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DELUGE OF OIL HIGHLIGHTS RESEARCH AND TECHNOLOGY NEEDS FOR OIL SPILL RECOVERY AND CLEAN UP

Testimony Submitted By

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Background

I am an Oceanographer in the Department of Marine Sciences at the University of Georgia (Athens, GA). My research aims to understand how microbially mediated processes influence elemental cycling in the environment. Over my career, a good deal of my research effort has focused on naturally occurring gas and oil seeps, commonly referred to as 'cold seeps', in the Gulf of Mexico. I am an internationally recognized expert on cold seeps and have published a number of high-profile papers describing the microbiology and biogeochemistry of these ecosystems. My testimony will describe the role of hydrocarbons in the Gulf of Mexico ecosystem, both in the natural context and with respect to the potential impacts of focused large inputs such as those resulting from the current Deepwater Horizon spill (hereafter referred to as the BP blowout). I will discuss the ecology of the Gulf of Mexico system, the ecological importance of oil recovery, the nature and potential ecological role of the observed subsurface plume features and highlight needs, current gaps, key features and required support for a successful coordinated federal research program in response to the oil spill.

Ecological role of oil and gas seepage in the Gulf of Mexico

Broader Context: In most pelagic oceanic systems, ecosystem energy flow begins with phytoplankton, who through photosynthesis oxygenate surface waters and provide organic matter to fuel heterotrophic processes and secondary production at higher trophic levels. Heterotrophic organisms consume phytoplankton (e.g. zooplankton) and recycle released dissolved organic matter (e.g. heterotrophic bacteria). Zooplankton are consumed by larger zooplankton and fish and, in the Gulf, this trophic energy cascade is topped by consumers such as sperm whales and predatory fish such as blackfin tuna (who both eat squid and fish). In the Gulf of Mexico, primary production and microbial dynamics have been studies extensively in coastal waters such as those around the mouth of the Mississippi River, but blue water (i.e. open ocean) data on these processes are limited. Studies of benthic processes and benthic communities in deep water are also limited relative to the Gulf's coastal waters but benthic data are more abundant than water column data.

A unique characteristic of the Gulf of Mexico is that its subseafloor sediments contain vast reserves of hydrocarbons. Some of this oil and gas (methane and higher alkanes) fluxes naturally from deep reservoirs through complex fault-networks to reach surficial sediments. In sediments, these reduced substrates fuel extremely high rates of microbial metabolism. Some oil and gas escapes from the sediments and reaches the water column, where it is subject to additional oxidation. A fraction of this water column gas flux ultimately reaches the atmosphere, but these fluxes are not well constrained (1). Natural oil seepage from the seafloor creates slicks that can be quantified and mapped using satellite imagery (2).

Naturally occurring oil and gas seepage plays a key role in shaping the ecology, microbiology, and biogeochemistry of the Gulf of Mexico system, particularly its deep sediments and waters. Under most circumstances, natural seeps are the most important source of petroleum to the marine environment (3). In the Gulf of Mexico, about 95% of offshore oil inputs are from natural seeps under normal conditions. Systems like the Gulf of Mexico are thus accustomed to slow, somewhat diffuse inputs of oil and gas, and the biological communities have adapted to endure and in some cases metabolize these materials such that negative impacts of such inputs are localized as opposed to widespread (3).

Sediment processes: Seepage of oil and gas at the seafloor supports the establishment and proliferation of diverse chemosynthetic ecosystems that includes seep endemic sessile fauna (e.g. tubeworms and mussels), mobile fauna that tend to stay around seeps (e.g. clams, urchins, eels, fish, shrimps) as well as foraging species, such as demersal fish that likely migrate between seeps (e.g. six gill sharks) (5). Some endemic seep fauna harbor chemosynthetic symbionts (e.g. tubeworms, mussels, clams) while others are heterotrophic (5).

While the macro-ecology of cold seeps in the Gulf of Mexico has been well described (5), the microbiology of these habitats is not (6-9), even though the microbial processes serve as the geobiological engine of cold seeps. Free-living microorganisms degrade oil and gas;

under the anoxic conditions typical of seep sediments, oil and gas degradation are largely performed by sulfate reducing bacteria and the product of their metabolism (hydrogen sulfide) provides an inorganic energy source (hydrogen sulfide) to the chemosynthetic macrofauna. The microbial degradation of oil and gas also generates carbonate ions, which subsequently drives precipitation of authigenic carbonates. These carbonate hardgrounds are colonized by deepwater corals (e.g. *Lophelia*), generating another unique seafloor ecosystem that is ultimately driven by natural seepage.

Water column processes: The impact(s) of natural oil and gas seepage on water column microbial communities has received little attention even though it is well known that both oil and gas are introduced into the water column at cold seeps in the Gulf of Mexico and elsewhere. Microbial oxidation of oil is carried out by microorganisms like the gamma-proteobacterium *Alcanivorax*. Microbial oxidation of methane is carried out by a diverse assemblage of methane-eating, or methanotrophic, microorganisms (10). Other low molecular weight alkane gases are similarly oxidized. Because the Gulf of Mexico experiences natural seepage, the natural microbial community here is poised to consume oil and gas. At least 1000 naturally occurring seeps along the Gulf of Mexico shelf and slope deliver from 1000-2000 barrels of oil per day into the Gulf's waters (4). The fact that this naturally derived oil does not accumulate on beaches underscores the ability of natural microbial and physical processes to consume it relatively quickly. However, as will become clear later in my testimony, the magnitude of this spill may saturate the microbial community's ability to consume the introduced oil and gas.

<u>The need document the rate of leakage</u>

In contrast to the naturally occurring hydrocarbon seepage, the BP blowout is injecting from 19,000 barrels (low-end estimate) to 70,000 barrels (high-end estimate) of oil per day into the water column via a focused, intense jet at a water depth of 5,000m. The amount of gas being injected into the system has not been constrained though BP has noted that the total flow could be as much as 40% gas. While natural seepage varies extensively in space and time, the BP blowout is an intense, localized input of labile organic matter to the deep ocean environment. Thus, the BP blowout is an unprecedented perturbation to the Gulf of Mexico system that has no natural equivalent.

It is virtually impossible to understand or quantify the ecological consequences of the BP blowout on the Gulf of Mexico ecosystem *without knowing how much oil and gas has leaked from the wellhead*. These numbers need to be estimated and corroborated independently based on available observational data. Unfortunately, the leak rate was not quantified robustly during the first month of the spill (at least that information has not been made publically available). Unless we know how much oil is leaking from the wellhead, we cannot gauge the full extent of the ecological consequences in deepwater or surface water environments. For example, how much deepwater water column oxygen consumption will be fueled by this influx of oil and gas? Which water column microbial communities will be stimulated by oil and gas? What is the time scale of this response? How will surface water microbial communities respond to surface oil and gas inputs? Potential fishery, marine mammal, and wildlife consequences of the BP blowout cannot be properly predicted until we know the magnitude of the disaster. To put it bluntly, the scientific community is hamstrung until we know precisely how much oil and gas has leaked and is leaking from the wellhead.

It is even more important to quantify the inputs from the wellhead since dispersants are being added to the fluid stream at the seafloor. The aim of deepwater dispersant addition is to break up the oil and reduce formation of surface slicks. The application of dispersants at the riser makes it impossible to estimate the size of the leak solely from surface observations (e.g. using satellite imagery). Given the importance of the estimating the magnitude of the spill, the challenge of monitoring hydrocarbons not only on the surface but also within mid- and deep waters, and of quantifying the hydrocarbon's impact on ecosystem services in benthic, pelagic and littoral zones, it is critical that leak rates are quantified at least every other day by independent scientists until the well is capped and the leakage stopped. There are many scientists who can make these measurements and I know they are willing and eager to help.

Ecological Importance of Oil Recovery

The Gulf of Mexico ecosystem provides a number of ecosystem services to the public, including, fisheries production, recreation and tourism, carbon sequestration and water purification in coastal marshes and mangroves, to name a few. The potential coastal impacts of the BP blowout have received the most attention because this is where the direct human impacts are perceived to be the greatest. Certainly tourism, fisheries yield and production, and wetland and submerged aquatic vegetation (e.g. seagrass) habitats will be impacted. But, the food web of coastal and offshore habitats is likely to be impacted significantly. Everything from the base of the food web – microorganisms – to the higher order consumers – invertebrates, zooplankton, jellyfish, fish, birds, sea turtles, marine mammals – will suffer direct consequences of the BP blowout as long as there is oil in the system due the inherent toxicity of crude oil components. This is why it is essential to recover as much of the spilled oil as possible and to remove it from the environment. While removing oil can be accomplished via skimming or burn offs on the surface ocean or clean up and removal from beaches and marshes, removing methane and other alkane gases is not possible; other than evasion to the atmosphere, the fate of methane dissolved in water lies in the hands of microorganisms that can utilize methane as an energy source.

A secondary effect of the input of oil and gas on the oceanic system arises from the perturbation of the carbon and oxygen budgets in the system. Before the spill, oxygen concentrations in the water column reflected a "steady state" balance between sources (photosynthesis) and sinks (respiration). [Note that while atmospheric exchange can also be important in some cases, for the present discussion, this term will be neglected.]

The direct injection of large quantities of oil and gas into the system has upset the delicate balance of oxygen in the offshore system. Basically, the oxidation of the oil and gas has stimulated respiration such that oxygen is being consumed more rapidly than it is being supplied. We do not know what the end result of this infusion of oil and gas will be on the Gulf's oxygen budget. But, we can use well-studied coastal ecosystems to inform us of the possible consequences of extremely high organic matter loading. In coastal ecosystems, excessive inputs of inorganic nutrients and hyper-production of labile organic carbon has driven increased respiration and heterotrophic oxygen consumption leading to the formation of coastal "dead zones". Low oxygen (hypoxic) or zero oxygen (anoxic) waters have been documented in coastal systems across the globe in recent years. These dead zones are a direct result of perturbation of the carbon and oxygen budgets of these systems. Scientists have previously defined an oxygen concentration of 2 mg/L as the threshold for "hypoxia"; this concentration is where many oxygen-requiring organisms begin to display symptoms of oxygen stress. Under anoxic conditions (0 mg/L oxygen), oxygen-requiring organisms are excluded from the system.

It is well known that methane and oil consumption proceed most effectively under aerobic conditions. This imbalance between oxygen inputs and outputs, if sustained over an ample period of time, could lead to hypoxia or anoxia in the water column, which would have substantial and potentially widespread negative impacts on any oxygen-requiring animal populations and on the food web of the system.

Dispersants. Initial concerns regarding the BP blowout focused on coastal impacts and the need to keep oil from damaging critical coastal ecosystems and the coastal economy, which depends heavily on tourism and fisheries (in addition to the oil industry). Certainly such concerns are valid and widespread efforts to protect the coastal zone from the oil are essential. It appears that the widespread use of dispersants in response to the BP blowout is due largely to the desire to keep the beaches clean and minimize the impact of the spill on coastal environments.

However, oil on the surface of the ocean and even on beaches can be cleaned up. Dispersed oil cannot be cleaned up, rather it moves with the water and the oil and dispersants are likely to influence oceanic ecosystems for years to come. Because dispersed oil cannot be effectively recovered, its fate is largely tied to the activity of microorganisms that degrade it, assuming the dispersants have no negative impact on their metabolism. The implication of this is that dispersed oil may stimulate the oxygen demand of the system and potentially promote subsurface hypoxia.

Oil and gas suspended in the mid-waters and deepwaters of the Gulf of Mexico

Little attention has been given to the offshore oceanic impacts of the BP blowout and initial reports of subsurface oil were received with skepticism. The BP blowout is introducing both oil and methane gas into the deepwater. The oil and gas mixture emitted from the pipe is derived from a very deep subsurface reservoir and the pressure/temperature field of the fluid is dramatically altered as it exists the riser pipe and enters the deep water. Previous studies of deepwater blowout events predicted (3) and illustrated (11) that a substantial fraction of the released oil and gas would become suspended in diffuse pelagic plumes (figure 1, taken from reference 3). Suspension of oil in the deepwater is predicted (and was documented, see ref. 11) to occur *even in the absence of added dispersant agents.* Mid-water oil may derive from coagulation and settling of oil from surface waters or from slowly rising deepwater plumes.

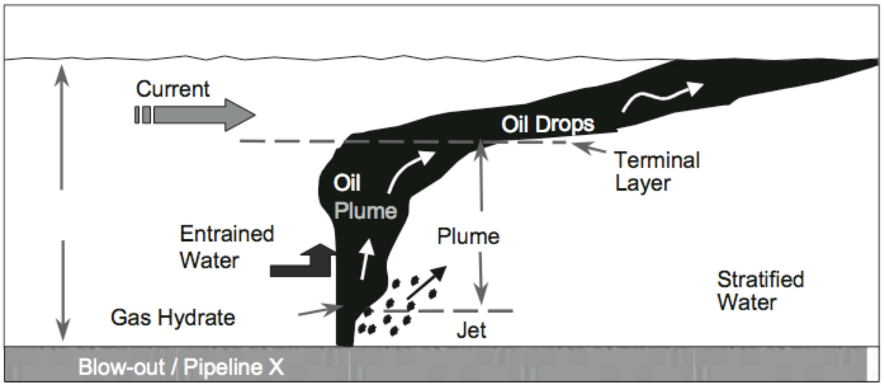

FIGURE 4-6 Schematic diagram depicting the basic physical processes involved in a deepwater subsurface oil and gas release.

Mid- and deep- water oil and gas will flow along the path of the prevailing ocean currents and along bathymetric anomalies. Satellite sea surface imaging has clearly illustrated how difficult it is to understand the movement of oil is in a two-dimensional setting. Mapping and modeling movement of deep and mid-water plumes will be even more challenging.

The fate of oil in the deepwater is likely to be very different from that of surface oil because some processes that occur on the surface do not occur at depth. Most importantly, photooxidation and evaporative loss are important terms of oil breakdown (former) and removal (latter) in surface slicks. Photooxidative processes transform crude oil into compounds that may, or may not, be susceptible to subsequent microbial oxidation.

Neither of these processes is important in deepwater, leaving microbially mediated oxidation and perhaps sedimentation along the seabed as the primary fates of the oil. For deepwater methane, the primary fate is likely microbial oxidation whereas both microbial oxidation and evasion to the atmosphere occur close to the surface.

In the water column, oil and methane oxidation are often coupled to aerobic (oxygen) respiration, meaning that microbially mediated consumption of oil and methane may generate oxygen depletion. Oxygen depletion in deepwater is a significant concern because deepwater oxygen is not replenished *in situ* by photosynthesis (as is the case for surface waters) rather it is replenished by physical processes (12). While surface water hypoxia/anoxia might be short-lived, deepwater hypoxia/anoxia could persist for years if (likely decades). Hypoxia or anoxia would have multiple impacts on the deepwater system, including changes in microbial community composition and the associated processes they mediate, exclusion of oxygen-requiring fauna (e.g. zooplankton, gelatinous zooplankton, fish, squid, whales, etc.) and altered nutrient cycles. For example, if the deepwater becomes anoxic, microbial respiration could switch to sulfate reduction, raising the possibility for generation of substantial volumes of anoxic, sulfidic water deep in the Gulf of Mexico. Furthermore, if such anoxic waters were to intersect with sediments or be pushed into the coastal zone, the impacts could be severe and widespread.

Coupled to the deepwater pelagic system is the benthic ecosystem. The seafloor in the vicinity of natural oil and gas seeps is home to diverse chemosynthetic ecosystems and colonies of cold water corals. Although these organisms can tolerate reduced oxygen concentrations and hydrocarbons, the impacts of the BP blowout will challenge the tolerance of sessile communities beyond any previous insult (12).

Research needs

To properly assess and monitor the oceanic impacts of the BP blowout requires a long term, coordinated research program. It is essential to quantify the mass of oil and gas entering the system, to determine their breakdown rates and fate in the environment, and to constrain their incorporation into the marine food web. Such monitoring must be done immediately and then we must track coupled biogeochemical dynamics of the system closely in the coming weeks, months, and years.

Little monitoring data for offshore sediments or pelagic waters is available in the immediate vicinity of BP blowout (lease block MC252), thus we have no robust baseline against which to compare post-spill conditions and responses. Through NOAA and DOE funding, a long-term research program was established at MC118, a site about 9 miles upslope from MC252, but that program is young and a long term monitoring data set of the benthic and pelagic system is not yet available. The BP blowout thus underscores the need for baseline monitoring in the offshore systems where deepwater drilling is occurring now and where it is planned for the future.

Current deepwater monitoring efforts have focused to a large extent on the area within about 20-30 miles of the leaking wellhead. Basin-wide measurements are needed as soon as possible because the dispersed oil, and the dispersants that generated it, may travel great distances from the site of the spill. It is therefore imperative to obtain background information from sites that may be potentially impacted as soon as possible.

Multiple types of data are needed and these data should be collected throughout the water column at as many places as possible. Detailed hydrographic and physical oceanographic characterization of the water column is essential. Such studies in surface waters (upper 200m), mid-waters (200-800m) and deep waters (800m to the bottom) should address at least the following specific objectives:

1. Quantifying the concentration of oil and the composition of the crude oil (PAH, BTEX, etc.) and fingerprinting the oil to trace it to its origin;
2. Quantifying rates of primary production and evaluating the potential impacts of dispersants on phytoplankton populations and activity (surface waters only);
3. Quantifying concentrations of dissolved oxygen, dissolved inorganic carbon, methane, dispersants, and nutrients and key trace elements (like iron);
4. Quantifying rates of heterotrophic respiration and methane oxidation;
5. Evaluating whether, and if so how, microbial activity is impacted by dispersants;

6. Conduct toxicity studies to evaluate the impact of dispersants on larvae, phytoplankton, zooplankton, and microorganisms;
7. Determine how the microbial community composition is altered by both dispersants and the presence of oil and gas;
8. Determine how microbial degradation alters the composition of the complex oil mixture present in the waters;
9. Quantify incorporation of oil and methane into higher trophic levels in the Gulf's food web;
10. Quantify bioaccumulation of oil-derived toxins (e.g. PAHs) into fishery species;
11. Develop oxygen and carbon budgets for different regions of the Gulf of Mexico that are a function of oil and methane inputs;
12. Quantify the dynamics and movement of oil aggregates from the surface to mid water to deepwater and from deepwater to seafloor sediments;
13. Evaluate benthic impacts of the BP blowout – both in terms of toxicity of the oil, fate of the oil, and potential impacts of water column hypoxia or anoxia – on sensitive benthic communities (chemosynthetic habitats and corals).

Gaps in federal research and technology for oil spill response

I recently spent about two weeks (May 25th through June 6th, 2010) on a research vessel working in the area of the BP blowout. Most of the instruments oceanographers use to sample water and sediments are not designed for working in oily water. Traditional Niskin water sampling bottles are made of plastic and they adsorb oil; they are difficult to clean and because they are open going down, could be contaminated during descent. The oceanographic community needs multiple sets of Teflon-lined "Go-Flo" bottles for sampling oil-impacted waters. Research ships need to be equipped with state-of-the-art optical sensors for measuring oil, colored dissolved organic matter (CDOM), and transmissometry remotely. Such sensors can be mounted onto standard CTD rosettes. Such sensors could also be mounted onto gliders or ROVs to survey wider areas. Acoustic systems, e.g. 12 kHz chirp sonar systems, could aid in visualizing mid- and deep- water plume features easily and rapidly. For sampling sediments, targeted sampling systems such as video-guided multiple corers are essential. At present, such a deep video-guided, remote sediment sampling system is not available through the UNOLS (University-National Oceanographic Laboratory System) fleet instrumentation pool. Without a remotely targeted sediment sampling system (e.g. a multiple-corer as noted above), use of remotely operated vehicles (ROVs like the JASON) and/or manned-submersibles (like the ALVIN) become essential components of the program.

Any long term monitoring would benefit from a dedicated fleet of ships and a core group of scientists to assure continuity in site access, analytical methods, and approach. Organizing a National Academy of Sciences sponsored workshop or symposium to organize oil spill related monitoring and assessment activities could help the Oceanographic research community mobilize, focus, and plan such efforts quickly.

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