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Establishing nearshore marine injuries for the *Deepwater Horizon* natural resource damage assessment using AQUATOX

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ABSTRACT

The Oil Pollution Act of 1990 (OPA) requires that the responsible party make the public whole for natural resource injuries attributable to an oil spill incident. We have presented our approach at establishing natural resource baseline conditions for multiple habitats in Coastal Mississippi and Alabama. This paper presents the subsequent steps that were taken to estimate natural resource injuries for the Deepwater Horizon Oil release (DWH) using AQUATOX Release 3.1 NME (Nearshore Marine Environments). TPAH (Total polycyclic aromatic hydrocarbon) exposure matrices in water and sediment were estimated over a spatial gradient based on observed data in Mississippi and Alabama. Bioaccumulation parameters were derived from literature and reasonable bioaccumulation calibration was verified using site specific data when available. TPAH was segregated into six different analyte groups, binned by Kow, based on observed sediment data. Toxicity data from NOAA and literature were used to estimate effects of TPAH and individual analytes on species observed on site. Combining each of these analyses, total injuries could be estimated for Mississippi and Alabama ranging from 0.2% to 4.2% of secondary and tertiary productivity lost over three years, depending on the habitat investigated and its spatial location in the study area. The analysis demonstrates the effectiveness of the AQUATOX model as a tool to quantify levels of injury by comparing the results of a baseline ecological model, calibrated and verified with pre-oiling observations, with post-oiling results. This alternative approach to injury assessment can be used to validate single-species approaches and also to evaluate the injury to, and recovery of, an integrated ecosystem.

1. Introduction

The Deepwater Horizon Incident (DWH) released millions of gallons of oil into the Gulf of Mexico in a deep offshore environment. This offshore oil release was carried into the nearshore environment where it impacted multiple nearshore habitats including nearshore bay bottom, marsh edge and submerged aquatic vegetation (SAV) resources and oyster reefs. Ecosystem damages in the nearshore environment included organism mortality, sublethal effects, and foregone ecosystem productivity (PDARP, Trustees, 2016).

The Oil Pollution Act of 1990 requires that the responsible party for such an event must make the public "whole" for ecosystem damages from any resulting spill or release. To properly remunerate the public for injuries sustained from the DWH incident, a best estimate of ecosystem damages must therefore be produced. The AQUATOX ecosystem model was utilized to estimate secondary and tertiary productivity impacts from direct and indirect effects of the DWH oiling. The resource metric utilized was "kg of productivity as compared to baseline," to assist in the calculation of restoration activities required to "offset" this productivity loss.

We have described the modeling process used for the Deepwater Horizon Incident for establishing baseline conditions necessary to establish what resources existed before the oil came ashore and impacted these multiple habitats in coastal Mississippi and Alabama (Blancher et al., 2017). The current paper moves beyond

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the quantitative evaluation of ecosystem services into the quantitative evaluation of *injury* to those ecosystem services.

As detailed in Blancher et al. (2017), four major habitat types were modeled for Northern Gulf of Mexico coastal areas: estuarine soft-bottom habitats, oyster-reef habitats, marsh-edge habitats, and shoreline beach habitats. Modeled species varied under different habitats; food webs include producers and primary, secondary and tertiary consumers. Table 1 summarizes the animals included in this modeling study and their modeled trophic level.

Model results comparing ecosystem productivity under oiled and background conditions form the basis for our injury evaluation. During the natural resources damage assessment, Natural Resource Trustees retained the authority and responsibility to assess natural resource injuries and losses and define appropriate restoration plans. The numerical models included within the Programmatic Damage Assessment and Restoration Plan (PDARP, Trustees, 2016) evaluated individual-species mortality and resulting foregone production. Marine damages were separated into water-column, benthic resources, and nearshore marine ecosystem categories. In contrast, the AQUATOX model provides an integrated ecosystem model that calculates both direct and indirect effects of toxicant perturbations throughout the food web (Park and Clough 2014). This approach, therefore, provides an alternative, scientifically defensible method, to quantify injury and recovery that can be used at differing levels of detail – from individual species of commercial importance to productivity of the whole, integrated ecosystem. Referencing our modeling approach, the PDARP stated "Independent analyses performed by State Trustees (Blancher et al., 2015) support the observation of reduced secondary productivity for these and additional species in the marsh edge environment" (Trustees, 2016).

For this assessment, we calculated the movement of weathered oil into the nearshore environment using data obtained by the Natural Resource Trustees and the subsequent environmental partitioning of the various compounds and subsequent organismal exposures in the nearshore environment. The AQUATOX 3.1 NME model was subsequently used to calculate internal body burdens of total polynuclear aromatic hydrocarbon (TPAH), critical body burdens of TPAH, and subsequent injuries to (loss of) secondary productivity across each of the baseline habitat models. The results of AQUATOX simulations across various habitats were then used to compile natural resource injury estimates for coastal environments in Mississippi and Alabama.

Table 1
Animal species modeled and average trophic level (baseline).

COMMON NAME	SCIENTIFIC NAME	MODELED TROPHIC LEVEL
Ladyfish	*Elops saurus*	3.9
Seatrout	*Cynoscion sp*	3.7
Black drum	*Pogonius chromis*	3.6
Flounder	*Paralichthys* sp.	3.6
Toadfish	*Opsanus* sp.	3.5
Stingray	*Dasyatis* sp.	3.5
Blue Crab	*Callinectes sp*	3.3
Sm. seatrout	*Cynoscion sp*	3.3
Pinfish	*Lagodon rhomboides*	3.2
Aurelia Large	*Aurelia* sp.	3.1
Killifish	*Fundulus* sp.	3.1
Pompano	*Trachinotus* sp.	3.0
Oyster Drill	*Stramonita haemastoma*	3.0
Polychaete Nephtys	*Nephtys sp*	3.0
Gulf Kingfish	*Menticirrhus* sp.	3.0
Silverside	*Menidia* sp.	2.9
Spot	*Leiostomus xanthurus*	2.9
Goby	*Gobiosoma* sp.	2.9
Stone Crab	*Menippe* sp.	2.5
Brown Shrimp	*Farfantepenaeus aztecus*	2.1
Grass Shrimp	*Paleomonetes* sp.	2.1
Ghost shrimp	*Callichirus* sp.	2.1
Emerita Mole Crab	*Emerita* sp.	2.1
Donax	*Donax* sp.	2.1
Anchovy	*Anchoa* sp.	2.0
Marine Mysid	*Americamysis* sp.	2.0
Bubble snail	*Acteon* sp.	2.0
Oyster veliger	*Crassostrea virginica*	2.0
Menhaden	*Brevoortia patronus*	2.0
Neritina Snail	*Neritina* sp.	2.0
Amphipod Haustorius	*Haustorius* sp.	2.0
Sack Oyster	*Crassostrea virginica*	2.0
Oyster Spat	*Crassostrea virginica*	2.0
Seed Oyster	*Crassostrea virginica*	2.0
Mediomastus Polych	*Mediomastus* sp.	2.0
Rotifer marine	*Brachionus* sp.	2.0
Taneid Crustacean	*Hargaria rapax*	2.0
Mysid	*Americamysis* sp.	2.0
Amphipod	*Lepidactylus* sp.	2.0
Streblospio Polych	*Streblospio* sp.	2.0
Bl Crab Zoea	*Callinectes* sp.	2.0
Acartia Copepod	*Acartia* sp.	2.0
Scolelepis Polych	*Scolelepis* sp.	2.0
Amphipod Ampelisca	*Ampelisca* sp.	2.0
Amphipod	*Gammarus* sp.	2.0
Surf clam Mulinia	*Mulinia* sp.	2.0
Meroplankton	*various*	2.0
Menhaden post-larval	*Brevoortia patronus*	2.0

2. Materials and methods

2.1. Study area and sediment exposure estimates

The EPA AQUATOX model is a general ecological risk assessment model that represents the combined environmental fate and effects of conventional pollutants, such as nutrients and sediments, and toxic chemicals in aquatic ecosystems (Park and Clough 2014). The model is available through EPA's web server at https://www.epa.gov/exposure-assessment-models/aquatox.

AQUATOX considers sorption and bioaccumulation of organic toxicants throughout trophic levels, including attached and planktonic algae and submerged aquatic vegetation, invertebrates, and forage, bottom-feeding, and game fish. A 2008 EPA peer review panel included this quote: "This is the first model that provides a reasonable interface for scientists to explore ecosystem level effects from multiple stressors over time" (US Environmental Protection Agency, 2008). The AQUATOX model was selected by Mississippi (MS) trustees following a model evaluation and model selection process in which nine alternative models were also evaluated for their suitability (Clough et al., 2015b).

When the baseline habitat model was established (Blancher et al., 2017), the remaining steps to quantifying injury were as follows:

- establish oil exposure based on empirical data
- establish bioaccumulation parameters based on site-specific data and literature
- verify model bioaccumulation (to the extent permitted by available data)
- establish toxicity parameters based on DWH-specific data sets and literature values
- quantify injury due to productivity loss

Data gathered from the NOAA Natural Resources Damage Assessment (NRDA) database went through a robust set of data management protocols and systems as described in section 4.1.6 of the PDARP (Trustees, 2016). Other model parameters and data were taken from the peer-reviewed literature, to ensure data quality. All model data and parameters were evaluated by our technical-review team including eight members from the University of Southern