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## Review

## A review of oil, dispersed oil and sediment interactions in the aquatic environment: Influence on the fate, transport and remediation of oil spills

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## ABSTRACT

The 2010 Deepwater Horizon oil spill has spurred significant amounts of researches on fate, transport, and environmental impacts of oil and oil dispersants. This review critically summarizes what is understood to date about the interactions between oil, oil dispersants and sediments, their roles in developing oil spill countermeasures, and how these interactions may change in deepwater environments. Effects of controlling parameters, such as sediment particle size and concentration, organic matter content, oil properties, and salinity on oil–sediment interactions are described in detail. Special attention is placed to the application and effects of oil dispersants on the rate and extent of the interactions between oil and sediment or suspended particulate materials. Various analytical methods are discussed for characterization of oil–sediment interactions. Current knowledge gaps are identified and further research needs are proposed to facilitate sounder assessment of fate and impacts of oil spills in the marine environment.

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**Nomenclature**

AFM	atomic force microscopy	NCP	National Oil and Hazardous Substances Pollution Contingency Plan
BTEX	benzene, toluene, ethylbenzene, and xylenes	o/w	oil-in-water
CLSM	confocal laser scanning microscopy	OSAs	oil-SPM aggregates
CMC	critical micelle concentration	PAHs	polycyclic aromatic hydrocarbons
DOM	dissolved organic matter	OSC	on-scene coordinator
DOR	dispersant to oil ratio	PFOS	perfluorooctane sulfonate
DWH	Deepwater Horizon	RRT	regional response team
ESEM	environmental scanning electron microscopy	SDBS	sodium dodecylbenzene sulfonate
FA	fulvic acid	SDSS	dioctyl sulfosuccinate
FlowCAM	flow cytometer and imaging system	SEM	scanning electron microscopy
GC-FID	gas chromatography flame ionized detection	SOM	sediment organic matter
GC-MS	gas chromatography-mass spectrometry	SPM	suspended particulate material
HA	humic acid	TOC	total organic carbon
HOCs	hydrophobic organic compounds	TPH	total petroleum hydrocarbons
IFO	Intermediate Fuel Oil	USF	University of South Florida
LIF	laser-induced fluorescence	w/o	water-in-oil
LISST	laser <i>in situ</i> scattering and transmissometry		

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**1. Introduction**

Oil may be released into the marine environment from routine or accidental releases as a result of human activities including drilling, manufacturing, storing, transporting, and waste management (NRC, 2003). For example, an offshore oil well blowout or pipe line ruptures can release large amounts of oil into the marine environment. The 2010 Deepwater Horizon (DWH) oil spill released an estimated 4.9 million barrels of South Louisiana sweet crude oil into the Gulf of Mexico, resulting in the largest marine oil spill in U.S. history and perhaps the second largest in the world, after the first Gulf War oil spill from Kuwait (Abbriano et al., 2011; Graham et al., 2010; Hemmer et al., 2011). Oil tankers carrying millions of gallons of oil can also pose a significant threat to the marine environment in the event of ship collisions or grounding (Bandara et al., 2011; Lytle and Peckarsky, 2001). The 1989 Exxon Valdez oil spill discharged 11 million gallons of Alaskan North Slope crude oil through the ruptured hull in Prince William Sound, Alaska, resulting in a contamination of ~2000 km of intertidal shorelines within the Sound and the Gulf of Alaska (Bragg et al., 1994). It is noteworthy that most oil spilled into the environment from well blowouts or pipe line ruptures is a mixture of oil and natural gas, and is known as “live oil” for its very high vapor pressures. On the other hand, oil from tankers or some pipelines has been separated from the natural gas, and is called “dead oil” for its low vapor pressure (Reddy et al., 2012).

Application of oil dispersants has been a critical response measure to mitigate impacts of marine oil spill for decades (Franklin and Warner, 2011). Following 1989 Exxon Valdez oil spill, an estimated 5500 gallons of the dispersant known as Corexit 9527 was applied to the oil slick (ADEC, 1993). The 1999 M/V Blue Master Spill resulted in a release of roughly 100 barrels of Intermediate Fuel Oil (IFO) 180 from the M/V Blue Master following a collision with a fishing vessel 55 km south of Galveston, Texas. Twelve hours after the spill, approximate 700 gallons of Corexit 9500 were

applied (Kaser, 2001). In 2000, around 2000 barrels of South Louisiana crude oil were discharged into the Gulf of Mexico from a 24 in. pipeline 65 miles south of Houma, Louisiana. In response to the oil spill, 3000 gallons of Corexit 9527 were employed (Stoermer et al., 2001). During the DWH response, BP applied approximately 2.1 million gallons of oil dispersants Corexit 9500 and Corexit 9527, of which 1.4 million gallons of the dispersants were applied at the surface and 0.77 million gallons at the wellhead (Kujawinski et al., 2011).

Generally, oil dispersants are complex mixtures containing three types of chemicals: solvents, additives and surfactants. Solvents are added primarily to promote the dissolution of surfactants, reduce the dispersant’s viscosity and affect its solubility in spilled oil. Additives may improve the dissolution of the surfactants into an oil slick and increase the long-term stability of the dispersant (NRC, 2005). Commercial chemical dispersants usually consist of two or more surfactants. These surfactants in fixed ratios can emulsify oil, and hydrocarbon-based solvents can help break up large clumps of high molecular weight, more viscous oil (Kujawinski et al., 2011; Ramachandran et al., 2004). Oil dispersants lower the oil–water interfacial tension, thereby breaking oil slicks into fine droplets and accelerating dispersal into the water column and dissolution of the hydrophobic oil components (NRC, 2005).

Once oil is released into the marine environment, it undergoes complex physical, chemical and biological transformations, including spreading, drifting, dispersion, stranding, and weathering. The important weathering processes include evaporation, dissolution, biodegradation, emulsification (i.e., “mouse” formation), and photo-oxidation (NRC, 2003). Whole oil droplets may be dispersed into the water column while monocyclic compounds (e.g., benzene and alkyl-substituted benzenes) with  $\log K_{ow}$  values between 2.1 and 3.7 and selected lower molecular weight, 2–3 ring polycyclic aromatic hydrocarbons (PAHs) with  $\log K_{ow}$  values between 3.7 and 4.8 may undergo partial dissolution (NRC, 2005; Payne et al.,

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