Field Observation and Modeling of the Impact of Oil Spill on Marsh Erosion in Southern Louisiana

Project themes: **OBSERVE** and **UNDERSTAND**

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1. Objectives

An integrated experimental and computational study is timely proposed to "observe and understand" the impact of crude oil on marsh erosion in Southern Louisiana, the "physical structure and stability" of the ecosystem, in wake of the recent BP oil spill that transforms some wetlands into a rare, valuable, large-scale, oil-contaminated experimental site for the proposed study. The main **objectives** of this project are three-fold: **(1)** to acquire the first datasets on the erosion of coastal marshes with different degrees of oil contamination; **(2)** to understand the physical and biogeochemical mechanisms controlling oil-contaminated marsh erosion via laboratory testing and computational modeling; and **(3)** to predict the resilience of the oil-contaminated marsh under storm and hurricane conditions.

2. Rationale

The wetlands of the Northern Gulf Coast, underlain by thick, soft cohesive sediments, have recently been increasingly impacted by severe sediment loss due to coastal erosion, sea level rise, and subsidence, e.g., "Louisiana loses one acre of land every 24 minutes" (Fischetti 2001, Marris 2005). The land loss poses a significant threat to the nation's economy and coastal community's safety and lives. Sustainable coastal wetlands, the most productive ecosystem on Earth (Friend & Amos 2007), are also a protective buffer zone for hurricanes and storms and hence very important to the protection of coastal civil and energy infrastructure, safety and lives of coastal community, and fisheries and shipping industries. Moreover, these wetlands, like others elsewhere, have great value for water quality, flood control, shoreline protection, and recreation (Corn & Copeland 2010). Therefore, understanding and hence minimizing LA's marsh erosion have significant technical, economic, and cultural significance.

The crude oil, after landing on coastal wetlands, will interfere in a complex manner with coastal cohesive sediments, marsh vegetation, and the microbial communities therein. For instance, our preliminary field trips found that heavy oil contamination could severely damage or even kill vegetation. Vegetation stems and leaves typically act as a protective "armor layer" for flow/wave energy reduction, while the roots behave as anchors and reinforcement for soil stabilization. Thus oil-induced damage to vegetation tends to worsen marsh erosion.

On the other hand, erosion of coastal sediments inevitably involves the sediment-biota-flow interactions (Friend & Amos 2007), as both physical and biological processes contribute to sediment erosional stability. Prior work revealed that biofilm-induced or biogenic stabilization of sediments is often achieved by microorganism-secreted extracellular polymeric substances (EPS) that bind sediment particles and thus enhance sediment stability, and hence well-developed microbial communities can reduce marsh erosion. Crude oil is a complex mixture of different aliphatic and aromatic hydrocarbons with various structures and properties, which will affect the physical, chemical, and microbial processes in marsh sediments. Highly viscous oil or oil emulsion tends to clog soil pores, reducing the permeability and other mechanical/geotechnical properties. Some oil compounds are highly toxic and may kill bacteria and fungi and thus microbial degradation can be inhibited, while others may stimulate microbial activities by providing a labile carbon source, resulting in accelerated degradation. Thus, in a highly dynamic, energetic coastal environment, crude oil can have either positive or negative impacts on the biofilm community. As such, it is unclear at present whether the interferences of crude oil with coastal sediment and biota are constructive or destructive in terms of sediment erosion. Therefore, this project, by distinguishing itself from other environmentally, chemically, or biologically-oriented studies, is the first of its kind to study the physical structure and stability of the coastal wetland ecosystem. Without stable coastal sediments as the foundation, the coastal wetlands cannot function as a sustainable, resilient ecosystem.

3. Methodology

Overall, research is proposed in three areas, which is divided into six tasks:

- Field measurements to acquire for the first time the erosional resistance and erosion rate of oil-contaminated coastal marsh, as well as wave measurement for subsequent modeling of erosion;
- Studying and understanding the science of oil-contaminated marsh erosion via laboratory characterization designed to uncover the underlying physical and biogeochemical mechanisms;
- Modeling marsh erosion using the obtained soil erosional resistance, vegetation data, and wave data, and predicting the resilience of contaminated wetlands under storm conditions.

Task 1. Field measurement of sediment erosion resistance

The upper Barataria Bay is one of the heavily oiled locations and will be chosen as the primary site for field testing. During each site visit, a Mike IV high pressure (60 psi) Cohesive Strength Meter (CSM) will be used for the direct measurement of erosional resistance or critical shear stress (Tolhurst et al. 1999). CSM tests will be performed on selected sites with varying degrees of oil contamination (accurate determination of oil concentration in sediments will be determined by subsequent laboratory testing). Uncontaminated sites will also be tested to provide baseline data for the purpose of comparison. We plan to have 10-12 site visits, thusly covering the seasonal variations of marshland erosional resistance.

Task 2. Field monitoring of the erosion rate of marsh edges

This task serves two purposes: (1) to directly collect data on the rate of erosion of marsh edges with and without spilled oil; and (2) to validate the results obtained by the above tasks on the erosional resistance of marsh cohesive sediments. Concurrent field monitoring of erosion rates will be achieved by the installation of erosion pins that have been extensively used for economical monitoring of river bank erosion (e.g., caused by boat wakes), coastal shoreline erosions, and even cultivated land erosion. Tidal flat edges, a narrow zone usually free of vegetation, with and without oil contamination, which are subjected to similar wave actions, will be selected for the installation of erosion pins. Vertical pins will be used to monitor the sediment erosion or deposition on horizontal sediment surface, while horizontal ones will measure the erosion of marsh edges typically characterized by a relatively steep slope. During subsequent site visits and testing, the amount of erosion will be obtained from the installed erosion pins, and results will be used to estimate the erosion rates of the tested sites. The measured erosion rate will also be compared with historical data reported from the literature (e.g., LA Geological Survey reports), serving the purpose to indirectly assess whether or not the obtained erosional resistance of oil-contaminated sediments is smaller than uncontaminated soils and hence validate the research findings.

Task 3. Sediment sampling

For each site visit, sediment samples will be obtained from locations near the tested locations. Immediately after retrieving, samples will be wrapped with plastic film, aluminum foil, and duct tape, and then placed in cooler boxes filled with ice to minimize the changes in biofilm concentrations and other microorganism activities that may otherwise take place during transportation. Samples will also be stored in a refrigerator with temperature controlled at 4 ^{o}C to stop or suppress microbial activities. These samples will be used for subsequent laboratory testing and characterization.

Task 4. Wave measurement and monitoring

It has been found that marsh erosion strongly correlates with the wave energy (e.g. Roland and Douglass 2005), as wind waves are the primary driving force of sediment re-suspension and marsh edge scour in a microtidal environment. However, wave monitoring in small estuaries are uncommon. The PI currently maintains a wave gage in Terrebonne Bay at the LUMCON marine monitoring station. It is therefore proposed to deploy a directional wave gage in Barataria Bay. The wave data will allow us to determine the hydrodynamic forcing at each monitoring site of marsh erosion.

Task 5. Laboratory chemical and biological analyses of sediment samples

Fundamental chemical analysis consists of a series of routine tests to determine the pH, porewater salinity, total organic matter content (TOMC), and oxidation-reduction potential. These parameters will help understand the basic chemical properties of the sediment samples. In addition, more sophisticated chemical analyses will be conducted to determine the crude oil and EPS concentrations. These two properties are of key importance for the correlations between oil contamination and sediment erosional resistance.

Microbial EPS concentration will be determined by the widely used method – phenol-sulfuric acid assay (Dubois et al. 1956, Perkins et al. 2004). This colorimetric method is sensitive to a wide range of carbohydrates, including sugars, methylated sugars, and neutral and acidic polysaccharides, which comprise most of the components of microbial EPS (Decho 1990). Although this method cannot determine the total EPS concentration, it can be used as an index of EPS in sediments. The crude oil or total petroleum hydrocarbon (TPH) concentration will be determined by the ASTM methods (D5369, D5368, D7066) on all sediment samples. For better accuracy, after treating sediments with drying agents, methanol-dichloromethane (Sporstol et al. 1985) and dimer/trimer of chlorotrifluoroethylene will be used to extract TPHs, followed by gas chromatography with mass spectrometric detection (GC/MS) and full spectrum Fourier Transform Infrared spectrometric detection (FTIR), respectively.

Microbial activities will be determined by two different measurements to assess the general impact of oil-contaminated soils versus non-contaminated soils on microbial activity. One will be the microbial biomass carbon measurement. The other approach is microbial basal respiration measurements (Zibilske 1994).

Task 6: Numerical modeling of marsh erosion

The PI is currently leading a multi-institution, multi-disciplinary research team funded by the NGI to investigate the resilience of marshes after hurricane impacts. The numerical model developed for the NGI project will be utilized to predict the resilience of salt marshes contaminated with oil based on the field data of soil, vegetation, erosion resistance and hydrodynamic forcing collected in this proposed project. Comparison of oiled and non-oiled marshlands will be made.

4. Budget

The total budget request is $133k, of which ~$65k is for senior personnel and two graduate assistants' salary, $12k is for the purchase of a directional wave gauge, $8k for travel to the coast for field experiments and to conferences, and $8k for materials and supplies.

5. Key References

Corn, M.L. and Copeland, C. (2010). The deepwater horizon oil spill: Coastal wetland and wildlife impacts and response. *A Congressional Research Service Report* R41311.

Decho, A.W. and Moriarty, D.J.W. (1990). Bacterial exopolymer utilization by a harpacticoid copepod - a methodology and results. *Limnology and Oceanography* **35** (5), 1039-1049.

Dubois, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A., and Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry* **28** (3), 350-356.

Fischetti, M. (2001). Drowning new orleans. *Scientific American* **285** (4), 77-85.

Friend, P.L. and Amos, C.L. (2007). Natural coastal mechanisms - flume and field experiments on links between biology, sediments, and flow. *Continental Shelf Research* **27** (8), 1017-1019.

Marris, E. (2005). The vanishing coast. *Nature* **438** (7070), 908-909.

Perkins, R.G., Paterson, D.M., Sun, H., Watson, J., and Player, M.A. (2004). Extracellular polymeric substances: Quantification and use in erosion experiments. *Continental Shelf Research* **24** (15), 1623-1635.

Roland, R., and Douglass, S. L. (2005). Estimating Wave Tolerance of Spartina alterniflora in Coastal Alabama. *Jounral of Coastal Research*, **21** (30): 453-463.

Sporstol, S., Lichtenthaler, R.G., and Oreld, F. (1985). Extraction efficiencies for hydrocarbons from sediments polluted by oily drill cuttings. *Analytica Chimica Acta* **169** (Mar), 343-347.

Tolhurst, T.J., Black, K.S., Shayler, S.A., Mather, S., Black, I., Baker, K., and Paterson, D.M. (1999). Measuring the in situ erosion shear stress of intertidal sediments with the cohesive strength meter (CSM). *Estuarine, Coastal and Shelf Science* **49** (2), 281-294.

Zibilske, L.M. (1994). Carbon mineralization. In: *Methods of Soil Analysis: Part 2, Microbiological and Biochemical Properties*, edited by S. H. Mickelson and J. M. Bighams, SSSA Book Series No. 5.