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Oil Spill Dispersants: Boon or Bane?

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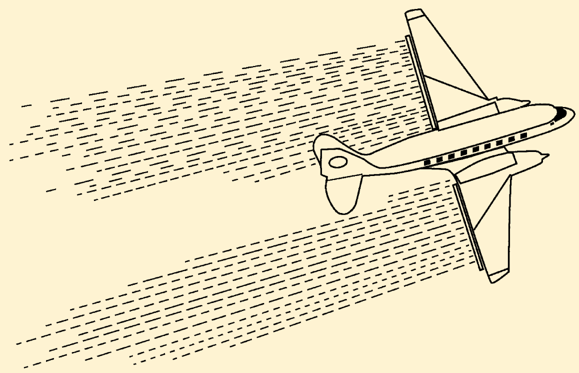

ABSTRACT: Dispersants provide a reliable large-scale response to catastrophic oil spills that can be used when the preferable option of recapturing the oil cannot be achieved. By allowing even mild wave action to disperse floating oil into tiny droplets (<70 μm) in the water column, seabirds, reptiles, and mammals are protected from lethal oiling at the surface, and microbial biodegradation is dramatically increased. Recent work has clarified how dramatic this increase is likely to be: beached oil has an environmental residence of years, whereas dispersed oil has a half-life of weeks. Oil spill response operations endorse the concept of net environmental benefit, that any environmental costs imposed by a response technique must be outweighed by the likely benefits. This critical review discusses the potential environmental debits and credits from dispersant use and concludes that, in most cases, the potential environmental costs of adding these chemicals to a polluted area are likely outweighed by the much shorter residence time, and hence integrated environmental impact, of the spilled oil in the environment.

■ INTRODUCTION

Oil fuels our modern world, accounting for some 33% of energy consumption in 2013; daily consumption was 87 million barrels per day.[1] Some of this crude oil is produced from wells drilled under the sea, and a large percentage travels by sea between production and consumption. Despite the best efforts of the oil and shipping industries, some gets spilled. Catastrophic spills appropriately garner the public's attention, although, in fact, most spills are rather small. Natural seeps are likely the largest contributor of oil to the world's oceans, followed by nonpoint sources on land.[2] Tanker accidents are becoming less common,[3] but it is still true that a few large spills contribute the most oil released to the sea by ships, and where such spills occur, they release far more oil in a few days than even the most active seeps. The tragic 2010 blowout from the *Deepwater Horizon* well[4] is a reminder that large releases can also occur from drilling operations.

Crude oil has been part of the biosphere for millions of years,[5] and a large number of microbes, both prokaryotic[6] and eukaryotic,[7] have evolved to consume it. Biodegradation is the eventual fate for all spilled oil that is not collected or burned, and both collection and combustion require that spilled oil be corralled with booms.[8] While skimming can be an effective process if equipment is close to hand and the weather is reasonably calm, and is frequently part of oil spill response plans (e.g., refs 9−12), large spills in remote areas can spread so quickly that skimming becomes extremely difficult. For example, the *Deepwater Horizon* response, despite enormous efforts, collected only some 3% of the oil released and burned another 5%.[4] Considerable research has been expended, therefore, on trying to enhance the rate of oil biodegradation.

Oil is an unusual substrate for microbial growth for two distinct reasons. On the one hand, most oil molecules have low density and are very sparingly soluble, so oil tends to stay as surface slicks or droplets dispersed by wave action. Biodegradation is then limited by the surface area of the oil−water interface. On the other, whereas hydrocarbons are rich sources of carbon and energy, oil contains no other useful elements for microbial growth. Nitrogen and phosphorus are the most usual limiting nutrients in the sea,[13] followed by iron and other trace requirements.[14] While seawater contains trace levels of these nutrients,[15] the biodegradation of significant concentrations of oil, such as on a shoreline, is likely to exhaust the local supply. Bioremediation, the stimulation of biodegradation, thus aims to overcome these two limitations.

In the case of oil stranded on shorelines in Prince William Sound AK following the spill from the *Exxon Valdez*, the first response was to remove oil from beaches by washing it back to the sea and collecting it with skimmers.[16] This had the effect of leaving a relatively thin film of oil on the gravel and rocks of the intertidal (and sometimes supra-tidal) zone, and this was bioremediated by the careful addition of oleophilic and slow-release fertilizers to increase the supply of bioavailable nitrogen and phosphorus. This worked quite well, stimulating oil biodegradation between 2- and 5-fold without causing any additional adverse effects,[17−20] but it should be born in mind that the oil had already been on the shoreline for a year before the quantitative experiments reported therein were begun.

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Floating oil presents different challenges. Floating oil is a very real hazard to diving birds and mammals (e.g., refs 21 and 22), and oil that beaches is a hazard to shorebirds,[23] invertebrates,[24,25] and mangroves.[26] Ameliorating these hazards was a primary impetus for the initial development of oil spill dispersants in the 1970s.[27] Modern dispersants are complex mixtures of anionic and neutral surfactants in a hydrocarbon solvent (e.g., ref 28) that lower the interfacial tension between oil and water so that minimal wave action and turbulence can disperse the oil into tiny droplets (<70 μm) in the water column. Such droplets are essentially neutrally buoyant, so with minimal turbulence they stay in the water column and diffuse apart. Concentrations of dispersed oil may be ≈1000 ppm in the first minutes after dispersion, but they fall to a few ppm, in a correspondingly larger volume, within hours, and to sub parts per million levels within a day.[29−34] Furthermore, even these concentrations are found only in the top few meters of the sea. Similarly, dispersants can harness the ejection turbulence of oil emanating from an uncontrolled subsea release and allow the formation of tiny oil droplets in the deep sea;[4,34−37] again, the droplets diffuse apart until they are in the sub parts per million concentration range. This diffusive dilution means that, although the levels of nutrients in the sea are relatively low,[13] it does not take long for oil concentrations to fall so that even those low levels are adequate for significant and rapid biodegradation. Hazen et al.[14,35] measured half-lives of *n*-alkanes of a few days in the dilute (2−442 ppb[34]) dispersed submarine plume from the *Deepwater Horizon* at 1100−1220 m (and 5 °C), and very similar results were reported for a broad array of individual hydrocarbons at low concentrations in New Jersey seawater at 8 °C,[36,37] in a flume in Trondheim, Norway,[38] at 30−32 °C and in water off the Penang, Malaysia, shore[39] at 27.5 °C. The approximate biodegradation half-life of the total measurable hydrocarbons was 11−14 days, both at low oil concentrations with indigenous nutrients[36,38] (2.5 and 43 ppm oil, respectively) and at slightly higher concentrations (100 ppm oil) with added nutrients.[39] Even the four ring aromatic chrysene and its methyl-, dimethyl-, and ethyl-alkylated forms had half-lives on the order of a month.[36]

■ DISPERSANTS

Dispersants have been used on a large scale in many responses, notably, the 1993 *Braer* wreck in the Shetland Islands,[40] the 1996 *Sea Empress* spill in South Wales,[41] and the 2010 *Deepwater Horizon* blowout in the Gulf of Mexico.[33] Seven spills in the US portion of the Gulf of Mexico were treated with dispersants between 1995 and 2004.[42] Dispersants are stockpiled, with equipment for their use, in large quantities around the world,[43] and substantial illustrated guidelines for their use are freely available.[44] Nevertheless, their deployment is still controversial, for clearly dispersants are not without potential drawbacks. Most dispersants are not themselves significantly toxic; they have toxicities indistinguishable from common household dish liquids and shampoos,[45] including those used for cleaning oiled seabirds,[46,47] and the majority, including those used in the *Deepwater Horizon* response, show neither androgen- nor estrogen-receptor activity.[48] Nevertheless, the use of dispersants involves adding more chemicals to an already impacted area, and the water under a recently dispersed oil slick is significantly transiently more toxic to organisms than under the undispersed slick, albeit because of the greater concentrations of oil in the water, not because of any increase in toxicity on an oil weight basis.[47,48,50]

So, how should spill response coordinators decide when and where to use dispersants? Most responders rely on a net environmental benefit analysis, often abbreviated NEBA.[51−55] At first glance, the concept seems oxymoronic: how can anything related to an oil spill have an environmental benefit? However, in actuality, the concept is very useful: everyone involved in a cleanup recognizes that an oil spill is a dreadful environmental insult and is working diligently to minimize adverse impacts and to remove the oil as quickly as possible. The question is whether a response tool will end up doing more harm than good, of whether there will be net environmental improvement despite potential collateral harm done in the short term by the response. Table 1 offers a comparison of the potential hazards and environmental fate of floating slicks and dispersed oils that need to be considered in such analyses.

The first hurdle for dispersants is to demonstrate their fundamental efficacy. In the United States, the U.S. Environmental Protection Agency (USEPA) maintains the National Oil and Hazardous Substances Pollution Contingency Plan Product Schedule[56] as part of the National Contingency Plan and lists chemical dispersants that may be authorized for use. Dispersants on the Product Schedule have demonstrated effectiveness; they can disperse at least 45% of Prudhoe Bay or South Louisiana crude oil in a standard swirling flask test.[57] The swirling flask test is one of several tests designed to discriminate between dispersants with different efficacies on a simple laboratory scale. It does this reasonably well (although the USEPA is considering revising it with a baffled flask test[58]), but unfortunately the passing grade of 45% has often been assumed to indicate expected field performance. In fact, the test dramatically underestimates efficacy in the field, primarily due to the amount of energy it imparts to the floating oil and the volume available for diffusion. Tests in the OHMSETT facility,[59] a wave tank in New Jersey that is 200 m long, 20 m wide, and 2.5 m deep, routinely measure dispersant efficiencies >95%, even at low temperatures with ice in the water.[60]

A second requirement for listing on the USEPA product schedule is that the acute toxicity of the dispersant to two reference species (silverside fish, *Menidia beryllina* (96 h), and mysid shrimp, *Americamysis bahia* (48 h)[49,59]) be reported. During the *Deepwater Horizon* response, the USEPA required that dispersants "have a toxicity value less than or equal to (sic) 23.00 (sic) ppm LC_{50} toxicity value for *Menidia* or 18.00 ppm LC_{50} for *Mysidopsis* (*Americamysis*)";[62] the dispersants being used passed this hurdle.[49]

As mentioned above, the toxicity of modern dispersants is usually so low as to likely have only minimal adverse effects at levels used in response operations (nominal aerial dispersant application rates are 5 gallons of dispersant per acre, 47 L/hectare;[63] diffusion into the top 20 cm of seawater would give concentrations around 23 ppm, and of course further diffusion will continually lower the concentration). However, dispersed oil is significantly more toxic, with acute LC_{50} values more than an order of magnitude lower.[49] There has been some confusion around quantifying the toxicity of dispersed oil;[64,65] acute toxicity arises from a general narcosis caused by dissolved hydrocarbons moving to the lipids of the test organism,[66−68] so if estimates of oil concentrations include small droplets, the toxicity expressed on a per milligram hydrocarbon basis are lower (higher LC_{50}) than that for dissolved components. In any case, dispersants encourage solubility by increasing the surface-

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Table 1

potential hazards and environmental fate of floating slick	potential hazards and environmental fate of dispersants and dispersed oil
	Dispersant application has the potential to create aerosols with potentially adverse effects on humans and wildlife. Such effects are seen only in the laboratory at quite high concentrations and with prolonged exposures.[99−102] They are minimized by protective equipment for applicators and exclusion zones around application. Aerial application is very unlikely to be approved within several miles of a coast.
	The addition of dispersants puts additional chemicals into a polluted area. Nominal application rates of dispersants are 5 gallons per acre (47 L ha^{-1}) for surface spills,[63] equivalent to a dispersant/oil ratio of about 1:20. Subsea injection seems to be effective at much lower doses, perhaps 1:100 or less. Dispersants are composed of chemicals that are generally acceptable for food contact and are biodegradable,[28,93,94] but when they are used at suboptimal doses, they may become incorporated into persistent tarballs.[96]
	Dispersants may persist in the environment. Dispersants are complex mixtures of surfactants and solvents, and very few techniques can measure them all.[104] Much published work has focused on individual chemicals, but since all of the components are widely used in consumer products on a far greater scale than in dispersants, care must be taken in attributing detection to dispersant use.[97]
	Dispersants may not penetrate heavy oils and may "roll-off" before they can be effective.[103,105] Nevertheless, dispersants have been shown to be effective with many heavy oils,[117] and new formulations are being developed to further this use.[106]
	Suboptimal dispersant application may not disperse the oil but may hinder subsequent skimming operations.
	Several studies appear to show that dispersants do not stimulate biodegradation very much.[139−141,36,78] Those experiments were based on a misunderstanding of the role of dispersants,[37] which is simply to disperse oil into tiny droplets that can diffuse apart. Such dilute small droplets, whether generated by dispersants or by low concentrations of oil, are degraded rapidly,[36−38,78] and dispersants show no significant stimulatory effect. Dispersed oils that can recoalesce into larger droplets, as occurs in laboratory experiments with more than a few parts per million oil,[139−141] again show only a small stimulation of biodegradation by dispersants. A clear stimulation of biodegradation by dispersants (many fold) is seen only when dispersed oil at environmentally realistic concentrations[29−36] is compared to an undispersed slick.[37] It is the latter that is the target of dispersants.
	Dispersants have been reported to be toxic to some bacteria.[142] These experiments looked at a few isolated cultivars from beach sand rather than pelagic organisms likely to be exposed to dispersants. Dispersants had no inhibitory effects in experiments with pelagic microbes[36−38,78] and were significantly less toxic than oil alone to *Vibrio fischeri* (now *Aliivibrio fischeri*[143]) in the Microtox test.[144]
Floating oil can be lethal to birds or mammals that penetrate it. The oil reduces the insulating properties of feathers and fur and may be toxic if ingested during preening or grooming.[21,22] Mild oiling may be transferred to eggs, chicks, and young.[107] Floating oil also likely kills small invertebrates, algae, fish eggs, and young that are at the sea surface under the slick.[108]	*Dispersed oil is potentially toxic to organisms close to the surface when the oil is initially dispersed.* This is particularly true for small invertebrates, algae, fish eggs, and young that cannot swim away.[109] Nevertheless, measured dilution suggests that they will not be exposed for very long.[29−36] The remarkably heterogeneous distribution of planktonic organisms, on all scales, probably has more influence on local populations than relatively small-scale mortality due to concentrated dispersions of oil.[145,146] Planktonic microbial species respond remarkably rapidly, even to diel cycles.[147] Fish kills are rarely noted after dispersant use, presumably because fish and other nekton swim away from the dispersed oil.
Floating oil is subject to photooxidation, which polymerizes polycyclic aromatic compounds to polar materials.[110,111] This eventually leads to very persistent tarballs.[112] Beached oil undergoes a similar process, leading to very persistent "pavements".[126,127]	
Transparent planktonic organisms may accumulate polycyclic aromatic compounds leached from slicks and beached oil and may be subject to phototoxicity in the surface layer of the sea.[113]	*Dispersed polycyclic aromatic compounds may be accumulated by transparent planktonic organisms, which may then be subject to phototoxicity in the surface layer of the sea.*[113]
Floating oil absorbs water; it is not unusual for floating slicks to increase their volume by >50% in 24 h.[114−116] This phenomenon makes dispersion more difficult but not impossible.[117] Over several days, many floating oils emulsify, forming water-in-oil emulsions known as mousse.[118−120] The encapsulated water no longer exchanges with bulk seawater, and biodegradation is likely even more nutrient- and oxygen-limited than in the floating slick. Mousse may be consumed by fish, turtles, etc. and also lead to tarballs.[111,112]	
Small molecules in floating oil evaporate rapidly, becoming volatile organic compounds (VOCs)[119,120] *that can reach levels of concern for spill responders.*[121] Evaporated molecules may be destroyed by photochemistry[122] or biodegradation.[123]	*Dispersion slows evaporation, especially if the oil is dispersed subsea, as some was in the Deepwater Horizon response.* The potentially toxic small molecules are retained in the water column until they are biodegraded or escape to the atmosphere over a much greater area due to diffusion at depth.
If it is not physically dispersed by storms or recovered mechanically, then an oil slick will likely beach on a shoreline. If it stays on the shoreline surface, then it may be possible to remove it by physical means, but storms will likely incorporate oil deep into sandy beaches,[124,125] where, if left alone, it will likely remain for decades.[126,127] Beached oil can be a major threat to turtle and shorebird nesting[128] and to mangroves[129] and marshes,[130] and recovery may take years.[131,132]	*Dispersants are typically used far from shore in deep water (e.g., >3 miles*[148]*).* Dispersed oil diffuses to sub parts per million levels and is very unlikely to reach a shoreline in noticeable quantities.
If the slick arrives at a shoreline, then biodegradation will be slow because of the high concentration of oil in comparison to the low concentrations of bioavailable nutrients in tidal flows. Biodegradation was too slow to measure directly in the absence of bioremediation in Prince William Sound following the *Exxon Valdez* spill,[18,19] but even with effective bioremediation, the half-life of total detectable hydrocarbons was of the order of 10 weeks.[18,19] The	*Dispersed oil dilutes to such low concentrations that biodegradation is rapid. Measured half-lives are in the days to few weeks time frame.*[14,33−37] Even the four ring aromatic chrysene and its methyl-, dimethyl-, and ethyl- forms have half-lives on the order of a month.[36] Nearshore waters from the Chukchi Sea,[78] the North West Atlantic,[36] and deepwater from Trondheim Fjord[38] all contained enough nutrients for substantial biodegradation of a few parts per million oil in 60 days, and it is reasonable to extrapolate that further dilution in more oligotrophic waters would allow similar degradation on similar time scales.

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Table 1. continued

potential hazards and environmental fate of floating slick	potential hazards and environmental fate of dispersants and dispersed oil
biodegradation of bulk oil in the Gulf of Mexico was very slow[74,75] compared to that of dispersed oil.[35,14]	
While oil hydrocarbons are essentially completely biodegradable (e.g., ref 36), many of the deeply colored molecules (resins, asphaltenes, polars, etc.) are more resistant to biodegradation, although at least some are consumed.[133,134] While these have minimal biological effects, the lifetime of these molecules in a sandy beach may be prolonged, especially if they have been entrained deep in a beach by storm action.[124,132]	*While oil hydrocarbons are essentially completely biodegradable (e.g., ref 36), many of the deeply colored molecules (resins, asphaltenes, polars, etc.) are more resistant to biodegradation, although at least some are consumed.*[133,134] Once the hydrocarbons have been degraded, these fractions lack oily characteristics and become essentially indistinguishable from other inert organic matter in the environment, such as humins.[135]
Physical cleanup of beached oil can take weeks to years and requires hundreds to thousands of workers with their ancillary vehicles and support services.[16,128,136]	*Optimal dispersant application for surface slicks uses planes that can carry 5000 gallons (19000 L) of dispersant, appropriate to treat 1000 acres (405 ha) of slick.*[63] Depending on distances from airfields, several sorties can be flown per day, and spills from a tanker can be treated in a few days. Aerial spraying requires daylight (Figure 1).
	Subsea injection has the advantage of continuing 24 h a day, and the lower application rates mean that dispersant stocks will potentially last longer. If fully successful, oil from a subsea release may never reach the surface before it is biodegraded.[103]

Figure 1. An updated DC3C spraying dispersants on oil from the *Deepwater Horizon* blowout. The wingspan is 29 m. Reproduced with permission from Airborne Support.

to-volume ratio of the oil, and there is a potential for short-term toxic effects in a dispersed plume. The question is how significant these effects might be in the field. Canonical acute toxicity tests involve constant exposures for 48 or 96 h,[61] but in a response at sea, the concentrations of oil will be dropping rapidly due to dilution by mixing and diffusion. As noted above, concentrations of dispersed oil drop to below 1 ppm within a few hours.[29−33]

Only acute toxicity tests are required for listing under the National Contingency Plan, but of course chronic effects are also a real concern. As expected, the longer exposure required to see chronic effects allows lower concentrations of hydrocarbons to exert an effect, and typical acute-to-chronic ratios are 1:10, that is, it may only take 10% of the acute LC_{50} to have a chronic EC_{50}.[69−72] Again, these concentrations are for prolonged exposures, and it is not clear how these relate to the very low concentrations[29−34] of dispersed oil that are found several days after dispersion.[73]

As noted at the outset, dispersants were initially conceived as a tool for minimizing seabird mortality, and early use weighed that benefit against potential toxicity to planktonic species.[27] However, an additional substantial benefit has now been clearly documented: the biodegradation of dispersed oil is dramatically faster than that of oil in a slick or on a shoreline. Oil on shorelines of Prince William Sound, Alaska, had a half-life of a year or more,[18−20] even with the substantial washing and bioremediation program.[16] Tarballs and mousse associated with the *Deepwater Horizon* blowout had similar persistence in the environment.[74,75] However, the biodegradation of dispersed oil is rapid and extensive.[14,35−37]

The oil spill response community agrees that the best response to an oil spill would be to collect it from the environment before it reached a shoreline, and many response plans focus on this requirement by staging large amounts of equipment aimed at achieving this goal even in the face of a very large spill (e.g., refs 9−12). However, if oil cannot be collected, particularly if it is unsafe for responders to perform mechanical recovery or because of remote location or hours of daylight, then responders must look to other methods. It is important to recognize that time is of the essence: deciding not to use a response option today may preclude its use tomorrow. This phenomenon, the window-of-opportunity,[76] is particularly relevant to the use of dispersants because as oil weathers by

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evaporation and absorption of underlying water, it becomes progressively more and more difficult to disperse with dispersants. (As an aside, dispersants incorporated into relatively fresh oil will help the dispersion of that oil even after some time if conditions are initially too calm for immediate dispersion,[77] a potential problem for requirements that dispersants be seen to be effective on a trial basis before large-scale application can begin.) Responders must weigh the potential additional short-term toxicity likely incurred immediately under a dispersed surface slick against the benefit of protecting diving birds and animals and having the oil removed from the environment by biodegradation on a time scale of a few weeks rather than years with a vastly smaller human footprint of spill response. The speed of biodegradation is particularly important if the over-riding concern about dispersant use is the potential local increase in toxicity; beached oil and undispersed mousse leach hydrocarbons and have their own potential environmental impacts for a prolonged period. It would also be prudent to bear in mind the environmental impact of large shoreline cleanup operations, which often involve hundreds of workers and the ancillary impacts of their support services. There is also the potential legacy of the final disposal of the oil, which may well involve burial at a secure landfill rather than combustion or biodegradation. Finally, while not an environmental impact, the economic impacts of an oiled marina or shoreline also need to be weighed as responders decide the most appropriate spill-response.

■ CONCLUDING REMARKS

In the final analysis, some accidents occur so close to shore that oil will undoubtedly reach the shoreline and most likely require some physical cleanup, perhaps followed by bioremediation. However, if the release is in deep water, then it ought to be possible to mobilize dispersants to keep bulk oil from ever reaching a shoreline. If oil is successfully dispersed into the water column, then it is likely that biodegradation will remove the vast majority of it in weeks to months, even in the Arctic and Antarctic.[78] What remains will likely be finely dispersed fragments of nonoily (to the touch) material depleted of hydrocarbons and rich in asphaltic materials and saturated biomarkers such as the hopanes.[36,79,80]

Many questions remain to be answered:

- How does the density of dispersed oil change as biodegradation proceeds? Alkanes are much lighter than water,[81] even at high pressure,[82] as are cyclic alkanes and monoaromatics. However, larger aromatic hydrocarbons, such as chrysene, have densities greater than 1,[83] as do the resins and asphaltenes.[84,85] Since biodegradation preferentially removes alkanes, initially buoyant droplets will become neutral and eventually sink. Is this partially degraded oil further metabolized once deposited on the surface sediment at depth? Reports of substantial amounts of fossil (radiocarbon silent) carbon on the surface sediment at depth[86] could be either unmetabolized oil molecules or the biomass of organisms degrading the oil or, more likely, both. As noted above, some molecules, such as the hopanes, seem very resistant to biodegradation and likely remain with very biodegraded oil (and degrading biomass) as a fingerprint of the initial source.[36,75,79,80]
- What fraction of the oil carbon is mineralized to CO_2 in the initial biodegradation, and what fraction is incorporated into biomass? Classical experiments with aerobes growing on glucose suggest a biomass yield of about 50%,[87] but what is the fate of that biomass? Levy and Lee[88] propose that it is the base for substantial fisheries offshore Atlantic Canada. Chemical analysis of the radiocarbon silent material reported by Chanton et al.[86] will shed light on this question.
- What role does microbial succession play in the biodegradation of oil? Such succession was clearly seen in the Gulf of Mexico following the *Deepwater Horizon* release,[87−92] but how did it relate to the chemical composition of the residual oil or to the nutrient levels in the water? Do dispersants affect this succession?
- How rapidly are dispersant components degraded in the sea? Early work established the biodegradation of nonionic surfactants in seawater,[93] and dioctylsulfosuccinate is known to be biodegradable[94] and clearly was being degraded close to the *Deepwater Horizon* spill site where it was being applied in the Corexit dispersant.[95] Nevertheless, traces of dioctylsulfosuccinate have been found far from the *Deepwater Horizon* accident;[96] was that associated with dispersant application? Traces found close to shore are more likely related to stormwater discharges.[95] Small quantities associated with tarballs[98] are likely the result of suboptimal dispersant application and highlight the need to apply an effective amount of dispersant if its benefits are to be achieved.
- Is biodegradation at depth (>1500 m) fundamentally distinct from biodegradation at the surface? Early work suggested that it is not,[137] but that work was clearly limited in its experimental tools, and there is much to learn. There is no doubt that active hydrocarbon-degrading microbial communities, both aerobic and anaerobic, are present in deep sea sediments.[138]

Already, however, we know enough from laboratory, mesocosm, and field experience to say that dispersed oil is degraded much more rapidly than undispersed oil, likely orders of magnitude more rapidly. This is the key piece of information that seems to be overlooked in most discussions of the potential adverse impacts of using dispersants. Even if there is an adverse local impact of dispersed oil, it will not last long. On the other hand, oil that reaches a shoreline may be there for years.

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Notes

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