Toxicity and Mutagenicity of Gulf of Mexico Waters During and After the Deepwater Horizon Oil Spill

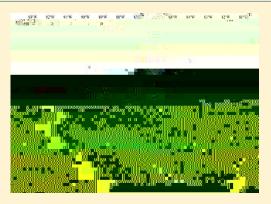
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ABSTRACT: The Deepwater Horizon oil spill is unparalleled among environmental hydrocarbon releases, because of the tremendous volume of oil, the additional contamination by dispersant, and the oceanic depth at which this release occurred. Here, we present data on general toxicity and mutagenicity of upper water column waters and, to a lesser degree, sediment porewater of the Northeastern Gulf of Mexico (NEGOM) and west Florida shelf (WFS) at the time of the Deepwater Horizon oil spill in 2010 and thereafter. During a research cruise in August 2010, analysis of water collected in the NEGOM indicated that samples of 3 of 14 (21%) stations were toxic to bacteria based on the Microtox assay, 4 of 13 (34%) were toxic to phytoplankton via the QwikLite assay, and 6 of 14 (43%) showed DNA damaging activity using the λ -Microscreen Prophage induction assay. The Microtox and Microscreen assays indicated that the degree of toxicity was



correlated to total petroleum hydrocarbon concentration. Long-term monitoring of stations on the NEGOM and the WFS was undertaken by 8 and 6 cruises to these areas, respectively. Microtox toxicity was nearly totally absent by December 2010 in the Northeastern Gulf of Mexico (3 of 8 cruises with one positive station). In contrast, QwikLite toxicity assay yielded positives at each cruise, often at multiple stations or depths, indicating the greater sensitivity of the QwikLite assay to environmental factors. The Microscreen mutagenicity assays indicated that certain water column samples overlying the WFS were mutagenic at least 1.5 years after capping the Macondo well. Similarly, sediment porewater samples taken from 1000, 1200, and 1400 m from the slope o the WFS in June 2011 were also highly genotoxic. Our observations are consistent with a portion of the dispersed oil from the Macondo well area advecting to the southeast and upwelling onto the WFS, although other explanations exist. Organisms in contact with these waters might experience DNA damage that could lead to mutation and heritable alterations to the community pangenome. Such mutagenic interactions might not become apparent in higher organisms for years.

■ INTRODUCTION

The Deepwater Horizon (DWH) well released an estimated 205 million gallons of liquid oil at 1500 m water depth between April 20 and July 15, 2010. In addition, approximately 1.8 million gallons of dispersant (Nalco Corexit 9500A and 9527A) was employed to solubilize the oil into tiny droplets to facilitate bioremediation. ²

In addition to surface plumes of oil, subsurface plumes were documented to the southwest of the wellhead at 1000–1200 m water depth,³ and to the northeast, multiple plumes at 400 m and 1000–1200 m water depth were discovered.⁴

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Mixtures of weathered crude oil collected from the Gulf of Mexico and Corexit9500 applied to mallard duck eggs resulted in decreased spleen weights in hatchlings compared to controls. Both the crude oil and the dispersant signi cantly inhibited the reproduction of the earthworm Caenorhabditis elegans. Dose-dependent inhibitions of hatched larvae production were observed in worms exposed to both crude oil and dispersant. Importantly, the chemical dispersant Corexit9500A potentiated crude oil e ects; dispersant—oil mixture induced more signi cant e ects than oil- or dispersant-alone exposures. While oil-alone exposure and dispersant-alone exposure have none to moderate inhibitory e ects on hatched larvae production, respectively, the mixture of dispersant and oil induced much more signi cant inhibition of o spring production. 11

Corexit9500A was also shown to result in acute e ects on

Sampling Sites. Water samples were collected during 2 process research cruises and 12 monitoring cruises in the Gulf of Mexico (see Tables 1aS and 1bS, Supporting Information). The rst process cruise sampled waters over the west Florida shelf (WFS) at stations along northern (NT) and southern (ST) transects aboard the R/V Bellows between July 10th and 17th, 2010 (Figure 1). The second cruise sampled waters in the northeastern Gulf of Mexico (NEGOM) to the east of the wellhead and in the vicinity of the DeSoto Canyon aboard the R/V Weatherbird II between August 3rd and 13th, 2010 (Stations PCB, FT, and DSH). Water samples were collected using a rosette sampler, equipped with 15 L Niskin bottles.

For monitoring cruise samples, ve were conducted on the WFS and seven were conducted in the NEGOM (Table 1bS, Supporting Information, and Figure 1).

Toxicity Assays. Samples taken from the Niskin bottles were deposited in 120 mL EPA approved precleaned sampling bottles. The Microtox microbial toxicity assay (SDI, Inc.) was used to estimate microbial toxicity as per the manufacturer's instructions using Vibrio fischeri as the light-emitting organism. The Acute Toxicity Assay was performed with the 81.9% Screening test selected from the Microtox Omni Software package. Two true replicates from each station were assayed each in duplicate using 2.0 mL of sample and 100 μ L of Reagent (that was reconstituted within 3 h of assaying). Both negative (autoclaved and 0.2 μ m ltered o shore seawater) and positive controls (0.133 mM phenol) were run during each assay.

The QwikLite toxicity assay (Assure Controls, Inc.) was used as a proxy for phytoplankton toxicity. This assay utilized the light emission from the dino agellate

used for rosette control, as well as the measurement of pressure, salinity, temperature, and output from several instruments. These instruments included a WETLabs, Inc. "ECO-FL" CDOM uorometer and an "ECO-FLNTU" chlorophyll uorescence and turbidity sensor. Fluorescence measurements were validated by comparison with discrete water sample

Table 1. Microbial and Phytoplankton Toxicity Response to Waters from the August 2010 Research Cruise to the NE Gulf of Mexico

| | | Microtox | | QwikLite | | Microscreen | | DCMU | | | | uorescence ratio (F225/330 nm) |
|------------------|--------|-----------------------------------|-------|--------------------------------------|-------|--------------------------------------|-------|---------------------------------------|------------------------------------|---|-----------|-----------------------------------|
| station | depth | % inhibition cont. light emission | range | % inhibition cont. light emission | range | % Increase λ phage abundance | STD | F _{DCMU} / F _o | phyto-plankton >20 μ m cells/L | Simpson Species Diversity Index ng/L (or ppb) | Total TPH | QSE |
| PCB01Surface | 2 m | <0 | 0 | <0 | 0 | 2.37 | 0.124 | 1.76 | 8733 | 0.593 | ND^{a} | ND |
| PCB01-10 m | 10 m | ND | | ND | | ND | | ND | ND | ND | | 11.00 |
| PCB01Bottom | 18 m | <0 | 0 | <0 | 0 | -92.58 | 0.106 | 1.71 | 3067 | 0.340 | 151 | ND |
| PCB02Surface | 2 m | <0 | 0 | 5.3 | 2.65 | -21.6 | 0.1 | 0.88 | 5333 | 0.117 | ND | ND |
| PCB02Bottom | 25 m | <0 | 0 | <0 | 0 | -15.43 | 0.36 | 1.53 | 2066 | 0.489 | 24 | 11.08 |
| PCB03-35 m | 35 m | <0 | 0 | 21.35 | 10.7 | 26.11 | 0.37 | 1.07 | 10333 | 0.551 | 242 | 13.46 |
| PCB03-50 m | 50 m | <0 | 0 | 54.4 | 23.5 | -62.9 | 0.36 | 0.68 | 10390 | 0.664 | 165 | 5.41 |
| DSH09-3 m | 3 m | 11.8 | 1.18 | 1.65 | 0.825 | 43.9 | 0.57 | 1.09 | ND | ND | ND | 20.23 |
| DSH09-75 m | 75 m | <0 | 0 | 11.5 | 5.7 | -43.6 | 0.19 | 1.23 | ND | ND | 88 | 4.12 |
| DSH10-Surface | 2 m | <0 | 0 | 14.4 | 7.2 | 66.17 | 0.52 | 1.17 | 333 | 0 | 74 | 4.88 |
| DSH10-60 m | 60 m | <0 | 0 | 28.2 | 14.1 | 165.6 | 1.1 | 1.15 | 667 | 0 | ND | 8.02 |
| DSH10-400 m | 400 m' | ND | | ND | | ND | | 0.68 | 2303 | 0.776 | ND | 8.71 |
| DSH08-Surface | 2 m | 18 | 3.44 | 6.2 | 3.1 | 158.9 | 0.54 | 1.03 | 405 333 | 0.193 | 203 | ND |
| DSH08-20 m | 20 m | ND | | ND | | ND | | ND | ND | | | 0.95 |
| DSH08-215 m | 215 m | <0 | 0 | 35 | 17.5 | 219.7 | 1.6 | ND | | | ND | ND |
| DSH08-275 m | 275 m | <0 | 0 | 56.8 | 28.4 | 283.5 | 0.5 | ND | | | 298 | 3.27 |
| DSH08-1000 m | 1000 m | ND | ND | ND | | ND | | ND | | | 276 | 2.05 |
| FT1 ^b | 2 m | 10.7 | 2.25 | ND | | 234.6 | 0.73 | 1.15 | | | ND | |

^aND, No data. Bold values indicate statistical signi cance for toxicity assays only. ^bSample collected from ship's surface





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