EFFECTS OF OIL AND CHEMICALLY DISPERSED OIL IN THE ENVIRONMENT

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ABSTRACT: *This paper describes the last phase of a project sponsored by the American Petroleum Institute (API). Using risk communication methodologies, this project was designed to produce three dispersant issue papers as unbiased reference sources that present technical information and study results in non-scientific language for the layman. The third issue paper, currently in press, was designed to provide the decision maker and layman with an understanding of how spilled oil and chemically dispersed oil affect resources in the environment. Synopses of key sections of this paper are presented here.*

Understanding exposure and effects is a complex task. Exposure to oil alone can cause a variety of adverse effects, including slowed growth, reduced reproduction, and death. Adding dispersants to spilled oil will change the way resources are affected. Today's dispersants are mixtures of solvents and surfactants and, although they can be toxic, are less dangerous than the dispersant products used in the 1960s and 1970s. How the addition of chemical dispersants to spilled oil will change the way resources are impacted has been a difficult question to answer.

Decision makers need to understand several concepts to evaluate how different resources will be affected by oil and chemically dispersed oil during a spill. These include understanding toxicity, what the different routes of exposure are for an organism, how resources from different areas (e.g., water column, water surface, bottom dwelling, or intertidal areas) typically are affected by oil exposure, and how the addition of dispersants changes their exposure to oil. These topics are addressed in this paper.

Introduction

Today, understanding how oil affects wildlife is an important part of spill response planning and damage assessment. To plan a spill response strategy, respond to an actual spill, or estimate the damage that a spill may cause, decision makers and other involved parties need to know how both the oil and response tools are going to affect the local wildlife. Knowing what types of resources at risk are more or less resistant to oil exposure and to the response tools being considered helps decision makers prioritize areas for first response and choose the tools to use.

A particular concern involves oil spills at sea and the use of chemical dispersants on the resulting slicks. One of the first well-known uses of dispersants took place in 1967, when the *Torrey Canyon* spilled 593,750 barrels of oil off the coast of Cornwall, England. As part of the response, over 66,000 barrels of "dispersants" were applied to approximately 87,500 barrels of oil as it came ashore. These dispersants were actually highly toxic degreasing agents, typically used to scrub the bilges off ships and barges. The result was an environmental disaster far worse than would have occurred if the oil had been left untreated. Today's dispersants are far different than the industrial cleaners used in the 1960s and 1970s. Although they are designed to be much less toxic, their use is still controversial. This is not only because of the negative impacts from past use, but also because of the fact that dispersant use represents an intentional introduction of chemicals into the water that, if successful, will result in an increased hydrocarbon concentration in the water column.

It is understandable that the use of chemical dispersants is controversial given the past history and resulting negative perceptions from their use. Scientific evidence, however, indicates that there are many situations when their use can be an appropriate and ecologically beneficial response. The question is: what are those situations? One important part of deciding whether dispersant use is appropriate in a particular situation is understanding how oil and chemically dispersed oil can affect local resources.

The following discussion focuses on several of the main sections of the American Petroleum Institute (API)-sponsored issue paper *Effects of Oil and Chemically Dispersed Oil in the Environment*, which currently is in press. This paper was designed to be an objective reference source that would provide the decision maker and layman with a basic understanding of how spilled oil and chemically dispersed oil affect biological resources in the environment. More detailed discussions of the topics presented in this paper can be found in the full publication.

Toxicity and exposure

To understand how oil and other chemicals affect organisms, it is first necessary to know how toxicity and exposure act together to produce toxic effects. Rand and Petrocelli (1985) define toxicity as the " inherent potential or capacity of a material [in this case oil or dispersed oil] to cause adverse effects in a living organism." Adverse effects may include behavioral, reproductive, or physiological changes, such as slowed movements, reduced fertility, or death. While toxicity generally is associated with the ability of a substance to kill an organism, toxic substances also can cause sublethal effects, which are not lethal and may be difficult to observe. An example of a sublethal effect would be the inability to reproduce or partial blindness. For a given chemical and organism, toxic effects are a function of the concentration, exposure pathway, and duration of exposure.

Historically, the view was that the dispersants themselves contributed greatly to the toxicity of the dispersant-oil mixture. Current studies, however, indicate that low levels of dispersant contribute less to the toxicity of the mixture than the oil itself does (Lunel and Lewis, 1999).

Exposure refers to the amount of contact an organism has with a chemical, physical, or biological agent. Exposure often is referred to as being acute (short-term) or chronic (long-term). Exposure in itself is not harmful. Humans are exposed to air continuously, but because it is not toxic to them, there are no harmful effects. Toxicity and exposure must act together to produce effects. Typically, the longer an organism is exposed to a toxic compound, the greater the toxic effects will be. A toxic chemical will not produce toxic effects in the absence of exposure to an organism.

Following a spill, biological resources can be exposed to oil through four different routes:

- *Direct contact*—This is the most visible route of exposure to an observer. When a plant or animal comes into direct contact with oil, it may only become lightly oiled. However, it could also become completely coated with oil, making it unable to move, function, or survive.
- *Ingestion*—Both direct and indirect. Direct ingestion occurs when an organism eats food coated with oil or simply ingests the oil itself. Direct ingestion can occur accidentally, such as when a bird attempts to clean oil from its feathers. Indirect ingestion occurs when an organism eats prey or food tainted with oil. For example, an eagle could ingest oil indirectly by eating an animal that swallowed some oil the week before.
- *Inhalation*—Inhalation occurs when animals breathe in evaporating oil components or oil mists caused by storm and wave action. Inhalation usually occurs when animals swimming along the surface breathe in oil fumes while moving through a slick.
- *Absorption*—This occurs when an organism absorbs the oil, or toxins from the oil, directly through its skin or outer membranes. Typical examples of organisms to which this could apply are bottom-dwelling shellfish, worms, fish, and plants.

The application of chemical dispersants to an oil slick will change the amount of oil exposure that different organisms receive. When dispersants are applied to the slick, they act to break up the oil into tiny droplets and move it downward into the water column. As a result, exposure will increase for some organisms and decrease for others. Typically, the application of dispersants will decrease oil exposure for surface-dwelling organisms, such as sea birds, and increase it for water-column and bottom-dwelling organisms. This is one reason that dispersants are not applied to a spill directly over a shallow coral reef. Without dispersant application, the oil may remain on the surface and not impact the reef, whereas with dispersant application, the reef may be showered with dispersed oil droplets.

Effects

Determining the effects of oil and chemically dispersed oil is complex, and generalizing about effects is difficult. One must remember that specific impacts are very species and situation dependent. This paper presents *generalized guidelines* derived from various laboratory, mesocosm, and field studies. For response preparedness and incident response, experts on the local species and environment must always be consulted. Mackay and Wells (1981), Mielke (1990), and National Research Council (NRC, 1985) summarize factors that determine the severity of ecological and organismic impacts from an oil spill, including:

- Organism habits and behavior, e.g., birds that dive through the water surface for food
- Concentration of the oil and the duration of the exposure
- Type of oil involved
- Whether the oil is fresh, weathered, or emulsified
- Whether a coastal, estuarine, or open ocean area is involved
- Whether the area is a nesting, wintering, or migratory ground for sea birds or other resources
- Season of the year with respect to bird migration
- Whether organisms are dormant, or actively feeding and reproducing.
- Oceanographic conditions, such as currents and sea state
- Life stages of organisms present
- Whether oil is in solution, suspension, or adsorbed onto suspended particulates or sediment
- Distribution of oil in the water column
- Effects of oil on competing biota
- An ecosystems previous history of exposure to oil or other pollutants
- Cleanup procedures used

For discussion purposes, organisms have been divided into four basic groups, based on their typical habitat: surface-dwelling organisms, water-column organisms, bottom-dwelling organisms, and intertidal organisms.

Surface-dwelling organisms. Birds and marine mammals are common examples of surface-dwelling resources. In general, birds that spend all or part of their time on the water are highly vulnerable to oil slicks. Smooth-skinned marine mammals (e.g., dolphins) are considered to be at low risk from exposure to oil. The marine mammals that are most likely to be impacted are the fur-bearers (seals, sea otters, sea lions) because oil can coat their fur. Birds and marine mammals may suffer from hypothermia when their feathers or fur becomes coated with oil. Inhalation and ingestion of oil can cause a variety of lethal and sublethal problems, including damage to the stomach, intestines, and kidneys. Eye damage, lung damage, and reproductive problems may also occur.

Generally, the application of dispersants will reduce the exposure of surface-dwelling organisms to the oil, thereby reducing the effects. One concern, however, is that dispersants may remove the natural water-repellent oils from bird feathers and marine mammal fur. This would make them less buoyant and susceptible to hypothermia. Birds and marine mammals should be frightened away before dispersants are applied or be avoided when spaying. Although accidental overspray with dispersants could occur, the long-term benefit of removing the oil from the surface may outweigh the chance of a short-term impact (Kucklick *et al.*, 1997).

Water-column (pelagic) organisms. Biological resources in the water column include plankton, invertebrates, and fish. Although exposure to oil can kill fish, biological effects from untreated oil slicks typically are brief and localized because of the rapid dilution of the oil, especially in the open ocean (Lewis and

Aurand, 1997). An oil spill may cause extensive fish kills, but this is relatively uncommon (Spies, 1987). Different types of plankton have been found to be sensitive to oil exposure, but the effects of an oil spill on plankton are difficult to discern, because of their extremely high numbers, relative to other biological resources, and their naturally high seasonal and spatial variability.

Water-column resources at risk are often of primary concern when the dispersant use is being considered. This is because the effective use of dispersants does increase the amount of oil present in the water column. However, experts also believe that exposure is concentrated in the top portion of the water column and decreases fairly rapidly over time in areas with depths over 30 feet and good circulation (NRC, 1989; SEA, 1995). In general, plankton, invertebrates, and fish are thought to be at no more risk from dispersed oil compared to undispersed oil (Kucklick *et al.*, 1997). In one study, tests on the effects of untreated and chemically dispersed oil on the homing mechanism of adult salmon found no significant difference in the percentage of fish that returned or in the time it took the fish to return (NRC, 1989). However, exposures and effects vary with incident conditions, making the use of risk assessments and trade-off considerations important.

There are some important factors to take into account when considering the possible effects on water-column organisms. Time of year is one of these factors. In spawning seasons, the water may be filled with larval or juvenile fish, which could be highly susceptible to even low levels of oil exposure. Water depth is another. Dispersant use in shallow waters results in the dispersed oil being more concentrated in the water column. This is one reason why dispersant use in shallow waters typically is discouraged, unless the overall environmental impacts of mechanical recovery and cleanup would be greater than with dispersant use, as recently has been assessed in Texas and California ecological risk assessments (Pond *et al.*, 2000a, b). The higher concentration of dispersed oil increases the exposure of water-column organisms to the oil. Flushing rates also affect the exposure. If dispersants are used in a semi-enclosed area with low flushing rates, or in a shallow, open ocean area with slow currents, the local organisms can experience longer exposure times to the dispersed oil, as dilution does not happen as quickly.

Bottom-dwelling (benthic) organisms. Bottom-dwelling biological resources include fish, invertebrates, and plants. Bottom-dwelling organisms generally are unaffected by oil slicks if in water deeper than 30 feet. Over time, or in rough conditions, oil from a slick may reach the bottom naturally by attaching to soil or other particles, and then sinking. If oil does reach the bottom, large impacts could occur. Massive kills of fauna have occurred when sufficiently large quantities of oil have reached the bottom following spills (Teal and Howarth, 1984). In some cases, oil can change the community structure, with sensitive species either dying out or leaving the area to be replaced by other species (Howarth, 1989).

In shallow-water environments, benthic organisms are more likely to be exposed to, and therefore affected by, dispersed oil then floating oil in the short term. Shallow-water environments are defined as being less than 10 meters deep and fewer than 3 miles offshore (Kucklick *et al.*, 1997). In the short term, chemically dispersing oil increases the likelihood of effects on benthic animals because it mixes the oil in with the water, allowing it to move down from the surface. However, over the long term, undispersed oil will cause more effects to these resources (NRC, 1989). This is because large volumes of undispersed oil may eventually sink and settle, coating the bottom, whereas currents will carry away dispersed oil quickly.

Intertidal organisms. Intertidal areas occur at the land/water interface, immediately along a shoreline. Biological resources of particular concern in the intertidal area primarily include invertebrates and plants. Impacts on intertidal areas are especially significant because these areas serve as habitat for many juvenile and adult organisms during certain times of the year. As the tide rises and falls, immobile organisms in the intertidal area are exposed to the water column, the surface of the water, and the air. Passing through all three of these environments increases the potential for exposures. If spilled oil comes ashore, the most damage typically occurs in intertidal areas that are exposed to stranded oil. This is especially true in low energy environments, where layers of oil may be deposited by each falling tide and the oil is not removed naturally by wave action. Organisms that become directly coated with oil can suffer heavy mortalities. Loss of plant-covered areas can affect the community at large because many animals use plants for habitat and as a food source.

Dispersing the oil *before* it impacts intertidal habitats is the preferred solution in most cases (IT Corporation, 1993; Kucklick *et al.*, 1997; NRC, 1989). In cases where the oil was dispersed appropriately prior to contacting these habitats, the net ecological effect was much less severe than it was when the oil slick was allowed to wash ashore (IT Corporation, 1993; NRC, 1989).

Spill studies of undispersed oil versus dispersed oil

A great deal of information from laboratory research on the effects of dispersed oil exists, but only a handful of studies from actual spill or field tests can be found in the literature. Data from actual spills, along with field testing, are important since the “real world” often produces different results than those found in the controlled environment of the laboratory.

The details and results from several field tests and spills are included in the paper that is the focus of this report. Chemically dispersed oil studies include the Searsport study (1981), the Baffin Island Oil Spill Project (BIOS, 1981), and the Tropics study (1984 and 1994). Naturally dispersed oil studies include the *North Cape* spill (1996) and the *Sea Empress* spill (1996).

These studies present real-world examples of dispersant application under various conditions. They also provide examinations of the biological effects caused by both naturally and chemically dispersed oil. In general, the results provide evidence that corroborates with the concepts presented in this paper. Data from these studies indicate that dispersant use typically prevents, or decreases, many of the impacts to water-surface and intertidal organisms caused by oil slicks. They also indicate that dispersed oil can cause short-term impacts to benthic organisms and, in very shallow waters, can cause more impacts to water-column and benthic organisms than undispersed oil.

Conclusions

Although the public traditionally has viewed the use of dispersants as ecologically risky, scientific evidence indicates that there are situations where their use is an appropriate and beneficial response. This concept is supported by data from both scientific testing and real-world spills. Dispersants and their use can have some environmental drawbacks, but, in certain cases, the overall ecological benefits outweigh the risks.

Research has shown that within the normal range of operating dosages, ecological effects often are due to the dispersed oil and not the dispersant itself. The dispersant alone is unlikely to contribute significantly to adverse effects.

In general, dispersants provide the greatest benefits and fewest environmental costs when used in offshore waters deeper than 10 meters. When dispersants are used in waters close to shore, such as bays or restricted water bodies, the likelihood of impacts to some organisms may increase. The impacts caused by such dispersant use, however, are sometimes an acceptable trade-off, considering the damage that may be caused by undispersed oil to waterfowl and marine mammals, or when it washes ashore in sensitive and productive habitats.

While scientific studies have indicated various benefits associated with dispersant use, clearly there are situations in which dispersant use is ecologically inappropriate and might result in more damage to environmental resources than undispersed oil. Decision makers must carefully weigh the costs and benefits before using dispersants. These decisions can be reasoned through in advance, as many areas have done with pre-spill authorization, using such methods as ecological risk assessments (Pond *et al.*, 2000a, b).

Biography

John Boyd is a marine biologist with 5 years of research experience in the effects of environmental variables on marine organisms. He has been with Scientific and Environmental Associates, Inc. since 1998.

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