assigned to one of five groups ranging from sensitive (I) to first-order opportunists (V) based on their correlation to total organic matter and sediment grain size. This study seeks to construct a Gulf-wide Foram-AMBI from 61 sites that will provide baseline EQS for the entire GoM that will satisfy the need for widespread geospatial coverage in the case of future natural or anthropogenic disturbances. The development of a GoM Foram-AMBI will provide an intraregional (Cuba, SGoM, NGoM) and international (North Atlantic, Mediterranean) comparison of benthic habitat suitability for economically important, fish, such as groupers and snappers, that depend on the health of the benthos and also encourage collaborative partnerships between academic scientists and living resource managers throughout the GoM to operationalize, refine and implement Foram-AMBI as a decision support tool.

Predicting Deep-Sea Coral Distribution in the Area Impacted by the Deepwater Horizon Oil Spill: Was the Damage Greater Than We Thought?

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In the years following the Deepwater Horizon oil spill, surveys of the deep benthos revealed extensive injury to deep-sea habitats, including cold-water coral communities dominated by *Paramuricea* species. One of the primary difficulties in assessing the full extent of the injury to cold-water coral ecosystems is the paucity of observational data and the subsequent lack of knowledge of their distribution within the affected region. To assist with the exploration efforts, habitat suitability models were created for *Paramuricea* sp. (haplotypes B1-B3) in order to estimate the number of potentially affected sites in the northern Gulf of Mexico. High-resolution (12.5 m pixel size) models were built using the maximum entropy (Maxent) approach using remotely sensed data including topography, seismic reflectivity of the seafloor, and the amount of productivity exported from the surface. Model outputs were used to estimate the number of potential coral sites, defined as areas with both high habitat suitability and the presence of hard substrate. The estimated number of potential sites was further adjusted based on empirically determined coral occupancy frequencies derived from sites that were surveyed by the autonomous underwater vehicle (AUV) Sentry. Across the entire study area, these models predicted 558 coral sites covering an area of 14.2 km2. Within the smaller 2,291 km2 region shown to have been directly affected by the spill, there were 66 predicted coral sites covering an area of 1.2 km2 with an estimated average of approximately 63 corals per site, which greatly exceeds the four sites found to be injured during surveys following this spill. These results provide important insights into the overall

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magnitude of injury to these vulnerable ecosystems and will help identify and prioritize areas for future research and restoration efforts.

The Deep-Sea Benthic Footprint of the Deepwater Horizon Oil Spill Was Bigger Than We Thought, Which Is Why Sampling Plans Matter

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An earlier analysis of 58 deep-sea stations collected in 2010 demonstrated severe and moderate damage to benthos in an area of 148 km^2 surrounding the Macondo 252 drilling site. An additional 58 archived stations have been analyzed to enhance resolution of that assessment and determine if impacts occurred further afield. A principal component analysis (PCA) was used to summarize oil spill impacts, and the benthic footprint of the oil spill was estimated using Empirical Bayesian Kriging (EBK) interpolation. The spill caused very high levels of total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAH), and Barium in the sediment, and the benthic response was low diversity, low evenness, and low taxonomic richness of the infauna communities, and high nematode to copepod ratios. Based on the larger sample set, we now know the area of impact was approximately 263 km^2 around the wellhead, which is 78% higher than the original estimate. Particularly severe damages to benthic communities were found in an area of 58 km^2, which is 142% higher than the original estimate. The addition of the new stations extended the area of the benthic footprint map to about twice as large as originally thought and improved the resolution of the spatial interpolation. This demonstrates that limiting sampling and analysis to save time and money will result in missing impacts that have actually occurred. Also, the new data proves that optimizing spatial extent is the true form of replication for environmental impact assessment study design.

Session 021: Outcomes from Large-Scale Fishery Monitoring Projects Following the Deepwater Horizon Oil Spill: What Have We Learned, and Where Do We Go from Here?

Restoring Fishes with Enhanced Monitoring: A Funder's Perspective on the Benefits of Investing in Fisheries

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The Deepwater Horizon Oil Spill resulted in an unprecedented injury to fishes in the Gulf of Mexico. It was estimated that trillions of larval fishes died from exposure to oil and dispersants, resulting in a significant loss of fisheries productivity. In 2013, as part of a settlement to resolve certain criminal charges against BP and Transocean, $2.544 billion was paid to the National Fish and Wildlife Foundation (NFWF) to conduct or fund projects that remedy harm or reduce risk of future harm to Gulf Coast natural resources of a type injured by the Spill. NFWF subsequently established the Gulf Environmental Benefit Fund (GEBF) to identify, fund, and administer these projects. Several Gulf States were

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particularly interested in utilizing the GEBF to restore fishes impacted by the Spill. It is, however, notoriously difficult to restore fishes because of uncertainty surrounding the drivers of population dynamics and potential confounding effects of changes to fisheries and their management. Because fishing pressure is one of the most powerful drivers of fish populations, improving the responsiveness and accuracy of management tools could have a meaningful impact on fishes in the Gulf of Mexico. Starting in 2013, NFWF's GEBF provided a total of $43.9 million to the states of Florida, Alabama, and Mississippi to restore fishes by enhancing fishery independent and dependent monitoring. Tools developed as a part of these efforts have promoted sustainable take of fishes by more accurately estimating recreational fishing effort and more precisely setting fishing season lengths. These projects have also provided status and trends for data poor stocks, enabling fisheries managers to respond to previously unknown species declines and evaluate the impacts of disasters like red tides. As these five-year projects are closing, NFWF and its grantees have begun synthesizing the impact of these investments. This presentation will highlight our progress to date.

Importance of Benthic Habitat Mapping and Species Characterization for Informing Oil and Gas Extraction Policies and Recovery of Wildlife Injured as a Result of Oil Spills

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As incongruous at it seems, the northern Gulf of Mexico supports intensive natural resource extraction (fisheries, oil and gas) but is one of the most poorly mapped ocean areas of the United States. In particular, the West Florida Continental shelf (WFS) supports lucrative commercial and recreational fisheries and abundant sea turtle concentrations but only about 5% of the shelf was mapped prior to 2016. Bathymetric mapping identifies the characteristics of the bottom topography (ruggosity) but cannot, in and of itself be used to characterize habitat types nor utilization and importance of target areas to a variety of biota. By employing *in-situ* towed video systems, one can pair imagery and sonar mapping products to define habitat types and calculate the relative and absolute densities of biota associated with each. These mapping products have considerable utility in defining essential fish and protected species habitats, for locating and assessing potential marine protected areas, and for identifying areas that should be excluded for consideration from offshore development activities. As a result of a grant from the National Fish and Wildlife Foundation's Gulf Environmental Benefits Fund (GBEF) we undertook a large-scale bathymetric and habitat classification program on the WFS. This program resulted in an additional 2,700 km^2 of high-valued habitat being mapped. A number of candidate areas for additional protections and ongoing recovery efforts have been identified. This paper outlines the process by which potential target areas are evaluated, the development of integrated habitat assessment products, and the value of such products supporting resource management and recovery planning.

Highlighting the Importance of Sustaining Enhanced Fishery Monitoring Efforts: The Influence of the 2018 Red Tide Event on Gulf Reef Fish Populations

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Efforts to quantify the effects of the Deepwater Horizon oil spill on economically- and ecologically-important nekton populations were hampered in many cases by a lack of baseline, long-term data from which quantitative comparisons could be made. Nearly ten years after the spill, tens of billions of dollars have been spent to remedy ecological and economic damage throughout the Gulf. Despite the tremendous financial resources brought to bear on the region, relatively little funding has been directed towards the improvement or establishment of long-term monitoring programs. One notable exception has been the Gulf Environmental Benefit Fund, through which the National Fish and Wildlife Foundation has funded several projects in the eastern Gulf. In the state of Florida, this funding has facilitated the expansion of video and habitat mapping survey efforts that have greatly improved our ability to quantify changes in reef fish populations, resulting in improved assessment and management capabilities. Enhanced data collection has also facilitated our ability to quantify population responses to environmental perturbations, such as red tide which impacted much of the southeastern Gulf of Mexico for most of 2018. Analyses of data provided by these enhanced survey efforts indicate that most economically- and ecologically-important reef fishes, including Red Snapper (*Lutjanus campechanus*), Red Grouper (*Epinephelus morio*), and Tomtate (*Haemulon aurolineatum*) declined markedly (most declines ranged from 20 - 50% from prior year relative abundance values) in waters off southwest Florida where red tide was prevalent. Analyses such as these demonstrate the importance of continuing these valuable surveys, although without sustained long-term funding, the future of this and other surveys remains highly uncertain.

Can Monitoring Inform the Debate About the Use of Artificial Reefs in Fisheries Management?

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The placement of artificial reefs in coastal areas has become increasingly popular in the Gulf of Mexico. Rationale for the placement of these structures varies. There is little doubt that these structures enhance the public's opportunity to utilize marine resources (e.g. SCUBA Diving, fishing); however, the role of artificial reefs in enhancing fish production is still very much in debate. While some have argued that this debate is academic in nature because artificial reefs fundamentally change the food web of an area, practical concerns for fisheries managers still exist and include the potential for fishing mortality to be elevated around these structures. Artificial reefs can enhance fish production through (1) a numerical response by adding recruitment habitat or by decreasing post-settlement mortality, a widely accepted process that limits population size, or (2) a bioenergetic response in which growth is enhanced above a reference level that existed without the structure. The first response assumes that structured habitat in the system is limited-an assumption which researchers have found reasonable in inshore areas where the loss of biogenic nursery habitats is well documented. The assumption requires further scrutiny in offshore environments; however, it is likely that low relief habitats designed for juvenile recruits may also be limiting. Positive bioenergetic responses require detailed examination of abundance at new reefs and adjacent reference areas as well as diet and growth patterns. Here, we detail how our monitoring data of the vast network of existing artificial reefs as well as new reefs in coastal Alabama can be used to assess many key issues surrounding the attraction-production debate.

* Student presenter

The Importance of Depth and Artificial Structure to Female Red Snapper Reproductive Parameters

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Long term monitoring of fisheries resources on Mississippi's offshore artificial reefs provides data not available prior to the 2010 Deepwater Horizon oil spill and allows an understanding of the role that these structures have to influence the demographic characteristics of living marine resources. We used machine learning algorithms to examine different reproductive parameters of female Red Snapper (*Lutjanus campecheanus*) captured from 2016-2018 on three artificial reef types with various structure heights at depths ≤100m to examine if reproductive phase, reproductive activity, spawning interval or batch fecundity varies with water depth and reef structure. Overall, the type (artificial reef, oil platform, and "rigs-to-reefs") and height of artificial structure does not appear to affect reproductive characteristics. However, reproductive parameters do differ by depth. We found that histological reproductive phase is best predicted by fork length (FL), month of capture and depth of water. The algorithm had an ~60% probability of correctly predicting phase using these explanatory variables. Similarly, the presence of reproductively active fish is best predicted by FL, month and depth, with depths > 27 m having more reproductive females. The Gonadosomatic Index (GSI) is predicted by month and FL, but with only a 36% accuracy. Non-parametric, frequentist, tests indicated a significant difference in spawning interval by depth ($p < 0.001$), with females in deep water (50 to 100 m) spawning more frequently than those at shallower depths. However, regression analysis showed that relative batch fecundity did not vary significantly by depth or structure height. Our results suggest that female Red Snapper reproductive effort is not related to artificial structure types or heights, but that reproduction is more common in deeper waters and by larger fish.

Incorporating Data from Artificial and Natural Reefs into Indices of Relative Abundance to Support Improved Assessment and Management of Reef Fishes

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Stereo-baited remote underwater video (S-BRUV) surveys have been used to assess trends in the relative abundance of reef fishes in the Gulf of Mexico since the early 1990s. Through time, efforts have increased through a collaboration between NMFS and the Florida Fish and Wildlife Research Institute (FWRI). Recent efforts to combine survey data across labs has demonstrated the efficacy of a habitat-based statistical modeling approach to generate a single index of relative abundance for the eastern Gulf, which has become one of the primary fishery-independent data inputs in recent reef-fish assessments. However, these ongoing surveys have focused solely on natural reef habitats, excluding anthropogenic habitats (i.e. artificial reefs) that are regionally important for several reef fishes, and are increasingly being deployed as a mitigation measure as part of DWH restoration efforts. Accordingly, the FWRI S-BRUV survey was expanded in 2014 to not only extend into the Florida Panhandle, but also incorporate artificial reef habitats, using funds provided by the National Fish and Wildlife Foundation through the Gulf Environmental Benefit Fund. In this talk, we apply the analytical methods used to develop a combined eastern Gulf index to integrate information on population trends from both artificial and natural reef habitats. By incorporating estimates of habitat quality and overall habitat availability, indices generated presumably better represent the overall status and trends of reef fish

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populations and will aid in improved assessment and management capabilities. Results from these initial analyses provide a reliable framework for incorporating these potentially valuable habitats into assessments of reef fish in the region. As time series continue for both artificial and natural reef habitats throughout the remainder of the eastern Gulf, these methods will be applied to create indices incorporating data from all available natural and artificial habitats in the region.

Monitoring Pelagic Bait Fish in the Tidal Rivers of Mobile Bay

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In the Gulf of Mexico, Gulf Menhaden, *Brevoortia patronus*, supports fishes, marine mammals, birds and a substantial commercial fishery. The annual average landings for Gulf Menhaden for the past five years are in excess of 500,000 metric tons (NMFS). Gulf Menhaden is the only prey species in the Gulf of Mexico that undergoes the SouthEast Data Assessment and Review, SEDAR, process and yet has no dedicated fishery independent surveys. Current surveys utilizing benthic trawls and seines have large variances and a recommendation out of SEDAR 63 was a dedicated survey to determine annual recruitment. A bow mounted surface push trawl was fabricated to better capture the abundance of young of the year Gulf Menhaden in coastal rivers. We were able to sample at night and generate an annual index of abundance across four coastal rivers in the Mobile Bay estuary. Catch per unit effort was on average three times greater for the surface push trawl and zero catches were decreased by a factor of two when compared to the benthic trawl.

Evaluating a Juvenile Reef Fish Survey to Improve Statistical Inferences for Estimating Temporal Changes in Population Abundances

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Robust stock assessments are central to proper fishery management, but statistically-robust fishery monitoring data is frequently not available. Even when fishery monitoring data are available, the data may not adequately sample important fishery species. The Florida Fish and Wildlife Conservation Commission's Fisheries Independent Monitoring group has monitored fish populations in eastern Gulf of Mexico estuaries since 1989, but juvenile habitat for estuarine-dependent reef species (i.e., 1.2-2.5 m deep, sloping, polyhaline seagrass beds) was under sampled. Existing data indicated that monitoring that included this habitat as a stratum would provide useful indices for stock assessments. Accordingly, haul seine and otter trawl surveys for juvenile reef fishes were implemented in 2008. With ten years of monitoring data, we aimed to re-evaluate the design to improve the statistical robustness of abundance indices for stock assessments. Specifically, we addressed whether two gear types were necessary, if we could reduce or re-allocate sampling effort within and among estuaries without sacrificing relevant catch and length information for key taxa, and estimated the statistical power we had to detect 1) year-to-year abundance changes and 2) long-term abundance trends. After assessing species composition and length-frequency distributions between gear types, we determined that we could obtain comparable data from a single gear type (trawl). Analysis of abundance data suggested that sampling effort in certain estuaries could be reduced without adversely impacting abundance trends. Power analyses indicated inadequate sample sizes, so additional effort was allocated to trawls to increase the power to detect changes in abundance. By evaluating data and amending sampling design, we have

improved data quantity and quality for the development of stock assessments for multiple Gulf of Mexico reef fish species.

Improving Management of Mississippi's Recreational Red Snapper Fishery Using the Tails n' Scales Electronic Reporting System

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Red Snapper is currently one of the Gulf of Mexico's most important recreationally targeted fishes. Accurate and timely estimation of harvest and angler effort is crucial for Gulf-wide management. Past management of Red Snapper led to a derby style federal season with multiple and highly variable state seasons leading to a need within Mississippi for a more robust and comprehensive fishery-dependent sampling program. Accurate estimation of harvest within a season is valuable for fisheries managers to set and adjust fishing restrictions. Estimation of in-season harvest in a timely manner is of utmost importance in preventing overages. In 2014, Mississippi adopted a modification to regulations, requiring mandatory reporting of all recreational Red Snapper landings in the state. In 2015, The MDMR partnered with a software developer to design a mobile application to accomplish this task. The goal of the mobile application design was to provide an easily accessible and intuitive system to enable Red Snapper private and for-hire anglers to report their Red Snapper landings in real time. MDMR now has four complete years of Red Snapper harvest data to complement Mississippi's suite of fishery independent sampling efforts funded through NFWF's GEBF. The Tails n' Scales reporting system methodology has been approved by a peer-reviewed federal certification process as a scientifically acceptable method to estimate Red Snapper harvest for the state of Mississippi. This program has provided the MDMR better data on effort in the fishery and a more precise number of Red Snapper landed in Mississippi. Currently, Tails n' Scales is capturing harvest data on Red Snapper; however, in the near future, MDMR hopes to expand the program to capture harvest data on other species. Through the success of the Tails n' Scales program and collaboration with other states, MDMR hopes to assist with the development of a Gulf-wide strategy to improve fishery-dependent monitoring capabilities.

Improving Recreational Fishing Statistics for Important Reef Fishes in the Eastern Gulf of Mexico

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The west coast of Florida supports the largest concentration of recreational fishing effort in the Gulf of Mexico. The Gulf Reef Fish Survey (GRFS) is a collaborative effort between FL FWC and NOAA Fisheries to provide enhanced recreational fishing statistics for assessing and managing economically important reef fish stocks in the eastern Gulf. The new survey was implemented in 2015 with funding through NFWF's Gulf Environmental Benefit Fund. The GRFS provides important insight into the temporal and spatial distribution of recreational fishing effort, and how it changes in response to variable fishing regulations, weather, tourism, abundance of reef fish species, and large-scale events such as the extended red tide bloom off the west coast of Florida from November 2017 through 2018. More timely and precise recreational fishing statistics provided through the GRFS allow state managers to set sustainable seasons for the large open-access Red Snapper fishery, and provide additional fishing days when in-season landings are lower than expected. Before the GRFS was implemented, the Marine

Recreational Information Program (MRIP) was the sole source of recreational fishing statistics for Florida. The two surveys have been conducted side-by-side since 2015, and point estimates for annual landings and discards through the MRIP are consistently 2 to 3 times higher. To evaluate whether the GRFS was potentially underestimating recreational fishing effort, a separate survey was conducted over two Red Snapper seasons in 2017 and 2019. This presentation will summarize what has been learned from the spatial and temporal trends in fishing effort over the five years the GRFS has been conducted, compare estimates from the new and legacy surveys, share results of a study to verify the accuracy of estimates from the GRFS, and demonstrate how more timely and precise data are facilitating sustainable management of a large open-access recreational fishery.

Results from a Decade of Fishery Observer Coverage in the Eastern Gulf of Mexico

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In response to declines in fish stocks, fishery managers have increased size limits and reduced bag limits and fishing seasons in recreational fisheries. As regulations have become more restrictive, there has been an increase in discards. In Florida, discards may represent upwards of 90–100% of catch for some species (NMFS, 2016). Managing discards in open access recreational fisheries is now one of the nation's most difficult challenges. Florida's fishery-dependent at-sea observer project was initiated off the West coast of Florida in 2009 and was later expanded when additional funds became available through NFWF'S Gulf Environmental Benefit Fund. This project collects detailed biological information and incorporates a conventional tagging component that supplies important information needed to support fishery management and stock assessments. The time-series serves as an important baseline prior to the 2010 Deep Water Horizon oil spill and spans a major Red Tide bloom that occurred in 2018. This talk will highlight how long-term at-sea monitoring by fishery observers enhances stock assessments and informs fishery managers on the impacts of regulations, such as seasons, size limits, and requiring the use of circle hooks when fishing for reef fish in the Gulf of Mexico. Data on size composition of discards, abundance, species distributions, and discard mortality rates are filling important data gaps in regional stock assessments. This long-term monitoring program has tracked the boom and bust of Red Grouper abundance and changes in the spatial distribution of Red Snapper as the stock rebuilds in the Gulf of Mexico. The FWC's at-sea observer project has ultimately resulted in a long-term data set spanning over ten years and is the largest tagging project in the eastern Gulf with over 100,000 tagged fish.

Contributions of Fishery-Independent Surveys Funded by the Gulf Environmental Benefit Fund to Reef Fish Stock Assessments in the Gulf of Mexico

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Fisheries-independent surveys are extremely valuable for providing data for use in stock assessments. Specifically designed to provide unbiased estimates of population abundance, fisheries-independent data can reflect changes in true population abundance over time. When available, fisheries-independent data are preferred over fisheries-dependent data to track trends in population abundance because data

collected from the fishery may be influenced by management measures such as closed seasons, trip limits, bag limits or minimum size limits. In addition to providing critical data needed for stock assessments, fisheries-independent surveys can enable holistic evaluations of multi-species interactions, which form the basis for many ecosystem-based modeling approaches. The recent increase in fisheries-independent data collection funded by the Gulf Environmental Benefit Fund has contributed greatly to federal stock assessments of reef fishes in the Gulf of Mexico, most notably for Red Grouper and Gray Triggerfish. We will review the consideration and use of these fishery-independent data in recent stock assessments conducted in the Gulf of Mexico. We will discuss in detail the utility of these data in the Red Grouper stock assessment, which utilized data from the combined video survey, made possible by the expansion of the video survey sampling on the West Florida Shelf, the summer SEAMAP groundfish trawl survey, additional life history samples, and the Florida Fish and Wildlife Research Institute (FWRI) repetitive time drop hook-and-line survey. While the terminal year of the red grouper assessment was 2017, the modernization of data processing and analyses of survey data enabled indices to be updated through 2019, which provided very timely insight into the potential impact of the 2018 red tide event on the red grouper population.

Session 022: Next Steps in Human Dimensions Research and Practice: Priority Actions for Building Community Resilience to Oil Spills

Building Community Resilience: Recommendations from a Synthesis of Research on the Health, Social, and Economic Impacts of the Deepwater Horizon Oil Spill

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This paper will present recommendations for research and practice based on a synthesis of results from studies on the health, social, and economic impacts of the Deepwater Horizon oil spill (DWOS). The aims of the synthesis are to identify: 1) current knowledge (and gaps in knowledge) about human behavioral health and socio-economic impacts of the DWOS; and 2) ways in which government and nongovernment stakeholders can build resilience in Gulf coast communities by aligning resources with scientific findings about specific impacts and broader resilience principles. The synthesis methods included a comprehensive review of research on human dimensions of the oil spill, integrated with output from a workshop of 25 scientists and stakeholders held in New Orleans, LA, February 2019. The results are organized via a multi-dimensional model of resilience and vulnerability through which we examine adaptive capacities and chronic stressors that have been shown to moderate the links between a hazard such as an oil spill and outcomes related to mental health, social well-being, and economic security. Implications of the results are discussed in terms of five key recommendations: 1) focus more on the needs of people, including disparities across groups; 2) address the complexity of the resource-dependent social systems in which disasters are managed; 3) enhance partnerships across local, national, and international levels, leveraging diverse sets of skills and strengths; 4) connect the past, present, and future contexts to support disaster recovery efforts; and 5) deepen and communicate the evidence base for decisions about how to build community resilience. Discussion will focus on implications for community leaders, governmental officials, nongovernment organizations, and funders

* Student presenter

about what changes are needed in research and practice to help reduce the impacts of large oil spills on communities and build community resilience.

An Interdisciplinary Framework for Building the Infrastructure of Social Capital and Resilience: Focus Groups and Tabletop Exercises

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Social scientific research has made substantive contributions to understanding the impact of disasters and oil spills and the building of social capital and resilience. A review of the literature on the effects of Hurricane Katrina reveals a lacunae with respect to the effects of disasters and oil spills on Asian immigrant-refugee communities and in particular Cambodian and Laotian communities. This paper provides a preliminary analysis of the responses from focus groups with members of the Cambodian and Lao communities in Bayou La Batre, AL and the emergency managers and first responders responsible for this area. At the suggestion of community leaders, we conducted separate focus groups for older and younger adults from both communities. We used the data from the focus groups to develop table-top exercises with members of the Cambodian and Lao communities and the emergency managers and first responders. The community-based participatory research with the Cambodian and Laotian communities of Bayou La Batre will contribute to the development of an interdisciplinary and culturally-responsive framework for building the infrastructure of social capital and resilience in immigrant-refugee communities.

Developing Culturally Responsive Emergency Management with Community Engagement

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University of South Alabama, Mobile, AL

Increasingly, emergency responders face larger call volumes, understaffing, and much more diversity in the communities they serve. The current Incident Command System (ICS) is a top-down management structure. Community engagement in the development of emergency plans is typically at the organization-to-organization level. We present a model in which the community and emergency responders are co-developers of a disaster response plan that draws on the expertise of professional managers and academic researchers with equal consideration of local knowledge from the community members. The setting is the Cambodian and Laotian communities of Bayou La Batre, Alabama. We conducted a table-top exercise compliant with the Homeland Security Exercise and Evaluation Program (HSEEP). We used aerial maps and pictures taken by the community to give responders images of the real terrains and possible barriers for response teams. The goal of the project was to make disaster management more culturally responsive.

The Cambodian and Laotian Disaster Experience from Respondents and Their Close People

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* Student presenter

Despite the numerous and repetitive experience of disasters for Cambodians and Laotians in Alabama, there are not much known their experience, recovery process, and resilience. The study here to present is to understand their disaster experience through a survey not only from respondents but also respondents' social networks. This presentation will explain and compare the disaster experience from Cambodians and Laotians respondents and their close people based on their demographic characteristics such as age, gender, income, and occupation, social characteristics such as religion and community cohesion, and disaster-related characteristics such as evacuation notices, decision, and received support. The data are from the social network survey for Cambodians and Laotians conducted 2019 March through June using snowballing sampling method. A total of 271 cases were selected after dropping case-wise deletion (147 cases for Cambodian and 124 cases for Laotian).

Translating Research Findings into Suggested Oil Spill Practices to Support Community Resilience

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Oil spills can have serious consequences on communities in proximity of the spills even when a disaster is not formally declared. Social science research has examined various aspects of how oil spills can impact communities and findings suggest ways to strengthen resilience among communities. However, research findings have not been incorporated into oil spill preparedness and response practices, that are constrained by pollution regulations and typically differ from those for natural disasters. Effective response to an oil spill, that has the potential to become a <u>social</u> disaster, requires leaders of the incident management team (IMT) to not only stop the release of oil and clean up the spill but to proactively address community aspects of a spill. To accomplish this, the response community needs to adapt current practices, e.g., proactively engage stakeholders at the grass-roots level to share information, seek support and include inputs for certain pre-spill decisions, such as the potential risks and benefits of response actions including dispersants use. The capacity of the IMT to engage with vulnerable communities and stakeholders before, during, and after an oil spill is one measure of a successful response. This paper highlights the collaboration among researchers, oil spill planners, responders, and community members on the Eastern Shore of Virginia over several months preceding a major oil spill exercise. Working together we identify new ways to adapt traditional oil spill practices, strengthen oil spill preparedness and response, and facilitate resilience among communities that could be affected by a major mid-Atlantic oil spill. Suggested adaptations also are relevant to other geographic areas.

Recognizing, Measuring, and Leveraging the Human Health Protecting and Promoting Effects of Natural - and Restored - Coastal Wetlands

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A substantial body of scientific evidence demonstrates strong, positive psychological and physiological health effects for people who are exposed to "nature," and biodiverse nature including "greenspace," and "blue space," such as coastal areas and their marshes, mangrove forests, seagrass beds, and other

wetlands. It is also becoming well-established that wetlands can be part of nature-based solutions, minimizing environmental impacts of extreme weather events and other disasters by buffering coastal communities from storms and erosion, absorbing flood waters, reducing pollution impacts, and in some cases lowering risk of disease transfer. These health benefits are important ecosystem services provided by intact wetland ecosystems. However, such benefits are all too rarely considered in disaster planning or mitigation, nor have they typically been part of the framework for planning or evaluating restoration projects, especially coastal ones. We propose that mental and physical well-being values of experiencing healthy wetlands could be measured to increase our understanding of the broad beneficial effects of coastal wetlands and leveraged to offset some stress and disease encounters related to disasters. Potential metrics for measuring health and possible therapeutic outcomes of exposure to natural and restored wetlands include reduction in depression and anxiety, post-traumatic stress symptoms, heart rate, blood pressure, and respiratory distress. Exposure to wetlands may also increase cognitive function and feelings of well-being and restoration. Conducting research using these and perhaps other health metrics might provide an additional and readily appreciated measure of the value to the public of natural wetlands and the success, or lack thereof, of wetland restoration projects. Incorporating wetland ecosystem service and human health-promoting contributions in disaster response strategies could reduce impacts, enhance resiliency, and facilitate recovery.

Comparing Perceptions and Reality: Convergence Among Gulf Coast Residents and Government Data on Water Quality in the Mississippi Sound

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Risk perception is a dynamic area of research within the social and environmental sciences. Much work focuses on catastrophic events, such as hurricanes or oil spills, but a considerable amount of research analyzes chronic hazards like water pollution. This study compares human perceptions of water quality in the Mississippi Sound to existing government data. It draws from reports by state and federal agencies and from results of a survey conducted in 2018 by an interdisciplinary research team at the University of Southern Mississippi. The team developed and administered a survey to Mississippi households south of Interstate 10 along the Gulf of Mexico coast. The survey included a series of questions that focused on how respondents feel about the Mississippi Sound and their beliefs about its water quality and risks to public health. Our results indicate that residents have a strong attachment to their coast, but they have a negative view of its water quality. Longitudinal data from state and federal agencies indicate that the fears of local residents are valid. Mississippi recently ranked 28th out of the 30 coastal U.S. states with regard to bacterial water quality. How people perceive risk does not always correspond well with the reality of risk. In this case, however, Gulf Coast residents seem to be accurate in their perceptions of the Mississippi Sound and its waters. These results build upon our previous findings and highlight the intricate connections linking perception, experience, and resilience among residents of the Mississippi Gulf Coast.

Environmental Restoration and Catastrophe: Analyzing Frames and Claims in Oyster Restoration News Stories

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* Student presenter

News media is an important source of information for environmental issues and can influence public opinion through framing. This content analysis examines 1,020 newspaper articles about oyster restoration to document what frames, sources, and topics were most prevalent in newspaper stories. Eighteen local newspapers from five Gulf Coast states and three high-circulation national newspapers were analyzed. Oyster restoration stories were most commonly told with respect to the environmental significance of restoration projects. The prevalence of an environmental article frame in oyster restoration stories was influenced by the occurrence of the Deepwater Horizon BP oil spill. Articles published before the spill were less likely to have an environmental frame than those published during and after the spill. Articles with community and economic frames were more likely to be published directly after the spill than two years later. Natural resource managers were the most commonly quoted sources, and government jobs were found to be the most common occupations of sources. Fishermen and seafood industry representatives were rarely quoted by reporters. Environmental newspaper frames were associated with scientists as sources, while economic articles were associated with natural resource managers as sources. This study contributes to discussions of framing of environmental issues in newspapers by analyzing the effect of an environmental catastrophe on the frames and sources used to report on a contentious natural resource issue. Newspapers' emphasis on one dominant stakeholder perspective over other relevant sources is an important finding for future management of oyster restoration projects.

Natural or Natech? Understanding the Relationship Between Hazard Perceptions, Institutional Trust, and Views of Recovery Following Hurricane Harvey

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Researchers have traditionally defined disasters as either “natural” or “technological,” and an extensive literature has documented differential social consequences based on this distinction. In disaster scenarios that are viewed as natural or an “act of God,” while social systems are disrupted, there also tends to be a sense that no one is to blame, consensus on the legitimacy of victims and their need for aid, and general social cohesion toward recovery. Technological or "human-caused" disasters, on the other hand, have been linked to the emergence of “corrosive community.” In such a context, those affected develop contested narratives of disaster impacts, responsibility, and blame, which, in turn, generates social rancor and discord, and, ultimately, more severe and chronic psychosocial consequences compared to natural disasters. There is also growing recognition that many disasters can be conceptualized as “natech”—processes characterized by a combination of natural and technological disaster elements. Drawing from the Survey of Trauma, Resilience, and Opportunity in Neighborhoods in the Gulf (STRONG), we analyze two waves of cohort panel data collected from households on the Texas Gulf Coast in 2016 and 2018 (before and after Hurricane Harvey). We examine differences in institutional trust and perceptions of recovery depending on whether respondents view Hurricane Harvey as a natural or natech disaster. Preliminary findings indicate that those who view Harvey as a natech disaster have less trust in government and the oil and gas industry; are more worried about their family’s mental health and the local economy going forward from the storm; and are less likely to believe their community and local political leadership is capable of dealing with the hurricane’s aftermath. Findings also show different types of hurricane exposure between the natural versus natech groups, with natech households reporting greater exposure to chemicals during the disaster.

* Student presenter

Predicting the Sequence and Duration of Post-Hurricane Housing Stages for Equitable Recovery Resource Allocation

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Housing recovery is an unequal and complex process presumed to occur in four stages: emergency shelter, temporary shelter, temporary housing, and permanent housing. This work questions the four-stage typology and examines how different types of shelter align with multiple housing recovery stages given different levels of social vulnerability. This work shares a novel Markov chain model of the post-disaster housing recovery process that focuses on the experience of the household. The model predicts the sequence and timing of a household going through housing recovery captured households that end in either permanent housing or a fifth stage failure. The probability of a household transitioning through the stages is computed using a transition probability matrix (TPM). The TPM is assembled using proposed transition probability models that vary with the social vulnerability of the household. Monte Carlo techniques are applied to demonstrate the range of sequences and timing that households experience going through the housing recovery process.

The predictive model is exemplified on a virtual community following a hurricane disaster. The analysis results in nearly 5% of households languishing in unstable housing thereby failing to reach housing recovery. These results are assessed against household-level data collected longitudinally in Lumberton, North Carolina. Lumberton was catastrophically flooded after Hurricane Matthew in 2016; the dataset consists of survey responses from 816 households who were impacted differentially, measured through damage level to home, dislocation times, access to recovery resources, repair times, household stability, and household socioeconomics. The findings can be used to inform decision-making and resource allocation in disaster recovery planning by highlighting the disparate trajectories experienced by households with different levels of social vulnerability.

Session 023: Understanding Processes Associated with Sub-Surface Oil and Gas Releases, with Special Focus on the MC20 Site in the Northern Gulf of Mexico

The Physics of Multiphase Fluid Flow as an Essential Guide for Incident Response

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Multiphase flow within petroleum infrastructure is carefully studied in order to effectively manage risk while optimizing the economics of production. Many of the physics principles essential to well engineering are transferable for incident response operations involving leaking infrastructure such as those originating from wells and pipelines. We describe fundamental aspects of multiphase hydrocarbon transport and examine how the inherent physical properties of source fluids and release conditions can influence observability. We present analytical models for evaluating the specificity and sensitivity of various observation methods along with experimental results. The Mississippi Canyon Block 20 site in the Northern Gulf of Mexico is presented as an illustrative example of where well-established physics principles can be applied for guiding ongoing incident response.

* Student presenter

Estimates of Oil Flux to the Ocean at MC20 Using Acoustical Methods

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Estimating flux of oil and gas from the seabed to the surface at the Taylor Energy Corporation (TEC) MC20 site presented challenges due to the mixture of gas and oil bubbles in the plume. Flux of oil from the seabed through the water column was estimated using two remote sensing techniques: a video bubblometer and echosounding backscatter integration. For this presentation we present plume models and flux estimates using acoustic techniques. Acoustic backscatter from cross-sections of the plume were delineated and analyzed to estimate concentration of gas and oil bubbles in the plume. The mixture of oil and gas was assumed to be homogeneous, but proportional to the ratio and sizes of oil and gas bubbles observed in the bubblometer, including oil that was contained within gas bubbles (35.6% oil by volume). To derive flux values, bubble rise velocities were calculated using a theoretical model and empirical observations of the acoustic echogram showing advection of the plume. Rise velocities were found to be 6-7 cm/s for slower rising oil components of the plume and between 18 and 24 cm/s for faster rising gas bubbles in the plume. Acoustic measures of oil flux ranged from 9 (large bubbles, higher gas proportion) to 47 bbl/d (small bubbles, higher oil proportion). Our flux rates match actual containment rates at the site as of May 2019 (24 - 31 bbl/d), are lower than previous satellite image methods, and exceed TEC estimates by two orders of magnitude. However, the method does not fully resolve how much oil is retained near the sediment, or oil that actually reaches the surface of the ocean because lateral advection diminishing the vertical fluxes to a degree that is not well-resolved by the acoustic observations.

Visual Assessment of an Oil and Gas Bubble Plume at MC20

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Plumes of oil and gas bubbles have been observed emanating from the wreckage of the Taylor Energy platform in MC20 block since the platform was destroyed by Hurricane Ivan in 2004. To establish the composition of these plumes and to estimate the associated hydrocarbon fluxes, we developed a unique sampling device (bubblometer), which collected physical samples of the plume and recorded HD video records of bubbles passing through a calibrated chamber. The bubblometer was deployed in September 2018 from an industrial ROV, which was navigated by ultra-short baseline techniques (USBL) and recorded water column variables with a CTD. Two separate plumes were documented issuing respectively from two erosion craters near the NW corner of the wreckage. Video frames were collected from the plume video recordings, each with associated depth and latitude-longitude location data. Machine vision algorithms were used to measure and count a total of 12,139 bubbles from plumes from the craters' floor (max 145 m) to the mid-water above the wreckage (min 110 m). Bubbles were visually classified as oil or gas-oil mixtures; bubble rise speeds were calculated from their size and apparent density using Stokes law. Bubble compositions and size distributions were stratified by depth and were different within the two plumes. Resulting estimates of vertical oil fluxes therefore depended on which stratum of which plume was assessed. Maximum oil flux was 108 bbl/day for the plumes in the crater, minimum flux was 33 bbl/day for plumes in the mid-water. Estimates of fluxes do not account for lateral movement of bubbles; precision of estimates would be improved by integration with acoustic data and calibration under field conditions.

* Student presenter

Temporal Variations in the Weathering and Source Characteristics of Crude Oil Escaping the Seafloor, MC20 Site, Northern Gulf of Mexico

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Persistent plumes of crude oil and gas have been exiting the seafloor at the MC20 Site since a subsea landslide toppled the Site's production platform in September 2004. The origin(s) of the escaping petroleum is a matter in litigation. Detailed chemical fingerprinting was conducted on 99 discrete oils - represented by surface sheens (blossoms) collected immediately after surfacing and water column grab samples collected by ROV - collected between March 2017 and December 2018. Long-term variations (measured in months) show no systematic trend(s) in oil composition. However, short-term variations (measured in minutes) in the oils' levels of biodegradation and source-specific characteristics are evident, thereby confirming that multiple oils or oil mixtures are escaping the seafloor at the Site. Among the source-specific characteristics the varying concentrations of specific PAH, a β-amyrin-derived triaromatic des-A triterpene (DAT-16), are particularly diagnostic.

Heterogeneity in the escaping oil is most reasonably explained by active leakage of different crude oils from multiple, damaged wells at depth, which mix to varying degrees (or not) before escaping the seafloor mostly in the area of the now-buried conductor bundle terminus. The range in variation among the escaping oils, including DAT-16 concentrations, are or are nearly represented by the range exhibited by three reservoired oils collected from two MC20 site wells prior to the platform's toppling.

Crude oils (6) collected from the Site's recently-installed sub-sea containment system (April 2019) are chemically homogeneous and exhibit weathering and source-specific features that are largely intermediate to the large population of discrete oils, which argues the heterogeneous oils escaping the seafloor are being collected and homogenized by the containment system. Despite the containment system's emplacement some surface sheening persists. Discrete surface sheens (6) collected in May 2019 are relatively homogeneous but distinct from the containment system oil, arguing they are not due to leakage from the system, but rather to seafloor leakage not currently being captured.

Molecular Understanding of Source Oil and Weathered Surface Sheens from Mississippi Block 20 Site

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The Mississippi Canyon 20 lease block has been continuously releasing oil since Hurricane Ivan destroyed an oil production platform in 2004. The resulting surface sheens are readily observable, stretch for miles, and are even visible from space. The composition of oil initially released into the marine environment and continued characterization as it weathers post-incident is critical to understanding the fate of the oil, its transport, and any associated toxicity to aquatic flora and fauna. Here, we identified a consistent subsurface source of petroleum and tracked it from its surfacing point of origin along its sea surface trajectory. Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR MS) combined with comprehensive 2D gas chromatography GC (GC×GC) analysis reveal compositional changes of the source (unweathered) oil recovered from a containment system relative to weathered surface sheens. GC×GC-TOFMS analysis establishes the biomarker similarity between all MC

* Student presenter

20 field samples and provides the detailed compositional changes at the level of isomeric differences caused by weathering processes. The inherent high mass resolving power and mass accuracy of FT-ICR MS enabled the detection and elemental composition assignment of oil transformation products, including highly oxygenated compounds that are suspected of having significant roles in oil fate, transport, and toxicity. Although the oil at the MC20 site is compositionally similar to oil slick samples from the DWH site, there is a noteworthy increase in oxygen-containing species in the freshly surfaced oil at the MC20 site indicative of longer-term weathering. The preliminary study herein offers a unique opportunity to analyze petroleum transformation products and compare the changes in composition with time and distance from the source. Work supported by the NSF Division of Chemistry through DMR-164479, a grant from the Gulf of Mexico Research Initiative, and the State of Florida.

An Assessment of Oil-Related Chemical Contaminants in the Sediment, Water, and Oil from the MC20 Site in the Northern Gulf of Mexico

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Oil, water, and sediment samples collected as part of a joint NOAA/BSEE survey conducted from 1 September 2018 to 7 September 2018 were analyzed for oil-related chemical contaminants. These include saturated hydrocarbons, Polycyclic Aromatic Hydrocarbons (PAHs), and petroleum biomarkers. Concentrations of oil-related contamination in sediments decline as distance from the northwest corner of the toppled Taylor Energy MC20 well jacket increases. No measurable evidence for MC20 oils were found in surface sediments beyond 500 m from the erosional pit. Sediment concentrations at the perimeter of the erosional pit at the northwest corner of the jacket are an order of magnitude higher than those found in the rest of the study area. Oil-related compounds measured in the sediments at the perimeter of the erosional pit are severely degraded as compared to mildly degraded oil collected mid-water column and at the surface indicating that oils in the water column and at the surface are not primarily sourced from sediment sampled at MC20. Mid-water column collected oil is mildly degraded and closely resembles historic reservoir degraded oil from MC20 Well #001 in both its API oil gravity and its n-C17 and n-C18 relative ratio to their pristane and phytane counterparts. Subtle heterogeneities observed between mid-water column captured bulk oil, mid-water column captured water, and surface water sheen samples, along with the variations observed from three historic MC20 oils point toward current ongoing release from multiple wells at the MC20 site.

Characterization and Source Type Identification of Gas Bubbles Observed at Mississippi Canyon Block 20 in the Gulf of Mexico

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An oil sheen and gas bubbles have been observed to be continuously seeping from the seabed in MC20 several kilometers offshore of Louisiana. Gas, oil, sediment, and water samples were collected by scientists and technical staff through a collaborative effort by BSEE, NOAA, and TDI-Brooks International aboard the R/V Brooks McCall in early September 2018 to understand the chemical nature of the release at the MC20 site. Gas chromatography (GC) and isotope ratio mass spectrometry were used to quantify and obtain the carbon isotopic ratios of the C1-C5 light hydrocarbon constituents of the gas bubbles collected from the water column. The molecular and isotopic compositions of the gas samples were

subsequently entered into models adopted by TDI-Brooks International for Surface Geochemical Exploration (SGE) to determine that the samples originated from an unfractionated thermogenic source.

Atmospheric Methane Concentrations at the MC20 Site in the Northern Gulf of Mexico

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A characterization of atmospheric methane (CH_4) concentration at 3 m over the ocean surface was made in September 2018 in the Gulf of Mexico over the Mississippi Canyon (MC20) site offshore of the Louisiana. In 2004, the Taylor Energy's production Saratoga Platform-A, located in the same site, was destroyed after a mudslide triggered by Hurricane Ivan over the Mississippi Delta. The toppled platform sank and move approximately 210 m downslope of its original position. After several surveys of the jacket, conductors, and wells it has been confirmed the release of hydrocarbons in the form of gas and crude oil to the water column and reaching the surface. Methane concentration and acetylene (C2H2) tracer were measured in the air using a gas tracer analyzer Cavity Ring Down Spectrometer (CRDS) Picarro 2200 connected to a Global Navigation Satellite System (GNSS) Trimble Pro Series using NMEA sentences. The highest concentration of dissolved methane in the water column close to the hydrocarbon plume fluctuated between 1.29 to 78.63 μM CH_4/L. Background methane concentration in the air fluctuated between 1.8 to 1.9 ppm. However, measurements of CH_4 in the proximity of where gas and oil plumes were detected in the water column spiked up to 9 ppm, with a peak of 11.74 ppm where gas bubbles were observed reaching the water surface. High CH4 concentration over the ocean surface at the MC20 site was mostly fixated around the area where bubbles reached the surface. However, in periods where wind gusts reach as much as 5 to 6 knots, the CH_4 plume was detected as far away as 786 m NNE of the source. Fugitive methane estimations based on Inverse Plume Modeling was used to estimate methane flux rate from the hydrocarbon plume in the water column to the atmosphere. Preliminary results provide an estimated flux of 9 g/s of CH4.

Thin Water Films Encapsulating Oil Droplets Delay Their Mixing with an Oil Slick

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Prediction of the fate of oil requires understanding of the dynamics of oil droplets rising under slicks and of the mechanisms contributing to the formation of emulsions. This study focuses on phenomena occurring during and after the oil droplet crosses the water-oil interface, which delay its mixing of with the bulk oil and contribute to the formation of micro water in oil emulsion. As this droplet approaches the bulk oil, it is stopped by a layer of water separating it from the slick. High-speed holographic imaging shows that as this water layer begins to break up and recede, it leaves behind very thin but continuous water film, as confirmed planar laser-induced fluorescence. This thin film engulfs the droplet, preventing it from mixing with the bulk oil, for a duration that is 3-4 orders of magnitude longer than the droplet crossing process. Formation of this film has been confirmed for a series of oil and waters, including refractive index-mated sugar water and silicone oil, as well as Millipore pure water with silicane oil and hexadecane. Hence, the thin film in an inherent property of the oil-water interface and does not depend on the presence of surfactants. In contrast, thin oil films do not form around descending water droplets crossing the interface. After crossing, the water-coated droplet slowly spreads along the oil-water interface, causing generation of surface kinks, where the film eventually breaks up into a cloud of

submicron droplets. This slow process is driven by electrostatic attraction of film segments located near the interface to the bulk water. The time scales of the entire process, from crossing to the eventual mixing increase with the viscosity of the fluids involved, from seconds for 1.0 cSt oil to nearly one hour for 50 cSt oil. When multiple droplets cross the interface, they form a layer that does not mix with the bulk oil containing various segments of the thin films, presumably affecting the entire slick dynamics.

A Rapid Response Solution Designed and Deployed at MC20 in the Gulf of Mexico to Successfully Contain the Longest Active Oil Spill in U.S. History

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In September 2004, Taylor Energy's Mississippi Canyon Block 20 platform was toppled in the Gulf of Mexico by a subsea mudslide that occurred during Hurricane Ivan. This low probability high consequence event occurred twelve miles from the Louisiana coast and resulted in the platform being dragged off station approximately 500 feet. All of the well bay conductors were buried beneath the mudline under sediment. After 14 years of constant monitoring, and failed attempts at containment, oil and gas was still consistently emitting from the seafloor and a constant sheen was still present on the ocean surface. In November of 2018 the United States Coast Guard partially federalized the worksite and brought in Couvillion Group to design, build, install and operate a Rapid Response System to capture the ongoing release of oil at the site. This presentation will discuss the solution that was designed and deployed in the Gulf of Mexico within a five-month time frame to successfully contain the oil subsea and arrest the sheen.

Detection of the Oil Slick from the MC20 Site with Aerial and Satellite Remote Sensing Before and After the Installation of the Containment Dome

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Remote sensing detections of the oil slick from the MC-20 site have been available for more than 15 years. In this presentation we show a comparison of the detections made by low altitude UAS, high altitude airplanes, and multiple satellites before and after the installation of the containment dome. The persistent slick that used to be observed on the surface and detected routinely by satellites has been mitigated largely by the efficiency of the containment dome. Satellite detections of the oil slick show a reduction on the size of the slick of more than 90% after the installation of the dome under comparable weather conditions.

* Student presenter

Session 024: To Disperse or Not to Disperse? That Is the Question

Findings of the National Academies of Science, Engineering, and Medicine on the Use of Dispersants in Oil Spill Response

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The large volume of dispersants used during the Deepwater Horizon (DWH) oil spill raised concerns that spurred interest in an evaluation of this spill response approach. Each oil spill presents a specific set of circumstances and challenges that requires an understanding of the capacities and limitations of the available response options to select the most effective tools for reducing impacts. In some situations, those response options may include dispersants to break up oil slicks at the sea surface. Dispersants contain surfactants which promote the formation of small oil droplets when mixed with oil in the water column. Smaller oil droplets are subject to greater dissolution and dilution, and under favorable conditions will biodegrade more rapidly. During the DWH spill, dispersants were applied both at the sea surface and at depth where oil emerged from the damaged well. Because of both the large volumes of dispersants used and the novel subsea application, the DWH spill spurred new research on dispersants, much of which was funded by GOMRI. To provide a synthesis of this new information and update two previous reports (published in 1989 and 2005), the National Academies of Sciences, Engineering, and Medicine (NASEM) conducted a review and evaluation of the science on dispersants funded by GOMRI, BOEM, NASEM's Gulf Research Program, EPA, and Clean Caribbean &Americas. This study focused on various aspects of dispersant use in offshore marine oil spills, including dispersant and oil fate and transport, potential effects on human health, aquatic toxicity testing and analysis, decision tools for Net Environmental Benefit Analysis, and comparison with other response options. Scientists with a range of expertise and perspectives were appointed as the study committee to provide an independent and objective analysis of the fates and effects of dispersant use in marine oil spill response. The committee's report was publicly released in 2019 and is available online (https://www.nap.edu/catalog/25161/the-use-of-dispersants-in-marine-oil-spill-response). This presentation will summarize the report's key findings and recommendations, with a focus on using this information to support planning and the decision-making process for future oil spills in which dispersants may be a response option.

An Evaluation of Models to Calculate Droplet Size and Subsurface Oil Releases

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Oil droplet size is one of the most important characteristics affecting the fate of a sub-surface oil release. Accordingly, millions of dollars have been spent developing improved models and conducting laboratory studies of oil droplets since Deepwater Horizon (DWH). At least seven new droplet models have emerged, three of them funded by GOMRI. Calibration and validation of these models have varied, and they can predict median droplet diameters (d50) that differ by more than an order of magnitude for DWH-like conditions. Our purpose here is to bring some closure to this major investment by summarizing the models, evaluating their accuracy, understanding their sensitivity to uncertainty in their input variables, quantifying their uncertainty (confidence limits), and understanding how the model uncertainty affects the calculated fate of the hydrocarbons in a blow-out. To do this, we reviewed

over 200 experimental observations of oil jets to develop a baseline test dataset consisting of 35 representative observations from six different lab facilities. Predictions from the seven models were then compared against the baseline dataset. Our examination of modeling error and sensitivity suggests that it is possible to achieve near zero bias and a 95% confidence limit of roughly 50% for prediction of d50 in the best models. By considering model sensitivity to the input parameters, we find that the better performing models are quite sensitive to the interfacial tension (IFT) under DWH-like conditions. This is unfortunate because IFT is difficult to measure, especially in field conditions, and often unknown in exploration drilling. We use this analysis to identify research needs: perhaps the most pressing is for further oil jet experiments conducted at larger scale, involving nozzle diameters at least between 1 and 10 cm, and experiments investigating the behavior of oil and gas subjected to both pressure and temperature drops at or immediately above the orifice.

Investigation of Droplet Dispersion and Distribution in Experiments and Modeling—Relevant Findings for Decision-Making and Dispersant Use

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In the aftermath of the Deepwater Horizon oil spill in 2010, sub-sea dispersant injection (SSDI) has been used for the first time in order to keep most of the spilled oil submerged. Ten years after the incident, the reasonableness of this response measure and its consequences on the oil fate are still under controversial debate. The most important input parameters for the oil fate modeling are the droplet size distribution (DSD) arising from the blowout and the subsequent rise behavior of the droplets. Both quantities depend on the specific physical properties of the hydrocarbon mixture (potentially including chemical dispersants) as well as on the conditions present in the reservoir, in the deep sea and during the blowout.

SSDI shifts the mean of the DSD towards smaller sizes. However, if the spilled oil is naturally dispersed into small droplets in the deep sea due to turbulent breakup alone, SSDI would be redundant and would cause further damage to the ecosystem. Experimental investigations on droplet dispersion in multiphase free jets and on drop rise behavior have been conducted at varying scales and pressure conditions. For modeling the DSD, a fundamental approach based on the turbulent kinetic energy dissipation rate has been developed. The rise behavior of individual gas-saturated droplets is implemented into the Connectivity Modeling System (CMS) for the Lagrangian simulation of the oil distribution.

Experimental results show a reduction of droplet sizes for cases with increased pressure drop and flow rate as well as an accelerated ascent for gas-saturated droplets as compared to low pressure-drop, pure-oil cases. Modeling these processes shows smaller droplets and still a fast arrival of oil at the surface. Here, we present experimental data in conjunction with modeling results. The consequences for decision-making in terms of SSDI are discussed. This research was made possible by a grant from the Gulf of Mexico Research Initiative (GoMRI), C-IMAGE III.

* Student presenter

Did SSDI or Natural Processes Create the Deep Oil Plumes Following the Deepwater Horizon Blowout?

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The experimental use of the sub-surface dispersant injection (SSDI) strategy for Deepwater Horizon (DWH) was done ostensibly for two reasons: (1) to reduce the quantity of volatile organic compounds (VOCs) entering the atmosphere around workers above the blowout, and (2) to more efficiently treat the large volumes of oil escaping from the well, compared to traditional surface application with aircraft (which was also done). Since DWH, the oil industry has invested in new technologies for delivering dispersants to BOPs and has stockpiled dispersants with the expectation that SSDI will be used as a primary response strategy for the next "ultra-deep" (i.e., ≥1,500 m) blowout. Despite extensive research on the topic, a number of essential questions remain unanswered, including: How effective was the use of SSDI in reducing the quantity of oil and VOCs eventually reaching the surface? Answering this question has enormous practical and economic consequences, as the marine oil industry both in the Gulf of Mexico and globally is increasingly reliant on ultra-deep production. However, current uncertainty in the fundamental mechanisms involving deep sea blowouts and the efficacy of SSDI as a response countermeasure remain. Thus, there remains a fundamental dilemma for oil spill responders: to disperse at depth or not. In this paper we discuss processes and information which argue that the creation of deep oil plumes at 1,100 m water depth as a result of DWH were in part created by a variety of physical and chemical processes other than SSDI. Further we consider scientific approaches to help resolve the dilemma for oil spill responders regarding the use of SSDI for the next deep blowout.

Modeling Degassing in Live Oil Droplets Rising from Deep-Sea Blowouts Settles the Droplet Size Debate

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The largest oil spill in US history occurred at a depth of 1522m in the Gulf of Mexico. A decade of studies on this particular event revealed important blowout characteristics where petroleum hydrocarbons disperse horizontally in deep intrusions while rising vertically in the water column. Important factors driving these processes include the reservoir's gas-to-oil ratio, the magnitude of flow rate and turbulent kinetic energy at the broken riser, and the effects of extreme and variable pressure the oil and gas at the blowout. Such fluid dynamic processes modulate the initial droplet size distribution and thus the rise velocity of oil from the deep-sea. No aspect of the Macondo blowout was more debated than the oil droplets' size: they may have been small enough to keep most of the oil submerged, yet rapid surfacing of oil could not be explained even with dispersant use at depth. But as gas-saturated oil droplets rise in the water column, hydrostatic pressure decreases and degassing occurs. Theoretically, the growing gas void fraction inside the droplet increases its size and decreases its density, thus contributing to accelerating the droplet ascent. While 'internal degassing' has been observed in laboratory-based high-pressure experiments, it remains unaccounted for in oil spill models. To simulate degassing, we developed a multiphase module for the Connectivity Modeling System, adding a fraction of methane with density and decay attributes. We perform a series of simulations with various degassing potentials and demonstrate the critical importance of degassing in increasing the droplet size during ascent and decreasing the oil arrival time to the surface, settling the droplet size debate. In the future, such

* Student presenter

processes fundamentally linked to high pressure in the deep ocean should be taken into account in the response options for uncontrolled subsea oil spills. This research was made possible by the C-IMAGE-III grant from the Gulf of Mexico Research Initiative.

Making the SMART Field Dispersant Effectiveness Protocol Smarter

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SMART protocol for dispersant use requires placing fluorometers in the water and towing them by boat to measure fluorescence resulting from excitation of aromatic compounds present in the dispersed/dissolved oil. A positive indication of dispersion requires fluorescence intensity five times background. Measuring this intensity during an actual spill event is extremely challenging. First, to protect the health of SMART teams, boats typically remain 2 miles away from slicks during aerial dispersant spray. After the spray completes, the SMART boats transit into oil slicks to take measurements. This delays SMART monitoring on the order of 30 minutes. Thirty minutes allows dispersed oil plumes to significantly dilute. Second, the release of oil from most spills is short - on the order of a few hours before the release stops. The period between the actual spill event and application of dispersants is likely 24 hours or more because of logistics, darkness, and the time required for decision making. During this time, slicks are continuously leaching soluble components into the water column, and many of the aromatic compounds are the most soluble. This allows most of the aromatics to leach from a slick before dispersants are applied. The leached aromatics are then transported with currents while the surface slick is influenced by both the wind and near-surface currents. The loss of aromatics combined with rapid dilution makes it challenging to meet the five times background fluorescence intensity requirement even if the treated slick completely disperses. The result is that data collected by SMART teams can confuse decision makers. A more direct indicator of dispersant effectiveness is needed. In this paper, we describe modeling to estimate the water-column aromatic concentrations from dispersed oil plumes assuming 12 – 24-hour response times. In addition, we describe smarter methods for implementing the SMART protocol.

Comparative Risk Assessment of Response Alternatives for the Deepwater Horizon Spill

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While the debate regarding efficacy and effects, and implied tradeoffs, of dispersant use at the surface has continued for decades, the unprecedented size of the Deepwater Horizon (DWH) spill, the scale of dispersant usage, and the novel application of dispersants through subsea dispersant injection (SSDI), have heightened concerns related to their overall impact on the Gulf of Mexico ecosystem. Stakeholders and decision-makers desire an understanding the full breadth of potential impacts of dispersants/oil on the ecosystem, human health and community-level socio-economic well-being. The potential use of SSDI on deepwater releases raises concerns regarding adverse impacts on deep benthic and mesopelagic sub-ecosystems, which might occur as the result of a tradeoff decision. A Comparative Risk Assessment (CRA) of response alternatives for the DWH spill was undertaken to inform the dispersant-use decision-making process. Oil spill modeling was used to predict the transport, fate and extent of DWH oil in various compartments of the Gulf of Mexico ecosystem for alternative cases of the incident: with the

actual response, minus use of any dispersant, minus use of SSDI, with SSDI applied throughout the response, and with no response. Exposures of water surface, shoreline, water column and seabed to oil above thresholds of environmental concern are used to compare relative risks of the response alternatives. The CRA weights the exposures to each Valued Ecosystem Component (VEC) by their relative densities in each Environmental Compartment (EC) and by their relative recovery time. The resulting composite CRA index may be examined using stakeholder values of relative importance of the various VECs and ECs, allowing comparisons of various response options to be examined. This study not only provides some clarity on the effectiveness of the DWH response methods but also provides important input into preparedness and response decision-making for any similar future incident.

Emulsification of Water in Crude Oil and Structural Changes Caused by Dispersants

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It is believed that dispersant application to break up marine oil slicks is effective only before stable water-in-oil emulsions develop. Both breaking waves and gentle mixing produce stable emulsions, and surfactants readily present in crude oil stabilize entrained sea water even in fairly calm seas. Once formed, the interaction of these emulsions with chemical dispersant is poorly understood, partially because field observation at microscopic scales is challenging, and laboratory studies involving dispersant-emulsions interaction have not examined the time evolution of the structure of the emulsion. In contrast, there is substantial literature on other types of emulsions. This study examines the effect of adding dispersant (Corexit 9500) on the structure of water in oil stable and metastable emulsions, with or without external mechanical energy. Microscopic imaging examines the size, spatial distribution, and time evolution of the water droplets prior to and after introducing dispersant. Initially, these droplets form a multi-scale lattice with small droplets aggregating around large ones, with sizes ranging from 0.29 μm to 274 μm. The viscosity of this emulsion is two orders of magnitude higher than that of the crude oil. Marangoni effects resulting from adding dispersant without mixing generates secondary flows and coalescence of the exposed portion the emulsion. In time, part of the water separates, a fraction forms a cloud of micron and submicron droplets, and the rest remains unchanged. Agitating the dispersant-emulsion mixture enhances the phase separation, removing about 66% of the entrained water. The removed fraction decreases with increasing viscosity (reduced water droplet sizes) of the original emulsion. However, the remaining emulsion, which contains the submicron droplets, has a higher viscosity.

Investigating the Influence of Oil Weathering on Dispersant Effectiveness

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It has been shown in laboratory experiments that oil photo-oxidation reduced the oil dispersant effectiveness as measured in the baffled flask test (Ward *et al*., *ES&T Letters* 2018, 5, 226-231). Here, we conducted a study to investigate how the combined effects of oil weathering (i.e., evaporation, photo-oxidation, dissolution, and biodegradation) of oil sheens in a mesocosm system affect the oil dispersant effectiveness. Replicate oil sheens were exposed to natural sunlight for up to 11 days in an outdoor

recirculating seawater system. The oil residues were collected at various timepoints, chemically characterized, and baffled flask tests were performed to determine dispersant effectiveness as a function of weathering. We will discuss changes in bulk and molecular properties of the oil residues that occurred during the experiment, and how these changes might have affected the measured dispersant effectiveness.

Effect of Surfactants on the Generation of Sea Spray During Tropical Cyclones

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Research on the impacts of dispersants for marine oil spill response has primarily focused on biological and ecological components of the ocean, including their effect on fish, corals, birds, and other marine organisms. Dispersants may also impact physical processes in the ocean, as the surfactants used to create them reduce surface tension, dampen short gravity-capillary waves, and suppress near-surface turbulence at the sea surface. The air-sea interface undergoes modification as wind speed increases, such as during tropical cyclones. Under tropical cyclone conditions surfactants may impact the generation of sea spray and spume. A shift in the size distribution of sea spray may influence heat and momentum flux between the hydrosphere and atmosphere during tropical cyclones. The relationship between surfactants, wind speed, and sea spray generation remains poorly understood. To further understand this relationship, we use computational fluid dynamics tools to model the effect of surfactants on sea spray generation under tropical cyclone conditions. ANSYS Fluent's Volume of Fluid to Discrete Phase Model converts water parcels to Lagrangian particles, which represent sea spray and spume in our model. Fluent's Evaporation-Condensation model allows us to also model sea spray evaporation. Preliminary model results suggest that the as the amount of surfactant present increases, the overall abundance of spray under tropical cyclone winds also increases. Laboratory results from an experiment conducted at the University of Miami indicated that surfactants alter sea spray generation by forming branch-like rather than finger-like structures, which fragment into differing sizes of sea spray or spume. Under tropical cyclone conditions, surfactants at the sea surface may affect heat, energy, and momentum exchanges due to altered size distribution and abundance of sea spray and spume. The effect of surfactants on sea spray generation may have consequences for tropical cyclone intensification or decline, especially in areas affected by oil spills and dispersants.

Forgotten Lessons? Revisiting Dispersant Use in Light of the Baffin Island Oil Spill Experiment

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The Baffin Island Oil Spill (BIOS) Project was a large experimental oil spill carried out at Cape Hatt, on the northern end of Baffin Island in Canada's eastern Arctic, between May 1980 and August 1983. A significant part was a pair of releases of ~100 barrels of Venezuelan Lagomedio crude oil (API = 31°) in the nearshore to two separate shorelines. In one case the oil was allowed to strand on the shore, and after a full tidal cycle the remaining floating oil was removed by skimming - about a third of the 100 barrels remained on the beach. The other case released pre-mixed oil and Corexit 9527 via a subsea

* Student presenter

diffuser pipe; essentially none stayed on the shoreline after a full tidal cycle. As we will describe, the fate, effects and persistence of the oil in these two scenarios was very different, and subsequent work suggest important learnings for oil spill response.

Session 025: Large Marine Vertebrates in the Northern Gulf of Mexico Ten Years After the Spill: New Findings, Synergies, Collaborations, and Opportunities

Large Marine Vertebrates in the Gulf of Mexico: Assessing Population Status and Habitat in a Changing Environment

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Cetacean Abundance Trends in the Northern Gulf of Mexico

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Line-transect vessel surveys have been conducted over the last two decades to study the distribution and abundance of cetaceans in the northern Gulf of Mexico. We estimated abundance from surveys conducted over the continental shelf and oceanic waters, from the 100m isobath to the U.S. economic exclusive zone boundary including five summer surveys (2003, 2004, 2009, 2017, 2018) and one winter survey in 2018. The last three surveys were part of the Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS) and included dual-observer methods to account for perception bias. We pooled sightings of oceanic dolphins, primarily from the genus *Stenella*, to estimate relative abundance as the total number of individuals divided by the km of survey effort. The relative abundance of oceanic dolphins decreased from an average of 0.727 individuals/km in the summer 2003, 2004 and 2009 cruises to 0.257 individuals/km in the summer 2017 and 2018 surveys. This decrease raises important questions about potential effects of the Deepwater Horizon (DWH) spill on oceanic dolphins and should be further examined. Distance-sampling analyses are being conducted to compare bias-corrected pre- and post-DWH cetacean abundance estimates.

Gulf-Wide Marine Mammal Population Monitoring: Integrating Data Sources to Improve Spatiotemporal Prediction

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The oceanic Gulf of Mexico (GoM) provides habitat for nearly 20 species of marine mammals. These offshore stocks are highly mobile and potentially migratory and/or transboundary, complicating efforts to quantify impacts of the Deepwater Horizon oil spill. Available monitoring strategies including shipboard visual surveys and passive acoustic monitoring do not individually provide enough spatiotemporal coverage to adequately monitor the expansive northern GoM. One solution is to

synthesize data from multiple monitoring programs with complementary strengths. Resulting models are capable of predicting distributions and densities across the broader region. We present a pilot study combining marine mammal sightings data from shipboard visual surveys conducted by the National Oceanic and Atmospheric Administration's (NOAA's) Southeast Fisheries Science Center (SEFSC) with detections of marine mammals from fixed passive acoustic monitoring data recorded by Scripps Institution of Oceanography.

Visual survey data provide high spatial resolution by covering a large area and provide an assessment of animal densities at snapshots in time. In contrast, fixed passive acoustic monitoring provides high temporal resolution, recording continuously over time, but at a limited number of locations. Habitat models were produced for sperm whales, Cuvier's beaked whale, and Risso's dolphin. Neural networks were explored as an alternative to generalized additive models for improved handling of data inputs with different detection probabilities and distributions. Models trained on joint visual and acoustic datasets out-performed models trained on either dataset independently at predicting presence and densities of marine mammals in novel datasets. The findings suggest that cross platform data synthesis may be a viable strategy for gulf-wide quantitative monitoring and management of marine megafauna.

Diversity and Distribution of Seabirds in Pelagic Waters of the Northern Gulf of Mexico

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Recent vessel-based surveys of seabirds associated with the Gulf of Mexico Marine Assessment Program for Protected Species (GoMMAPPS) have resulted in the spatially and temporally most extensive seabird monitoring effort to date. From April 2017 - October 2019, 14 surveys with GoMMAPPS seabird observers documented seabird occurrence and abundance across ~35,000 km and ~2,000 hours of survey effort. This more than doubles the seabird survey effort associated with the injury assessment phase of the Deepwater Horizon oil spill; ~15,000 km and ~950 hours. For GoMMAPPS, ~7,000 observations representing ~31,500 individuals of 67 marine bird species have been observed. To assess distribution and abundance, we grouped species by foraging guild and population status to provide both ecological and regulatory contexts. Results from preliminary models explore the associations of guilds and common species, including black terns (*Chlidonias niger*), with bathymetric and dynamic environmental features. Dynamic variables assessed are from models created by the HYCOM consortium, and include sea-surface temperature, salinity, sea-surface height anomaly, and surface current direction. Future modeling efforts and analyses will further investigate spatial associations with active oil and gas platforms and habitat-use by highly sensitive and less abundant species. Current and future analyses will provide much needed insights into the distributions and habitat use of marine seabirds using the northern Gulf of Mexico which can inform future traditional offshore energy development (e.g., oil and gas), as well as potential alternative energy development (e.g., wind energy, wave, and current energy).

* Student presenter

Aerial Seabird Surveys in Northern Gulf of Mexico: Progress and Pitfalls

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The Northern Gulf of Mexico is a vital resource for many large marine vertebrate (LMV) species, including seabirds. Characterizing species' composition, distribution, and abundance is essential for assessing the impacts of changing environmental conditions and for guiding management practices and regulatory decisions. Because there is limited information available to quantify seabird species-use in the region, we developed a statistically sound sampling framework for aerial seabird surveys in the near-shore environment as part of the Bureau of Ocean Energy Management's Marine Assessment Program for Protected Species (GoMMAPPS). We are conducting low-level aerial surveys from the USA-Mexico border near Brownsville, TX to Key West, FL including the Dry Tortugas. Using the U.S. EPA Environmental Monitoring & Assessment Program's 40-square kilometer hexagon sampling grid and a generalized random tessellation stratified sampling technique, we drew a random sample of 180 hexagons to survey. We then selected a random flight direction for each hexagon, which defined two additional, adjacent hexagons thereby increasing the spatial coverage and creating a three-hexagon sampling unit. We are utilizing a double observer protocol with three observers collecting data: the pilot-biologist, and two biologists who rotate their seat position daily. Our results so far indicate that observers detect birds consistently, however, discrepancies exist in flock counts and species-level identification. We propose suggestions for handling these issues, including modeling species groups instead of individual species and using an ordinal modeling approach to address potential discrepancies in flock sizes. Understanding cumulative impacts on seabirds in the Gulf will provide information needed for effective management and conservation of LMVs in the Gulf of Mexico.

Synthesis of Sea Turtle Dive Patterns in the Gulf of Mexico: Getting to Abundance Through Aerial Correction Factors

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The 2010 Deepwater Horizon Oil Spill highlighted the lack of baseline information on sea turtle distribution and abundance in the Gulf of Mexico. Dive patterns and behavior, in particular, are not well understood for marine turtles despite having significant implications for management and conservation actions. Since 2010, several projects have been funded that included depth-logging satellite tags affixed to sea turtles captured in the Gulf. These tags collect dive activity information by 'binning' the data into a specified number of bins from 0 meters (surface) to 100 meters in depth within a 24-hour period. Here, we present summary information on sea turtle dive patterns, specifically focusing on the proportion of time they spent at depth. We focus part of this presentation on one depth bin in particular, i.e., 'surface' or upper 2 m of the water column, to integrate with aerial surveys conducted by NOAA and USFWS. Dive behavior and location data were acquired from 136 turtles (59 loggerhead, *Caretta caretta*; 63 Kemp's ridleys, *Lepidochelys kempii*; 14 green turtles, *Chelonia mydas*), spanning Gulf wide and covering the majority of the continental shelf. Results indicate there are differences between species, spatial location, and season for the % of time at surface (TAS). On average, loggerhead turtles spent 16% TAS; Kemp's ridleys spent 18% TAS; and green turtles spent 19% TAS. We identified knowledge gaps in our understanding of sea turtle dive behavior, including a critical need to cover

* Student presenter

seasonal gaps in satellite tracking efforts as well as identify which factors influence the amount of time sea turtles spend at the surface which is when they are available to be seen by aerial or vessel-based surveys. Ultimately, this information can contribute to modeling efforts to quantify sea turtle abundance and distribution in the Gulf of Mexico.

Sustained Maternal Illness and Low Reproductive Success Rate in Barataria Bay Bottlenose Dolphins Following the Deepwater Horizon Oil Spill

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In the aftermath of the Deepwater Horizon (DWH) disaster, impacts to bottlenose dolphins in heavily-oiled areas of the northern Gulf of Mexico were well documented, and included a high incidence of reproductive failure in Barataria Bay (BB), Louisiana. Despite comprehensive veterinary examinations of BB dolphins, the exact mechanism of reproductive failure was undetermined due to limitations in reproductive health protocols and techniques. The purpose of this study was to advance methods for evaluating dolphin fetal, placental, and maternal health in order to investigate the potential mechanisms of reproductive failure. Emphasis was placed on diagnostic ultrasound, blood-based testing, and exhaled gas techniques which could be rapidly developed with animals in human care and then applied to wild dolphin examinations. Capture-release health assessments were conducted in BB to specifically evaluate pregnant dolphins living within the oil spill footprint, and photo-ID field studies were employed to determine whether these pregnant females had positive or negative reproductive outcomes. Results demonstrated that BB dolphins have a sustained low reproductive success rate of ~20% (44 dolphin pregnancies diagnosed and monitored; 2011-2018), with no significant improvement detected over time. Newly-developed diagnostic techniques were utilized to examine the health of pregnant BB dolphins and 96% had evidence of maternal illness. Maternal oxygenation data showed pulmonary disease was likely contributing to acid-base imbalances and may have contributed to low-grade, sustained fetal hypoxia. Additionally, 65% of dolphins with negative outcomes had supporting evidence of placental dysfunction as early as the first trimester of pregnancy. Therefore, we do not expect the low reproductive success rate to improve until the overall health of reproductive females in BB recovers.

Insights on Gulf of Mexico Bryde's Whale Foraging from Suction Cup Tagging

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The Gulf of Mexico (GOM) Bryde's whale is known to have a small endemic population, with fewer than 100 individuals. Little is known about their foraging ecology. Suction cup tags (Greeneridge Sciences - Acousonde) were attached to GOM Bryde's whales to collect information on their diving kinematics and foraging behavior. These tags contain a hydrophone, pressure gauge, three-axis accelerometer and three-axis magnetometer so that depth, body orientation and swimming kinematics could be observed. During foraging dives, these whales only execute a few strokes of fluking during descent, execute a limited number of feeding lunges at depth, and ascended by steady fluking. Cessation of fluking during descent and ascent are interpreted as the depth of neutral buoyancy, related to whale body density. The

tagged whales primarily exhibited lunge-feeding near the sea bottom, and to a lesser extent in the water-column and at the sea surface. During foraging dives near the sea bottom, the whales typically circled the prey before executing a single feeding-lunge, less frequently were two or more lunges executed during a dive. Longer duration dives and dives with more feeding-lunges were followed by an increase in the number of breaths. These data allow the energetic cost associated with lunge feeding in Bryde's whales to be estimated and it may be a significant factor in shaping our understanding of their foraging ecology. Efforts to mitigate threats to the GOM Bryde's whale will benefit from improved understanding of patterns in habitat use and fine-scale ecology within the population.

Gulf of Mexico Bryde's Whale Distribution from Moored Passive Acoustic Monitoring: Call Variation and Occurrence in the Northwestern Gulf

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The Gulf of Mexico (GOM) Bryde's whale, the only year-round resident baleen whale in the GOM, occurs within a restricted range along the northeastern GOM shelfbreak near the De Soto Canyon. With a 2009 estimated abundance of 33 whales, they were recently listed as endangered under the Endangered Species Act. This small population was the most impacted offshore cetacean by the Deepwater Horizon oil spill in 2010, with an estimated 48% of their habitat oiled and an estimated 22% population decline due to the spill. Human activities such as oil and gas exploration and extraction, fisheries, and shipping in the GOM could pose additional risk to this already small population, and it is necessary to better understand their distribution and ecology. While modern sightings outside the core habitat are rare, historical whaling records suggest Bryde's whale range may have extended throughout the GOM. Use of autonomous passive acoustic methods are the best tool for finding rare whale species where they occur infrequently and where they have been historically sighted. To determine if the whales occur beyond the northeastern GOM, acoustic recording packages were deployed at five shelfbreak sites in the northwestern and northcentral GOM from July 2016 to May 2017. Individual calls were manually detected in long-term spectral averages, and hourly and daily presence and number of calls were derived for each site. Review of recordings at four sites yielded over 1500 novel stereotyped tonal call detections. These calls appear to be variants of the long-moan call produced by GOM Bryde's whales in the northeastern GOM. Calls were detected on 12% of days at the westernmost site and call detections decreased heading east across sites. Annual occurrence was sporadic with no evidence of seasonality. This information is crucial for understanding GOM Bryde's whale distribution for use in designating critical habitat and determining whether human activities pose a risk to this species.

Loggerhead Sea Turtle (*Caretta caretta*) Nest Productivity in the Northern Gulf of Mexico Considering Disturbances

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The Northern Gulf of Mexico (NGM) loggerhead sea turtle (*Caretta caretta*) Recovery Unit (RU), which nests on beaches from Franklin County, FL west through Texas, is one of the smallest populations of loggerheads nesting in the Gulf of Mexico. Small populations such as the NGM RU are sensitive to the effects of natural and anthropogenic perturbations. Identification and management of perturbations are key to building and strengthening the resilience of this RU under the rationale that stable, maximized reproductive output will ultimately help maintain a large breeding population. To this end, many nests in the NGM RU are protected and/or relocated to mitigate the effects of predation, inundation, and stochastic disturbances such as oil spills. To our knowledge there has been no formal, RU-scale analysis of the effects of such interventions on recent hatchling output for the NGM RU. To inform management practices towards maximizing reproductive output of turtles nesting in the NGM RU, and therefore improve RU resilience, we determined current hatchling productivity across 12 nesting beaches used by this RU in FL and AL from 2012-2018. Specifically, we investigated how hatchling productivity would increase if the most common disturbances were 100% mitigated. Annual mean hatchling productivity at individual sites ranged from 501 hatchlings to 17,677 hatchlings per year. When examining all 12 sites together, predation (27.5% or 271 nests/year), wash-over (23.3% or 230 nests/year), and wash-outs (17.2% or 170 nests/year), respectively, were the most common disturbances. At most sites, mitigating wash-outs could lead to the highest gain in hatchling output (5.3-67.2% increase), but such efforts are labor intensive and would require careful examination of potential side-effects (i.e. altered sex ratios). Identifying current site-specific productivity allows for an improved understanding of the impacts that future disturbances may have on hatchling productivity in the NGM RU.

Space-Use Patterns Among Surface-Pelagic Juvenile Sea Turtles in the Gulf of Mexico

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Sea turtles occupy a variety of different habitats through their life cycle, from beaches to the open ocean to coastal lagoons. While all life stages were exposed to oil as a result of the Deepwater Horizon spill, the majority of turtles impacted were in the early surface-pelagic stage. Estimates of surface-pelagic turtles killed after the spill ranged from 56,000 to 166,000, with high uncertainty due in part to a lack of baseline information on the abundance and distribution of individuals in this life stage. We captured 82 surface-pelagic sea turtles from sampling sites in the northern and eastern Gulf of Mexico in the years following the spill from 2011 to 2017. Turtles sampled included four of the five species found in the Gulf of Mexico: green turtle (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempii*), hawksbill (*Eretmochelys imbricata*), and loggerhead (*Caretta caretta*). Each turtle was sampled for mitochondrial DNA haplotype analysis to estimate probable source rookery, and outfitted with a small solar-powered satellite tag to track movements after release. The majority of turtles captured were Kemp's ridley and green turtles, the species most impacted by the spill. Seventy-nine individuals remained in the Gulf for the duration of their tracking period which ranged from 1-140 days. Three turtles entered the North Atlantic via the Gulf Stream, all of which were tracked north of Cape Hatteras within two months of leaving the Gulf. The combination of spatial and genetic data suggests that oil spills in the northern Gulf of Mexico may disproportionately impact surface-pelagic juvenile sea turtles from Mexican rookeries.

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Slow Science: Sea Turtle Ontogeny Ten Years After the Deepwater Horizon Oil Spill

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The 2010 Deepwater Horizon (DWH) oil spill highlighted critical data gaps for large marine vertebrates in the Gulf of Mexico. These gaps influenced, hindered, and informed spill response, assessment, recovery, and restoration of the region. Data gaps associated with highly migratory, late-maturing, and long-lived species pose unique problems that are difficult to solve quickly. This is particularly true for sea turtles in the Gulf of Mexico (GoM). Several sea turtle populations have rookeries rimming the GoM, and the Gulf's oceanic waters provide nursery habitat for many of those species prior to recruiting to coastal habitats as larger juveniles. These young turtles were directly impacted by the DWH spill, yet early ecology and demography were among the most glaring gaps in sea turtle population assessments, along with understanding the mechanisms driving turtles' ontogenetic shifts from oceanic to neritic habitats. Since 2011, we have used empirical and theoretical approaches to quantify oceanic to neritic ontogenetic shifts of young sea turtles in the GoM, characterize the habitat use, foraging ecology, and behavior of wild-caught oceanic turtles, identify rookery contributions and regions of risk to the turtles, and examine their relationships with gene expression—the underlying mechanisms potentially driving sea turtle ontogenetic shifts. Our ~decade of results show that the West Florida Shelf is an important ontogenetic transition zone where multiple turtle species undergo shifts in habitat and likely diet as they transition from the oceanic to more neritic life stages. Satellite tagged oceanic turtles exhibit directed orientation and swimming behavior, as well as plasticity in habitat selection and global gene expression profiles. Our work challenges long-held assumptions about early sea turtle life history, yet so many questions remain, making a case for support of 'slow science' of long-lived, late-maturing, highly migratory marine species into the next decade.

Session 026: Modeling Oil Spills from Small to Large-Scales: Recent Research Results and Synthesis Toward Improving Oil Spill Response

Transfer of Hydrocarbons from a Natural Seep to the Water Column and Its Footprint on the Sea Surface

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Natural hydrocarbon seeps in the marine environment are found on all continental margins. In the Gulf of Mexico naturally occurring hydrocarbon seeps are abundant at various depths that have been studied for their effect on biogeochemical cycling and physical effects through direct observations at the seafloor or satellite remote sensing. It is, however, very challenging to characterize the bubble dynamics at the seafloor or and explore the fate of the released hydrocarbons throughout the water column over long periods of time. Our work is the first to address the day-to-day variability of bubble dynamics and the hydrocarbon release rate at the source of a seep cluster in GC600 lease block. The results were obtained by processing the videos collected by a time-lapse video camera (VTLC) every 6 h over 153 days. The vertical upwelling induced by the plume measured with an Acoustic Scintillation Flow Meter (ASFM) at 20 mab for two weeks. In addition to the direct measurements near the seafloor, transport of

bubbles was simulated over two 6-day periods using the Texas A&M Oilspill Calculator (TAMOC) model Single Bubble Module (SBM). The surfacing location of bubbles derived from simulations was in excellent agreement with the oil slick delineated from a satellite Synthetic Aperture RADAR (SAR) image.

Prediction of Transport and Dissolution of Oil and Gas Released from Accidental Subsea Spills: A Coupled Near- and Far-Field Model

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Oil and gas released underwater following an accident on an oil production system pose not only a major safety risk at the sea surface for response operations (fire and explosion hazards, risk of loss of buoyancy of floating ships and structures) but also subjects open water and coastal environments to risks related to toxicity. It is consequently important to predict if oil and gas will reach the sea surface, and if so, where, when, and the quantities of oil and gas involved. Thus, there is a need for improved tools to simulate the fate of oil and gas spilled in the deep ocean. In this study, we coupled two numerical models for oil and gas spills: the Texas A&M Oil spill Calculator (TAMOC) and the General NOAA Operational Modeling Environment (GNOME). TAMOC and GNOME are popular oil spill models freely available to the public, with up-to-date versions posted on the GitHub website. While GNOME is designed to predict the 'far-field' particle transport, TAMOC simulates the behavior of the 'near-field' plume. TAMOC includes a dedicated model of the complex physical and chemical processes happening in the near-field including the behavior of gas bubbles, oil droplets, as well as phase transitions and the phase transfer of petroleum compounds within this multiphase system (oil, gas, and seawater). Using our coupled model, we report on the key fluid and chemical dynamics controlling the fate of oil and gas from accidental subsea releases. We simulated several fictitious scenarios of releases in the Gulf of Mexico. The simulated petroleum fluid mixtures were based on the ADIOS oil Library of NOAA for common crude oils (e.g., Louisiana Sweet Crude oil, Hoops oil). We compared simulations using different approaches for coupling TAMOC and GNOME: at the end of the near-field or on the edge of a cylinder about 1 to 2 km in diameter from the emission. With this comparison, we intend to identify the optimal coupling criterion and to assess the resulting coupled model, aiming to provide a new robust simulation tool for potential future deep-water spills.

Coupling an Earth System Model to the Connectivity Modeling System Allows Dynamic Estimates of Oil Photo-oxidation in the Gulf of Mexico

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The Deepwater Horizon (DWH) blowout revealed challenges and limitations for reliably predicting oil transport and fate from ultra-deep waters (>=1500m). While fate processes such as evaporation, dissolution, and biodegradation are relatively well understood and accounted for in oil spill models, photochemical degradation referred to as ‘photooxidation’ of oil at the sea surface is not fully established. Yet, this weathering process led to the formation of persistent Macondo oil oxidized compounds still found in shoreline sediments. Moreover, photooxidation modified both biodegradation rates of the surface oil and the effectiveness of aerial chemical dispersant application. Despite the fundamental significance of photooxidation in the fate of oil spilled, this pathway is complex and not

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explicitly represented in Lagrangian 3-D oil models and thus ignored in DWH oil budget calculations. This study is the first to dynamically model oil photooxidation. We developed an irradiation module by coupling an Earth System Model, the Navy Global Environmental Model, to the oil application of the Connectivity Modeling System. The novel algorithm estimates the dose of solar radiation individual oil droplets receive while moving in the GOM, and accounts for photooxidation changes. The dose of incoming solar radiation is computed from i) the intensity of the incoming solar irradiance ii) a spatially-temporally explicit coefficient of absorption (*Kd*) of ultraviolet (UV) wavelengths, which varies with oil presence, and iii) the depth of the oil droplet. We examine the potential effects of UV photooxidation rates on surface oil concentrations in a hind-cast simulation of the DWH spill in comparison with a base-case scenario with no photochemical degradation. The irradiation module can be used to test oil weathering hypotheses and inform first response in future spills. This research was made possible by the C-IMAGE III grant from The Gulf of Mexico Research Initiative.

Reynolds-Averaged Simulations of Langmuir Circulation in Shallow Water

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Wave-current interaction can generate Langmuir turbulence consisting of a wide range of Langmuir circulation (LC) scales, parallel counter rotating cells roughly aligned in the wind direction. In unstratified shallow water, the largest of the LC scales can span the full depth of the water column becoming more coherent and persistent than ordinary LC in a mixed layer setting. Traditionally, flows with LC are computed via (1) large-eddy simulation (LES) in which a range of the LC scales is resolved or (2) Reynolds averaging in which none of the LC scales are resolved and the Langmuir turbulence is accounted for through the turbulence model or closure. A new solution strategy based on Reynolds averaging is introduced, relying on the coherency and persistence of full-depth LC. Here these cells are treated as a secondary component to the wind and/or pressure gradient-driven primary flow. Thus, the Reynolds-averaged governing flow equations and the mesh are designed to resolve both the primary flow and the full-depth LC with the turbulence model accounting for the smaller Langmuir scales. Popular turbulence models such as the k-epsilon model updated to account for the unresolved LC scales will be described. The Reynolds-averaged cells computed through the new solution strategy and associated statistics will be compared with their counterparts in LES. The new solution strategy will also be used to simulate full-depth LC in variable water column depth between 5 and 15 meters over lateral distances spanning several kilometers. The goal is to understand the effect of water column depth, lateral boundaries, and cross-cell currents on the intensity, coherency and aspect ratio of the cells (cell height-to-cell width). The newly proposed solution strategy offers the potential for the accurate resolution of full-depth LC and associated vertical mixing and horizontal dispersion of pollutants such as spilled oil in hydrodynamic models of estuaries, lakes and the coastal ocean.

Development of a Predictive Bayesian Oil Spill Model for Tracking of Sunken Oil

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The formation of sunken oil (oil on the bottom) is occurring more frequently due to a rise in the production and transport of heavy oils. Detection and recovery of sunken oil can be difficult because of

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the murkiness of rivers, depths of coastal and oceanic waters, lack of remote sensing techniques to track the sunken oil, and scarcity of sunken oil spill models to predict the transport. Therefore, development of the sunken oil spill sub-model in SOSim (Subsurface Oil Simulator) can assist responders during operational detection and recovery operations by providing guidance for responders working to locate and track the movement of sunken oil. SOSim uses Bayesian inference, based on any available observations of the location and concentration of sunken oil coupled with bathymetric data, to predict the location of the sunken oil in space and time. In particular, field data and bathymetric information are used to infer the velocity and spreading of the sunken oil, and the number of oil patches on the bottom. In addition, SOSim provides uncertainty bounds on the results, to assist responders in determining the scope of oiling on the bottom of the water body. SOSim is capable of handling spills in rivers as well as ocean waters. A user-friendly GUI (Graphical User Interface) has been developed, and the model has recently been demonstrated versus historical data on the T/V Athos I oil spill in the Delaware River. Currently, SOSim uses the boundaries of the river as the limits of the modeling area to provide a 2-D result within the river. Further, to address situations in which the coordinates of the river boundaries are unavailable, current work includes expanding capability to model in one spatial dimension. Upon completion, SOSim will provide ground-truthed forecasts of the location and movement of sunken oil during emergency response and oil recovery operations, and may also be useful for assessing the geographical extent of damage after the response period.

Numerical Study of Oil Droplets Dispersion Under Breaking Waves by Coupling Computational Fluid Dynamics with a Population Balance Model

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The dispersion of oil droplets under breaking waves was studied by coupling computational fluid dynamics (CFD) with a population balance model. The Reynold Averaged Navier-Stokes equations were solved within the open-source CFD code OpenFOAM to simulate the movement of breaking waves in the absence of wind stress and large-scale turbulence. A plunging breaker was reproduced using the approach proposed by Rapp and Melville et al. (1990). The hydrodynamics of the generated breaker (i.e., wave profile, velocity, vorticity, and turbulent intensity) were compared with experimental results from published literature. The CFD results were then used as the input of population balance model VDROP to predict the droplet size distribution (DSD) of dispersed plumes, and the droplets kinematics were simulated by solving the equation of motion accounting for major local forces (i.e., drag, added mass and lift forces) and turbulent diffusion under breaking waves. The behavior of plumes of different droplet sizes was studied. The successful coupling of OpenFOAM and the VDROP model for oil droplets transport under breaking waves unlocks many potential investigations and can be applied to other scenarios of oil spills such as oil leaking in rivers and deep-water blowouts.

Transport of Oil Droplets in the Upper Ocean: Impact of the Eddy Diffusivity Profile

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The transport of oil droplets following a surface oil spill was investigated by two models for the vertical distribution of the vertical eddy diffusivity: A uniform and one following the KPP (K-Profile-Parameterization) model, which increases initially with depth to reach a maximum at one third of the mixed layer depth (MLD), and then subsequently decreases gradually. The initial droplet size distribution was assumed to be acquired based on the Delvigne and Sweeney (1988) model, and it resulted in the mass concentration (mg/L) increasing almost linearly with the droplet diameter. Using a uniform eddy diffusivity, Kave, in the mixed layer, an exact analytical solution was produced and gave the steady state concentration of a given droplet size at the water surface as cd=Md*wd/Kave, where Md is the total (initial) mass of oil of size "d", and wd is the rise velocity of droplets of size "d". This means that neutrally buoyant material would not persist at the water surface. This result could explain observations that droplets smaller than 100 microns do not persist at the water surface. The concentration at 24 hours could be approximated by 0.9~0.97Md*wd/Kave. Thus, in the absence of detailed modeling, one may use one could use this the relation above to interpret the measurements at sea following a spill. It was found that the KPP produces smaller concentrations at the water surface in comparison with the assumption of a uniform K, and that the difference increases with the wind speed and the decrease in droplet diameter. The impact of waves was introduced into the KPP model through a roughness height, zo, that is comparable to the wave height. It was found that the introduction of the zo makes the results more reasonable., as the traditional KPP model does not allow for the downward transport of droplets at the water surface.

A new dimensionless formulation was provided for the transport of oil droplets due to turbulent diffusion and buoyancy, and it allowed generalization of the results of oil droplet transport. The investigation herein reveals that the Delvigne and Sweeney (1988) approach, commonly used in oil spill modeling, is not sufficient to predict the oil droplet size distribution (DSD) in the water column, and that one needs to use a vertical eddy diffusivity to accurately predict the transport in the following hours and days.

Turbulence and Dynamics in the Wake of Stabilized Bubbles in a Water Tunnel

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Dynamics in the wake of gas bubbles in turbulent bubbly flows has been widely studied among various research institutes and organizations for its impact on mass transfer, which is controlled by molecular diffusion at the gas/water interface and turbulent mass transport in the bubble boundary layer and wake region. Bubble size and turbulent wake dynamics further affect bubble drag, the rising patterns of the bubbles, and the fate of gases transported by bubbles in the ocean water column. We developed a new, small-scale water tunnel with a downward-draught counterflow to stabilize bubbles and which enables long periods of image capturing of the wake of the same bubble. With this water tunnel system, we present the experimental quantification of bubble-induced turbulence properties (i.e. turbulent intensity, energy cascade, and vortex identification) in the bubble wake based on non-intrusive measurements using the Particle Image Velocimetry (PIV) technique. A high-speed/high-resolution camera at 200 frames per second (FPS) collected 10 sets of 2,005 images of successive PIV data with 50 µm polyamide seeding particles. These data are analyzed to calculate the terminal velocity of the stabilized air bubble and the local swirl strength and velocity fluctuation of ensemble-averaged flow fields in the wake region to identify the formation of vortices. These analyses are important to understand transport dynamics of natural seep bubbles where large-scale plume dynamics do not play a

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role. This situation is also similar to particle (bubbles/drops) rising from an intrusion layer formed during an accidental oil well blowout.

Investigation of Turbulent Mixing and Primary Breakup for Turbulent Oil Jets

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Knowledge of the trajectory of an oil jet/plume is important for predicting the pathways of hydrocarbons and to devise countermeasures. In this work, two scenarios were considered for ambient water: streaming and quiescent. At first, we conducted large-eddy simulations of an oil jet into water crossflow for different oil flow rates: 40 liters/min and 140 liters/min. The corresponding crossflow water velocity was 0.27 m/s and 0.51 m/s, respectively. The numerical predictions of the plume trajectory and the oil dilution were compared against our large-scale experiments in the Ohmsett tank and prior integral modeling studies successfully. Different types of vortical structures including shear vortices, wake vortices and counter-rotating vortex pair (CVP) were obtained and quantified. The turbulent mixing was quantified along the symmetry plane and the cross-sections of the plume at different horizontal distances from the orifice. Higher turbulent mixing was observed along the upper boundary of the plume due to the jet-crossflow interactions and near the leeward side of the plume due to the CVP vortices and wake vortices. This work reveals that the droplet size distribution which was influenced by the turbulent mixing will be different across the cross-section of the plume and should be taken into consideration in the models employed. In the second scenario, the primary breakup mechanism leading to ligaments that break into oil droplets was investigated through an underwater oil jet into quiescent water. In this work, we simulated an experiment conducted by Prof. Joseph Katz's group where an oil jet was released from a 1.0 cm vertical orifice at a flow rate of 16 liters/min. The predicted contours of oil volume fraction and the droplet size distribution compared well with the observations. The highest shear and vorticity magnitudes were predicted along the boundary layer at the inner surface of the pipe and along the oil-water shear layer with a vorticity magnitude higher than 10^3 1/s. The flow field revealed the hairpin vortices along the shear layer, the boundary layer transition, and the formation of ligaments and oil droplets in the primary breakup region. The shear stress which peels the ligaments from the shear layer and the shear stress creates the droplets from breaking ligaments were also quantified.

Measurements of Flow Structure and Turbulence in the Nearfield of an Oil Jet in Water

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Experimental observations on the flow structures occurring in the near field of crude oil jet breakup in water is a challenge owing to optical obstruction. Therefore, the available experimental data on the structure of immiscible liquid jet is restricted to the periphery or the far-field of this jet. To probe into the near field, refractive index-matched silicone oil and sugar water are utilized as a surrogate liquid pair. Their density ratio, viscosity ratio, and interfacial tension are closely matched with those of crude oil and seawater. Simultaneous planar induced fluorescence (PLIF) and particle image velocimetry (PIV) measurements are conducted by labeling the oil and seeding both phases with particles. Compound

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droplets containing multiple water droplets, some with smaller oil droplets, form regularly at Re>1358, the origin of some of the encapsulated water droplets can be traced back to the entrained water ligaments during the initial roll-up of K-H vortices. The profiles of the mean velocity, as well as normal and shear Reynolds stresses for the immiscible oil jet are compared with those of the single-phase water jet at the same Reynolds number. The spreading rate of the near field of the oil jet is lower than that of the single-phase flow, but increases with the Reynolds number, presumably owing the reduction in droplet sizes. The turbulence is dampened in the oil phase due to its higher viscosity, creating quiescent islands within the oil, consistent with the PLIF observations that while the oil droplets are deformed by the jet's shear field, the interior water droplets are nearly spherical.

High Resolution Simulations of Oil and Gas Blowouts

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We illustrate the potential role of rotation and crossflows in oil and gas blowouts using the MITgcm in a multiphase and non-hydrostatic configuration. We also present a new numerical package, "spoil", which can be used and coupled with chemical and biological models to assess the different impacts oil and gas releases may have in the environment.

Effect of Chemical Herders on the Structure of Breaking Waves

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In-situ burning is one of the oil-spill response options in open waters but requires thick slicks to initiate and sustain the burning process. Application of chemical herders around the oil slick contracts the spilled oil into thicker slicks, thereby facilitates in-situ burning. The water-insoluble but oil-soluble surfactants present in commercial oil herders form a monolayer on the air-water interface and may alter the wave breaking process, thereby impacting the stability of the slick. This laboratory study compares the characteristics of mechanically generated breaking waves of varying scales in clean seawater to those developing in water treated with a herder containing 65% Span-20 and 35% 2-ethyl butanol at various concentrations. The experiments are performed in a 6x0.3x0.6 m transparent acrylic tank, and the waves are generated by a programmable pedal-type wavemaker that has been used in recent years for studying the breakup of oil slicks. The evolution of the wave breaking process is recorded by multiple high-speed cameras. An Acoustic Doppler velocimeter is used to measure the time-varying velocity and turbulence under the waves. For a plunging breaker in clean water, before impingement, the wave crest contains multiple ripples and small fingers, reducing the amount of air entrainment as the plunger hits the surface. In contrast, in the presence of herders, the capillary waves are suppressed, hence the wave-front is smooth and coherent, resulting in engulfment of a large pocket of air, and deeper subsequent penetration of the bubble plume. Accordingly, the phase-averaged vertical velocity component under the wave increases significantly, while the streamwise velocity is unaffected. These phenomena are expected to have an adverse effect on the herding process. Conversely, damping of capillary waves on the wave crest by the herders delays the breakup of relatively weak spilling breakers, hence improving the surface stability, and helping the herding process. However, once breaking of the spillers starts, the herding agent does not seem to have a significant effect on the appearance, penetration or velocity under the waves.

* Student presenter

Session 027: Biogeochemical Tracers in Oil Spill Science: Advances, Lessons Learned, and Future Directions

History of Persistent Organic Pollutants in Offshore Cuban Sediments: Understanding Pollution Preservation in a Tropical Coastal Environment

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Through the analysis of Persistent Organic Pollutants (POPs) such as organochlorinated pesticides (OCPs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs), we can construct a history of pollution events ranging from oil spills to general pollution from agriculture. Temporal and spatial trends of POPs in sediment cores are directly related to socioeconomic, political, and land-use changes over time and space. The historical database for Cuba is limited, especially related to pollution events. To construct the pollution history of Cuba a research cruise (May 2017) collected sediment cores along the northern and northwest coasts of offshore Cuba. Four sites (SL37, SL39, SL43, and SL44) were selected to identify spatial and temporal trends in POPs in relation to pollution. The offshore cores should reflect events that occurred onshore: SL37, located furthest west, is our 'pristine' site located in a national park and nature preserve, the Gulf of Guanahacabibes; SL39, 100km east of SL37, is offshore of the small city Santa Lucia; SL43, 140km east of SL39, is located offshore of the city of Mariel; and SL44, 40km east of SL43, is located offshore of Havana Bay. Havana Bay is the most agro-developed area of Cuba. In this presentation, we will discuss how POP concentrations decrease with further distance from Havana Bay. We will also discuss three distinct time periods in each core: before the 1960s, when Cuba was heavily influenced by the United States, between the late 1960s to 1991, a time when Cuba was supported by the USSR and since 1991during which Cuba has been largely self-sustained. These distinct time periods have had varying influence on the agricultural, economic, and urban developments of Cuba. Our results provide insight into long-term preservation of pollution occurring in tropical coastal environments. This method focused on POPs can be used as a forensic geochemistry tool to evaluate oil pollution and other contaminant histories.

Oil-Derived Trace Metal Signature in *Crassostrea virginica* Shell May Provide Historical Record of Oil Exposure

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Bivalves are useful biomonitors because they assimilate particles from their environment into their tissues, with shells recording changes throughout the oyster's life, while soft tissues only reflect the most recently assimilated elements. To determine if bivalves incorporate oil-derived elements, we exposed juvenile oysters to various oil types (fresh crude, weathered, and controlled spiked oil forms) and concentrations under controlled laboratory conditions during a 4-month period and determined the resulting chemical signatures in their shells. To incorporate the effects of multiple stressors, oysters were exposed to regionally relevant estuarine salinities (14 or 25). Trace element profiles of Ba, Cd, Co, Cr, Cu, Ni, Pb, Sr, V, and Zn were determined using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Biological response to oil exposure and salinity conditions were monitored by measuring the dry shell weight. Preliminary data indicate that oysters may assimilate Vanadium into their shell when exposed to highly weathered oil at lower salinities (14). High background levels of trace

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metals were detected in Mobile Bay and have the potential to interfere with the detection of oil contamination. Additionally, oysters that were exposed to an oil treatment grew less than those exposed to the control treatment and oysters that were exposed to salinity 14 grew less than those exposed to salinity 25, indicating differences in feeding or metabolism among oysters due to variation among treatments. This study demonstrates the potential for using oyster shells to study longer-term contaminant exposure and enhance existing environmental monitoring programs, which currently are largely based on short-term contaminant exposure reflected in soft tissues.

Using Hopanes and Steranes for Assessment of Petroleum Contamination in Marine Invertebrates

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Large crude oil events such as the 1979 Ixtoc I and 2010 Deepwater Horizon (DWH) have released millions of gallons of crude oil into the Gulf of Mexico (GoM) within the last forty years. With such large-scale events, the identification and assessment of contamination in marine organisms and sediments are crucial to understanding the impact of spills on the GoM. One facet of understanding oil spill impact is identifying the source of crude oil contamination. However, in assessment studies oil spill identification using biomarker diagnostic ratios (e.g., hopanes, steranes) use only non-biological samples such as sediments and tar residues. Often, biota exposure to residual oil, particularly years after the spill, remains unsolved regarding the identification of the source of contamination. In this study, we analyzed biomarkers in the tissue of marine invertebrates to test if hopanes and steranes can be used to asses biota exposure to spilled oil and to identify the source of contamination. The mollusk *Hydrobia ulvae* and the crustacean *Corophium volutator* were tested under controlled laboratory settings with exposure to MC252 crude oil (collected from the Macondo well during the DWH oil spill in 2010). Also, we studied the deep-pelagic crustaceans *Acanthephyra purpurea* and *Systellaspis debilis* collected from the GoM one- and six-years after the DWH oil spill. Results indicate that biomarker ratios from all the species studied, both from the laboratory and collected post-DWH event, matched MC252 oil. These findings indicated that the source of petroleum contamination could be identified in marine invertebrates exposed to weathered oil. Our approach provides new insights on contamination uptake of oil residues by marine invertebrates and long-term potential for transfer of these into the marine food web, important for connecting benthic oil contamination with upper trophic levels, including commercially important species.

The Potential of Radium-224 as a Tracer of Timescales of Gulf of Mexico Crude Oil Exposure to the Marine Environment

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Petroleum pollution in the marine environment can be deleterious to coastal and marine ecosystems and can have sustained effects for years. While oil slicks on the surface of the ocean are tracked with relative ease using satellite-based technology, deep sea, neutrally-buoyant hydrocarbon plumes remain

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exceedingly difficult to track. Investigators studying the deep plume produced by the Deepwater Horizon spill came to contradictory conclusions regarding the timing of microbial activity within the plume. Such ambiguity arose in part from to the lack of a tool to accurately determine how long hydrocarbons have been exposed to the marine environment. We provide evidence for the utility of ^{224}Ra as a potential hydrocarbon tracer to determine the marine exposure time of crude oil. We employed time course incubations to constrain a time dependent ^{224}Ra release signature and tested a variety of timescales, temporal resolutions, oil sources, seawater sources, and experimental treatments to determine potential factors that contribute to the variability of ^{224}Ra release from hydrocarbons in seawater. Our results show quantitative release of ^{224}Ra from crude oil in contact with seawater and similar temporal variability in ^{224}Ra activity between two oil sources, regardless of the overall magnitude of release. The magnitude of ^{224}Ra release from crude oil is suspected to vary depending on the geochemistry of the source reservoir and biological activity therein as well as geochemical alterations as the oil flows through geologic conduits. Mechanisms of release are thought to be primarily associated with chemical degradation (i.e., photo- and bio-degradation) of the oil matrix and cation exchange processes. These interpretations warrant further investigation. However, our results provide the first evidence that ^{224}Ra is released from crude oil which represents a disequilibrium from its particle-sorbed parent isotopes suggesting this isotope may be useful for examining the temporal dynamics of oceanic hydrocarbon plumes.

Application of Natural Radioisotope Tracers to Understand Transport and Accumulation of PAHs in Marine Environments

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Following the Deepwater Horizon (DWH) oil spill in 2010, it became evident that quantitative understanding of transport and residence time of oil related organic contaminants; including polycyclic aromatic hydrocarbons (PAHs) in the ocean are limited, mainly due to sampling logistics and analytical challenges. This study utilizes a suite of natural radioisotopes (^{210}Pb, ^{234}Th, ^{14}C) to estimate transport fluxes, removal rates, residence times and seafloor accumulation rates of hydrophobic particle-reactive PAHs in northern Gulf of Mexico (GOM) after the DWH oil spill. These indirect radioisotope-based flux measurements were validated with direct estimations, using surface-tethered free-floating sediment traps. Concentrations of particulate $\sum PAH_{43}$ varied between 0.17-1.31 ng/L in deep ocean, and 0.92-7.04 ng/L in coastal GOM. Particulate PAHs showed strong positive correlation with POC, indicating that POC plays an important role in distribution and transport of PAHs in marine systems. The direct sediment traps-based vertical fluxes of $\sum PAH_{43}$ (6.7 ± 1.0 μg/m^2/d at 150m of the water column) were similar to indirect ^{234}Th-based $\sum PAH_{43}$ fluxes (4.0 ± 0.6 μg/m^2/d). Vertical flux was found to be an important loss term for particulate PAHs from the upper ocean, with 3-7% of the particulate PAHs being lost daily via this mechanism. Sediment trap-derived residence time of particulate PAHs (15-32d in upper ocean) were similar to ^{210}Pb-derived residence times (2-39 d). We used ^{210}Pb, ^{234}Th and Δ^{14}C based PAHs accumulation estimates to link the water column observations with seafloor processes. The concentrations and accumulation rates of sediment $\sum PAH_{43}$, after 1 to 3 years of the DWH spill, varied between 26-160 ng/g and 1.4-63 ng/cm^2/y, respectively. The isotopes-≤based method provides a larger spatial coverage in relatively shorter time and thus can be more appropriate for ocean PAHs flux estimation in high traffic areas like the GOM.

* Student presenter

Stable and Radioisotopes in Tissues and Otoliths as Natural Biogeochemical Tracers of Food Web Effects of the Deepwater Horizon Oil Spill

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Food web effects in the northern Gulf of Mexico have been well documented from plankton to fishes to marine mammals following the Deepwater Horizon Oil Spill (DWH). Stable and radioisotopes, $\delta^{13}C$ and $\Delta^{14}C$, respectively in red snapper muscle tissues and otoliths were used as natural biogeochemical tracers to examine assimilation and transfer of petrocarbon through the marine food web. Red snapper muscle tissue did not display depleted ^{13}C or ^{14}C values until year two post-spill, which reflects tissue turnover rates that are approximately 200 days. Once incorporated, red snapper muscle tissue showed depleted $\delta^{13}C$ and $\Delta^{14}C$ values for two years following DWH; thus, indicating assimilation and cycling of DWH-derived petrocarbon through the nGOM metazoan food web. By year five, $\delta^{13}C$ and $\Delta^{14}C$ had returned to expected values. Muscle petrocarbon signatures were ephemeral due to tissue turnover, but analysis of otoliths from young-of-the-year red snapper indicated ^{14}C-depleted organic C was incorporated into their $CaCO_3$ structure, thus providing a permanent, time-referenced recorder of DWH food web impacts. Metabolic C has more of a direct pathway of incorporation into otoliths, and since otoliths are inert once formed, they provide a permanent marker that can be used to identify environmental disturbances such as DWH. Results from this study clearly demonstrate that stable and radioisotopes in tissues and otoliths can be used as natural biogeochemical tracers of food web impacts following DWH.

Session 028: From Databases to End Users – Transforming the Myriad of Coastal Information and Data Sets into Wickedly Useful Tools

NOAA's DIVER Data Warehouse Platform for Emergency Response, Assessment, and Restoration Data Collection and Sharing

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The DIVER (Data Integration Visualization Exploration and Reporting) application is a collaborative data management platform supporting integrated environmental data management and sharing in the Gulf of Mexico and entire coastal US. The DIVER application is a central part of the funded effort under the Deepwater Horizon (DWH) Natural Resource Damage Assessment to build a gulf-wide data management system, and is used to manage and report on restoration project status and progress and restoration monitoring data. The DIVER application is also widely used by NOAA's Office of Response and Restoration and partners across the coastal US and Great Lakes as a centralized data management platform for gathering, organizing, and sharing critical data and information for emergency response, assessment, and restoration. The DIVER platform is custom built using open source tools and technology with a flexible workspace interface that can be customized to manage data files and documents, calendars and other team management and communication tools. DIVER File Collections provide an organized and flexible location for centralizing and sharing "unstructured" data and documents, and also

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integrate NOAA's electronic data templates used to structure and ingest response and restoration data into a data warehouse. In addition to established data templates and data models for samples, toxicity data and field measurements, NOAA has recently released templates for structuring and importing geolocated photos and Shoreline Cleanup Assessment Technique (SCAT) data. These templates are built upon existing data standards and can serve as data exchange formats to increase data sharing, ease of data exchange and data transparency. DIVER is also coupled with NOAA's Environmental Response Management Application (ERMA), with queries from DIVER able to be securely displayed in ERMA.

Mapping Hydrologic Response to Land-Use Change in the Gulf Coast

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Hydrologic response of flood plain ecosystems is of great importance in choosing a land for conservation purposes. Land-use change is important and often less understood in the most vulnerable flood plain ecosystems. Protection of water quality and quantity is one of the main goals of land conservation in the Gulf Coast of the United States. Following the Deepwater Horizon Oil Spill, an unprecedented amount of funds became available for land conservation along the Gulf Coast, creating opportunities to target landscapes that are beneficial for maintaining flow regimes. To identify areas along this region that are important for maintaining flow, we sought to evaluate the hydrologic response of watersheds at the HUC12 scale to anthropogenic conversion by comparing peak flow estimates at the current land composition and a hypothetical pre-developed state. We mapped the pre-developed state of each watershed by replacing all anthropogenic lands with the most dominant natural landcover present within the watershed, and compared the peak flows using 24-hour unit hydrographs. The hydrologic response of each watershed to land-use change was calculated as the percent change in peak flow between pre- and post-developed states of landcover. This change in peak flow will be available as a data measure in the conservation prioritization toolkit developed as part of Strategic Conservation Assessment project funded by US Fish and Wildlife Service.

Gulf TREE: Your Ultimate Climate Tool Selection Guide

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Gulf TREE (Tools for Resilience Exploration Engine) is a filter-based search engine designed to match users with relevant climate resilience tools quickly, easily, and confidently. With over 100 tools relevant to the Gulf of Mexico (and more being added all the time), Gulf TREE sorts through all these options to match users with a climate resilience tool that meets their criteria. In order to ensure relevance to a wide range of stakeholders, the project centered around two series of Gulf-wide workshops, reaching nearly 200 prospective end-users. The first series of workshops focused on gathering an understanding of what stakeholders wanted out of this resource and the second series of workshops focused on beta testing of the draft resource. This second series resulted in ample feedback in multiple formats, all of which were then organized and prioritized into actionable solutions to identified concerns. The goal in organizing these types of data is to do so transparently, fairly, and within any constraints (e.g., budget, time) a project may have while addressing as many stakeholder concerns as possible and ensuring that

the product is intuitive and user-friendly. The end result is a powerful and capable resource for Gulf of Mexico stakeholders and a solution to common obstacles faced by stakeholders interested in climate resilience. In this presentation, the Gulf TREE approach to stakeholder engagement and lessons learned throughout will be discussed, key findings from both sets of workshops, and the final resource will be reviewed. Explore the site at www.gulfTREE.org.

Ocean Reports — Investigating Ocean Neighborhoods

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Ocean Reports is a publicly available web based application that allows users to select an Area-of-Interest (AOI) in the ocean space and instantly obtain over 70 unique infographics containing analyses of the location; its energy and minerals, natural resources, transportation and infrastructure, oceanographic and biophysical conditions, and its contribution to the local ocean economy. Users can select infographics of interest, explore pertinent ocean data through interactive pop-ups and visualizations, toggle map displays of each layer related to infographic content, share results by web link, and print custom reports to inform various permitting processes. Metadata, data download, background information, and the analysis rule-sets are all available for each infographic. Potential and current users of Ocean Reports include coastal and marine planners, public-sector resource managers, private sector companies, legislative staff, researchers, educators, and the general public who are not otherwise skilled in Geographic Information Systems. Specific topical areas where the tool is relevant include aquaculture siting, offshore energy development, natural resource management, and navigation planning. Ocean Reports is designed for use in all waters of the U.S. Exclusive Economic Zone. This includes the contiguous U.S. as well as Alaska, Hawaii, and the Pacific and Caribbean territories. The data supporting the tool has a wide range of resolutions. In cases where a user draws a small AOI built-in processes prevent the tool from reporting potentially misleading statistics for coarse resolution data. All of the data supporting the tool are available for download through Ocean Reports or Marine Cadastre.gov and are routinely updated as needed to maintain the most current results possible. No specialized skills are needed to run the tool or produce reports.

Development of an International Response Oil Assay

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NOAA's Office of Response and Restoration (OR&R) Emergency Response Division (ERD) is in the process of developing a new publicly available database of oil properties to support the international oil spill response community. As part of this effort, the Response Oil Assay Workshop was held in Seattle on January 14-15, 2020, funded through a Fisheries and Oceans Canada Multi-Partner Research Initiative (MPRI) grant to NOAA ERD. The key findings of the workshop are presented today. The goals of the workshop were: to identify which physical and chemical properties of oils should be included in both an ideal and a minimum oil database record for the purposes of oil spill response and modeling; to discuss recommended lab protocols for measuring the properties identified above (the Response Oil Assay); and to discuss recommended lab protocols for artificial weathering of oils. Attendees included US and international members of the oil spill response community, including field responders, oil spill modeling

* Student presenter

specialists, and analytical chemists, and spanning the academic, governmental, and private sectors. In advance of the workshop, attendees were asked to compile a list of oil properties that they considered important to know in advance of a spill, as well as the analytical methods that they were already using to measure those properties. An analysis of the gaps in the existing NOAA ERD oil database was also presented, with recommendations for oils that should be sought out and analyzed in a lab for future inclusion in the database.

A Science Based Land Conservation Prioritization Framework Based Multicriteria Acceptability Analysis

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There is an overwhelming consensus among conservation experts that an efficient, data-driven, science-based geospatial conservation prioritization tool can help guide or optimize the dollars spent on land conservation. In this work, we developed and implemented a conservation prioritization framework that integrates open-source data and an optimization method based on stochastic multicriteria acceptability analysis (SMAA). SMAA is capable of handling problems with multiple constraints, unknown user preferences, and insufficient or missing data. The data measures were developed from openly available peer-reviewed data from federal and state agencies. These data were used to evaluate projects based on their ecological merit. Since the data that indicate ecological factors tend to be in different scales (geospatial, non-geospatial) and type (raster/vector/table), each of these data measures were converted into a 1 square km hexagonal grid format over the entire study region (Gulf of Mexico RESTORE Region) for further analysis. SMAA algorithms incorporated over 100,000 user preferences to evaluate the merit of conservation projects by assigning random weights. The increasing use of web applications to provide visualizations of geospatial data has improved access to scientific information. Yet many applications lack capabilities in “on-the-fly” processing and analytics. The framework developed as part of this work was implemented as a web-based, user friendly, geospatial tool that can prioritize conservation lands “on-the-fly” based on geospatial footprints. From early validations with the stakeholders, the developed framework produces valuable recommendations for conservation agencies based on an easy to use geospatial web interface. This tool will be a part of Strategic Conservation Assessment project toolkit.

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