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Commentary

Toxicity testing of dispersed oil requires adherence to standardized protocols to assess potential real world effects

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ABSTRACT

Recently, several researchers have attempted to address Deepwater Horizon incident environmental fate and effects issues using laboratory testing and extrapolation procedures that are not fully reliable measures for environmental assessments. The 2013 Rico-Martínez et al. publication utilized laboratory testing approaches that severely limit our ability to reliably extrapolate such results to meaningful real-world assessments.

The authors did not adopt key methodological elements of oil and dispersed oil toxicity standards. Further, they drew real-world conclusions from static exposure tests without reporting actual exposure concentrations. Without this information, it is not possible to compare their results to other research or real spill events that measured and reported exposure concentrations.

The 1990s' Chemical Response to Oil Spills: Ecological Effects Research Forum program was established to standardize and conduct exposure characterization in oil and dispersed oil aquatic toxicity testing (Aurand and Coelho, 2005). This commentary raises awareness regarding the necessity of standardized test protocols.

1. Introduction

In the wake of the 2010 Deepwater Horizon (DWH) oil spill, substantial research funding has been allocated to examine further the fate and effects of oil and dispersed oil in the aquatic environment. This pattern of elevated interest in dispersant and dispersed oil research has been observed after other significant spills where dispersants were used in the response effort (e.g., Sea Empress spill or the Usumacinta rig explosion). However, since 2010, we have observed a number of publications attempting to address environmental fate and effects issues surrounding the DWH incident using laboratory testing and extrapolation procedures that are not fully reliable measures for environmental assessments. Most recently, the publication by Rico-Martínez et al. (2013) utilized laboratory testing approaches that severely limit our ability to reliably extrapolate such laboratory test results to meaningful real world assessments.

The challenge with this recent influx of research interest in studying dispersant use during oil spills and enhancing response decision-making efforts is twofold. First, performing toxicity testing with complex hydrocarbon mixtures in seawater presents unique challenges due to the inherent difficulties in interpreting and quantifying exposure concentrations when the toxicant consists of compounds with varying degrees of volatility and water solubility. As a result, a reliable characterization of exposure during toxicity tests is critical to ensure correct interpretation of the results. Several recent publications, including that of Rico-Martínez et al. (2013), did not provide fully characterized exposure concentrations to allow comparisons to either concentrations measured during actual spills or exposure concentrations used in prior studies.

In the 1990s, a research program known as the Chemical Response to Oil Spills: Ecological Effects Research Forum (CROSERF) was established to better standardize and conduct exposure characterization in oil and dispersed oil aquatic toxicity testing (Aurand and Coelho, 2005). The forum consisted of academic institutions from five universities within the US, as well as team members from industry, federal agencies including NOAA, MMS and EPA, and many international groups. Several key methodological elements identified during the CROSERF program are particularly relevant and have not been incorporated in recent and on-going research such as the Rico-Martínez et al. (2013) study:

- Development of a standardized methodology for preparing test solutions of oil and dispersed oil to ensure that test results are comparable between different research laboratories.

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- Emphasizing the need that toxicity tests quantify actual oil exposure concentrations in terms of specific analytical measurements, namely the concentrations of Total Petroleum Hydrocarbons (TPH) and Total Polycyclic Aromatic Hydrocarbons (TPAH) in the water.
- Identifying a minimum list of target analytes to be included in the chemical analysis of all test solutions so that the TPH and TPAH values could be compared between different test conditions (e.g., different species, different oils, etc.) and different research laboratories.

The second issue with recent studies is that many fail to put dispersant research into the context of Net Environmental Benefit Analysis (NEBA). Dispersants are used to combat oil spills and are applied to open-water oil slicks to purposefully change the fate of the oil. Oil spill response decision-makers in both industry and government understand that when dispersants are applied effectively in well-mixed open water environments, there is a resultant short-term increase in water column exposure concentrations. Data collected during field trials and incident response operations confirm that in open water situations, short-term increases in exposure concentrations (which persist for minutes to hours) are rapidly diluted to concentrations well below acute thresholds within several hours (McAuliffe et al., 1981; NRC, 1989; Wright et al., 1994; Coelho et al., 1998). In most cases, during laboratory toxicity tests organisms are exposed to dispersed oil concentrations at or above acute thresholds for two to four days, which is at least an order of magnitude longer than such concentrations persist during actual oil spills. The temporary increase in exposure, which will last for minutes to hours in most circumstances, was recognized by resource trustees and stakeholders during DWH as an environmental tradeoff needed to mitigate the well documented, damaging consequences of previous oil spills where surface slicks reached and contaminated shoreline habitats. For sub-sea injection of dispersants, in the case of the DWH incident, the area affected by dispersed oil concentrations exceeding acute toxicity thresholds was likely limited to less than a kilometer from the release site, as monitoring data collected by Coelho et al. (2011) showed very low concentrations at distances exceeding 1 km.

Often there is a misconception that other response options are highly effective alternatives to the use of dispersants for a large offshore oil spill. Although physical removal has the advantage of capturing spilled oil and placing it back into containment, booms and skimmers often cannot be applied rapidly enough or effectively during prevailing sea states. For example, despite a massive response effort during DWH, booms and skimmers only recovered a small percentage of the oil spilled. While this reflects the incident-specific response decisions made during the DWH incident, the effectiveness of open water response can be limited by relying only on mechanical containment and recovery equipment.

Even as incident-specific response conditions greatly affect the utility of each spill response option, sole reliance on mechanical recovery for large, open water spills means that the majority of oil will form and persist as surface slicks that can ultimately strand on shorelines. Physical removal will always be a key consideration for most oil spills; however, all response options have limitations, and physical removal of oil can be accomplished most effectively only for small spills, or for larger spills only under calm wave and weather conditions. Further, recovery of spilled oil is only one facet of considerations for this technology; transport, treatment and disposal of recovered oil and associated water and debris must be taken into account. Other response options *should* be considered if the goal is to reduce the overall human and environmental impact of the incident.

Dispersants can be used under a broad range of weather and sea state conditions, and give the response team the option of choosing what part of the environment is exposed to oil. An objective NEBA will often conclude that it is preferable to expose offshore water column organisms to a rapidly diluting dispersed oil plume rather than allowing a slick to remain on the water surface and potentially impact sensitive shorelines. Further, the increased surface area and rapid dilution of a dispersed oil plume allows naturally occurring petroleum degrading microorganisms to aerobically biodegrade a dilute solution of dispersed oil without exhausting available oxygen and nutrients (Prince et al., 2013).

The above concerns are exemplified in the recent publication by Rico-Martínez et al. (2013) in their paper entitled, “Synergistic toxicity of Macondo crude oil and dispersant Corexit 9500A to the *Brachionus plicatilis* species complex (Rotifera).”

The methods used by the authors do not adhere to the aforementioned key analytical elements of oil and dispersed oil toxicity standards that have been widely adopted. Further, the authors draw real-world conclusions from static exposure laboratory tests without reporting the actual exposure concentrations. It appears that none of the test solutions discussed in the article were analyzed to characterize actual hydrocarbon exposure. Without reliable exposure concentrations, it is not possible to compare study results to other literature that report exposure concentrations. Furthermore, it does not allow a contextually relevant comparison to be made between the dispersed oil concentrations noted in the authors’ laboratory exposures and those measured from the DWH spill, as reported in the OSAT 1 (2010) report and the Subsea Dispersant Monitoring report (Coelho et al., 2011).

2. Presentation of the concerns

Specific shortcomings of the Rico-Martínez et al. (2013) publication are highlighted as follows:

2.1. Methodological

- For Water Accommodated Fraction (WAF)/Chemically Enhanced (CEWAF) tests, neither the oil loading nor the mixing conditions used to generate WAFs/CEWAFs are provided. The loading and the mixing conditions directly impact the exposure concentrations in the WAF/CEWAF and the resulting toxicity, the use of varying loadings may explain the toxicity observed at the different dispersant-to-oil ratios (DOR).
- The authors state that in the third experiment, the same amount of dispersant (0.01%) was added to differing amounts of oil corresponding to the No Observed Effect Concentration (NOEC) for the organism. However, a discrepancy exists as 0.01% equates to approximately 100 mg/L while table 2 in the Rico-Martínez et al. (2013) article lists the 24 h NOEC as 5–10 mg/L.

Interpretation of data reported by Rico-Martínez et al. (2013):

- Although the authors quote an early methods paper by Singer et al. (1998), they did not report that subsequent publications by Singer emphasized the critical importance of expressing toxicity test results based on measured concentrations. The State of California authorized dispersant use in some locales based in large part on this additional data generated by Singer et al. (2001a, 2001b) during the CROSERF research program.
- The authors reference the 1989 National Research Council (NRC) report, “Using Oil Spill Dispersants on the Sea,” a report that is more than two decades old. The 2005 NRC update to this report, “Understanding Oil Spill Dispersants: Efficacy and Effects,” emphasized the importance of standardized methodology and reporting results in measured concentrations. NRC (2005) included a detailed discussion of how dispersants

change the bioavailability of oil, emphasizing the potential for erroneous interpretation of actual exposure using nominal dilution as a measure of exposure consistent with early findings and recommendations of CROSERF. Therefore, it was concluded that LC50s should be reported in mg TPH/L, not as % WAF or CEWAF as done in the Rico-Martínez et al. (2013) study. While the % WAF or CEWAF is reported to assist other scientists in replicating and validating the experiment, where possible, the LC50s should also be reported in mg of TPH/L and PAH/L, in order to enhance exposure-response analyses.

- Interpretation and extrapolation of results are questionable because no actual hydrocarbon exposure concentrations were provided in these studies with no exposure measurements provided in the tests, it is impossible to address the role of dissolved hydrocarbons versus Corexit 9500® in contributing to observed toxicity. The data reported in the study does not support the claim that there is a synergetic effect.
- Differences in oil exposures that result in dispersant treatments appear to be confused with higher toxicity. The toxicity of Macondo oil does not change when dispersants are added. Rather, the dispersant has effectively changed both the rate and location of organism exposure to the oil by moving it from the water's surface to the water column. However, this key insight is missed since exposure concentrations were not quantified. Dispersants allow control over the location of the marine exposure following a spill. Without dispersants, the oil remains on the surface for longer periods. This not only allows potential impacts to marine wildlife, e.g. birds, mammals, turtles, but also increases risks to shoreline habitats. So for many spills where the effectiveness of other response options is limited, the trade-off with dispersant use is relatively straightforward: short-term exposure to water-column organisms (many of which are not impacted or rebound quickly) versus greater impacts to marine wildlife and potentially long-term impacts to near shore and shoreline areas.
- The 1:130 DOR for DWH seems to be based on the total volume of dispersant used (reported amounts used in surface and subsurface applications) with total reported volume of oil released. This represents a clear misunderstanding of dispersant operations and fails to recognize that not all oil was targeted by dispersants. It can be argued that the DOR used in this study has no relevance to DWH.
- In our view, the only tenable finding supported by this study is that dispersants likely made the oil more rapidly bioavailable to water column organisms, a premise that has been well-documented in earlier literature (Ramachandran et al., 2004; NRC, 2005; Schein et al., 2009).

2.2. Applying laboratory toxicity data to the real world

- The Rotoxkit-M kit utilized in monitoring the subsea dispersant injection during DWH is based on a cultured strain of the rotifer genus *Brachionus*, the same genus reported here. This assay was conducted on more than 900 shipboard tests during the summer DWH incident. No discernible response was observed even when organisms were exposed to full-strength water samples collected close to the wellhead. Thus, the claim that the results obtained by Rico-Martínez et al. (2013) support the contention that the toxicity of dispersed Macondo oil was underestimated is in direct contradiction to the wealth of field data that was reported by the Joint Advisory Group (OSAT 1, 2010).
- Concurrent laboratory acute toxicity tests with *Brachionus* were conducted with chemically dispersed Macondo oil (using Corexit 9500®) in parallel to the shipboard field testing effort during DWH. The LC50 values verified in the lab were more than an order of magnitude higher than any reported concentrations near the wellhead (Aurand et al., 2010).

2.3. Implications for future research

As future research on oil and dispersed oil toxicity is conducted and published, it is our hope that this document raises awareness in addressing some of the challenges we have highlighted. In summary

1) While laboratory experiments are useful in showing the relative toxicity of various oil and dispersed oil test solutions, the real world utility of laboratory toxicity tests lies in the ability to compare concentrations of oil that cause impacts on laboratory test species with measured concentrations of oil and dispersants in the water column following dispersant use during actual oil spills. This requires reporting water-column concentrations of total hydrocarbons, PAHs and detailed chemical characterization of laboratory exposure solutions.
2) The decision to use dispersants should involve the assessment of environmental resource trade-offs through a Net Environmental Benefit Analysis (NEBA). As such, it is critical that future studies and subsequent publications of research findings recognize that controlled exposure of water column organisms to a rapidly diluting dispersed oil plume is often preferred to the potential impacts of a surface slick on marine wildlife and shorelines.

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