OIL SPILL SCIENCE

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MICROBES AND OIL: WHAT'S THE CONNECTION?

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Microbes may be tiny organisms, but they play a large role in removing oil from the environment. How do these microscopic organisms make large-scale impacts?

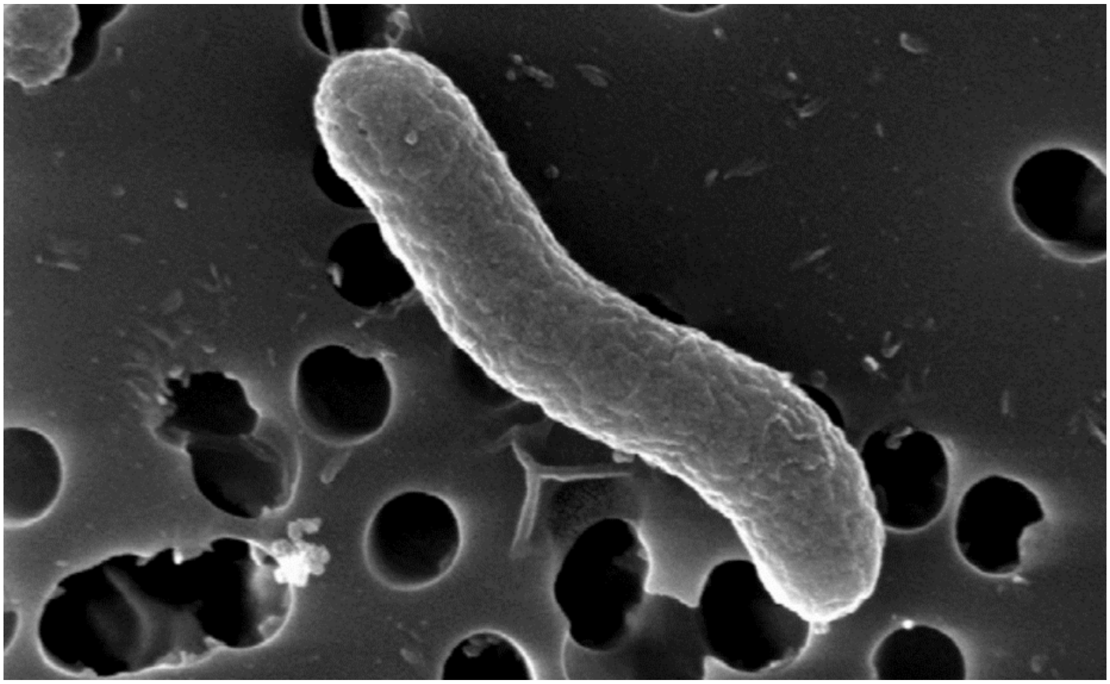


FIGURE 1. *Microbes, like the one pictured above, break down oil that has entered the environment. The bacteria pictured above is 50 times smaller than the diameter of a human hair, yet this particular species is capable of degrading 25 to 60 percent of the oil it comes in contact with under cold water conditions. (Reprinted from Baelum et al., 2012)*

MICROBES & OIL

Oil can enter coastal and marine environments through natural **oil seeps** or by human activities.[1] Once there, multiple factors break down oil, including microbes.

Microbes are microscopic, single-celled, living organisms that include bacteria (for example, *Cyanobacteria, Proteobacteria, Actinobacteria*) and fungi. They are the oldest form of life on the planet and play critical roles in the many chemical cycles in our global ecosystem. Species of microbes that naturally break down oil as part of their diet live in coastal and off-shore environments around the world.[2,3,4] For example, one laboratory study showed that under ideal conditions, one species from the *Rhodococcus* genera can degrade, or break down, up to 65 percent of oil in water in a little more than one week, depending on the type of oil.[5] These oil-degrading microbes live in many environments, including beaches, wetlands, mangroves, deep water, and surface waters.[3,6,7,8,9]

OIL-DEGRADING MICROBES

How do they do it?

How do these microscopic forms of life break down oil? Scientists found that many species of microbes (for example, *Alcanivorax dieselolei B-5* and *Halomonas* sp. TG39) produce natural **surfactants** that help them eat the oil.[10,11] These surfactants are similar to those found in manmade **dispersants**. Multiple types of natural surfactants exist. These mixtures can include sugars, **amino acids**, and/or **lipids**.[12,13]

Oil is made up of many types of chemicals, including **alkanes** and **polycyclic aromatic hydrocarbons (PAHs)**. Microbes that feed on alkanes often release surfactants from their cells to begin the breakdown process, while those that consume PAHs typically move the PAHs into their cells where they are degraded by enzymes.[14,15,16] **Genes** determine which oil-based chemicals a microbe can break down and under which conditions.[17,18,19] For example, some species break down alkanes in high oxygen environments while others break down alkanes and PAHs better in low oxygen conditions.[19]

Factors that influence the breakdown of oil

Oil-eating microbes live in all waters and climates. One such group is Gammaproteobacteria — some members thrive under cold water conditions (for example, *Colwellia*), while others (such as *Psuedomonas* and *Acinetobacter*) can be found in warm waters.[16,20,21] Microbe species found in the warm (77° F) surface waters of the Gulf of Mexico quickly and completely break down many types of oil-based compounds. Some species living in the deep colder (41°F) waters have also adapted to break down oil, but it can take up to nearly one month longer to break down the same compounds when compared with warm water conditions.[16,20] Even then, the compounds are not broken down completely. Cold temperatures exacerbate this further as they can cause oil to thicken, reducing the amount of surface area available for microbes to attack.[2]

The physical and chemical characteristics of the oil can affect how it is broken down.[2,22] Oils that are thick due to their chemical make-up may, like oils under cold conditions, break down more slowly because there is less surface area available to microbes. Further, oils with relatively simple chemical structures are typically more readily consumed by microbes than oils with more complicated chemistries.[23]

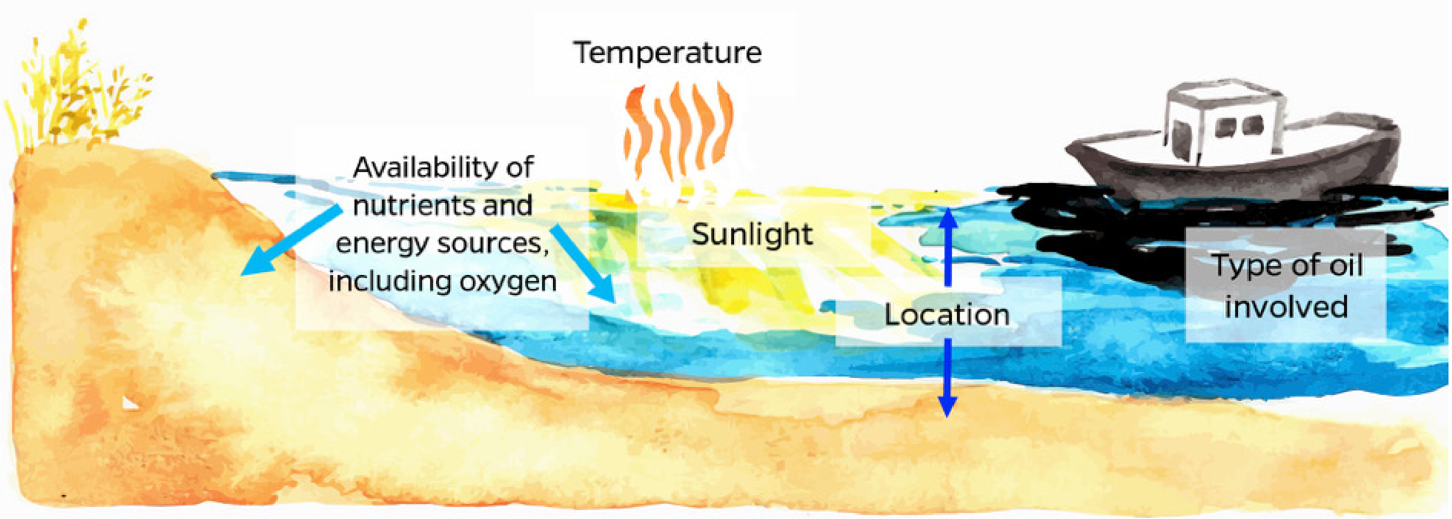
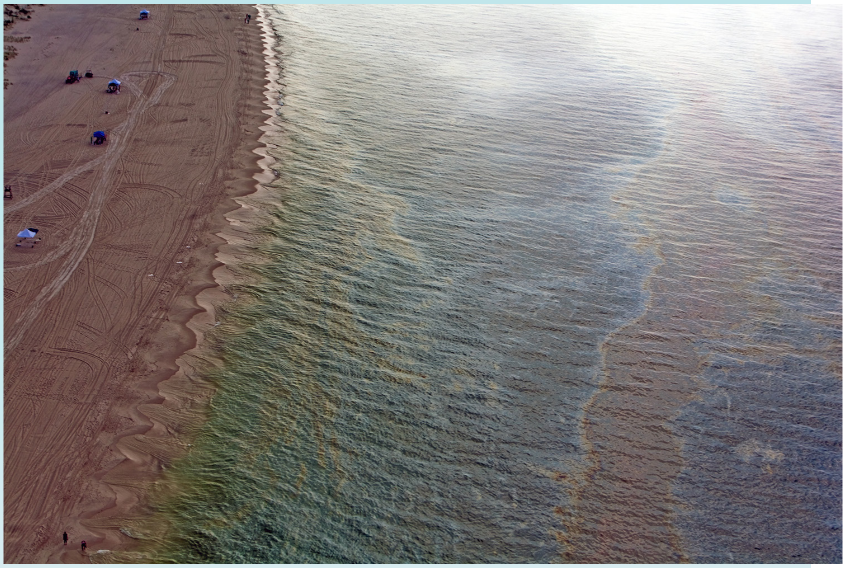


FIGURE 2. *Multiple factors influence the breakdown of oil by microbes. These include sunlight, temperature, availability of nutrients and energy sources, location in the environment, and type of oil involved. (Anna Hinkeldey)*

MICROBES ALONG THE SHORE

Various compounds serve as energy sources for microbes, but some are more ideal than others.[21] When ideal energy sources are plentiful, like in the upper sediment layers of a beach, oil-eating microbes efficiently break down oil.[43] However, breakdown is slower in deeper layers of the beach where lower oxygen levels create less ideal conditions for microbes to degrade oil.[21] Work done on beaches after the DWH oil spill shows that oil buried up to two feet below the sandy surface does significantly break down, but it can take up to one year to do so.[44]



Oil from the Deepwater Horizon incident approaches a beach during the summer of 2010. Oil-eating microbes living on the upper layers of the beach can break down oil. Any oil that becomes buried in the beach will also be broken down by microbes, though at a slower rate. (David Rencher)

Chemically dispersed oil that reaches shore can also be subject to slower breakdown. During laboratory studies, scientists found that oil treated with dispersants may carry oil deeper into beach sands than might otherwise be possible.[45] Typically, oxygen is low at deeper depths. Such conditions are less than optimal and slow down the breakdown process. However, it is unlikely that this occurred during an offshore spill like the DWH. During the disaster, dispersants could not be applied within 3.45 miles of the shoreline or in areas with water depths less than 33 feet deep.[46] Any dispersed oil typically becomes mixed and diluted in the upper layers of the sea within a day of a spill and even more so in the weeks following.[34] This allows time for open water microbes to break down the dispersed oil before it can reach the shore.

Levels of **nutrients**, such as nitrogen and phosphorus, also dictate oil breakdown rates.[2,22] Adding nitrogen to heavily oiled waters can fuel microbes to break down oil more quickly.[24] Stimulating the natural microbial community into breaking down oil is a form of **bioremediation** and considered another response tool.[23] Plentiful levels of nitrogen and phosphorous existed in the deep waters in the Gulf of Mexico during the Deepwater Horizon (DWH) oil spill, which may help explain why populations of oil-degrading microbes bloomed during the spill.[25]

Scientists found that levels of oil-degrading microbes increased in wetlands and beaches in response to oil exposure. (U.S. Fish and Wildlife Service/Tom MacKenzie)

SHIFTS IN MICROBIAL COMMUNITY STRUCTURE

Because oil acts as a food source, its release into an area can increase the number and proportion of oil-eating microbes in the water and along the shore. Scientists documented this in the lab and in the deep waters of the Gulf of Mexico, as well as in its marshes and beaches during the DWH oil spill.[6,7,20,26,27] As expected, the microbial communities returned to their pre-spill states with fewer oil-degrading species after the spill. Exposure to sunlight causes similar shifts in microbial communities living in crude oil containing surface waters of the Gulf of Mexico.[28,29]

MARINE SNOW

Marine snow is a stringy substance that drifts from the upper reaches of the water down to the seafloor (Figure 3). A common occurrence in marine waters, it can consist of a mixture of items, including bacteria, dust, **phytoplankton**, dead animal fragments, plants, and other material.[36]

Marine snow is held together by a sticky substance produced by microscopic phytoplankton and bacteria called **exopolymeric substances (EPS).** While more work is needed to understand it, there is a push-pull relationship between dispersants and EPS. Scientists think the blooms of bacteria that formed during the DWH oil spill used man-made dispersants as a food source to produce EPS.[37] While forming EPS is natural, experiments in the laboratory suggest that dispersants added during the DWH oil spill likely created large amounts of EPS. This in turn created large amounts of marine snow.[38] However, while dispersant use may increase production of EPS, dispersants can also disperse EPS which reduces marine snow formation.[39]

As the marine snow sinks through the water column, it combines with oil droplets, carrying oil to the sea floor.[38] Falling marine snow may be colonized by oil-degrading bacteria on its journey (Figure 4) and also be eaten by tiny animals, called **zooplankton**, along the way.[40,41] Pellets of zooplankton feces carry any oil eaten to the seafloor.[41] Oil carried by the marine snow to the sea floor may accumulate over time.[40] This occurred during the DWH oil spill and possibly during other major spills in the Baltic Sea, Pacific Ocean, and Gulf of Mexico as well.[40,42] The impacts and movement of this accumulated oil on deep water habitat and animals continue to be investigated.

FIGURE 3. *Marine snow (pictured left) is a fluffy substance that drifts from the upper reaches of the water down to the seafloor. It is a sticky mixture made up of bacteria, dust, dead animal fragments, and plants. Oil can get trapped in marine snow and travel with the snow to the seafloor. (Reprinted from Passow et al., 2012)*

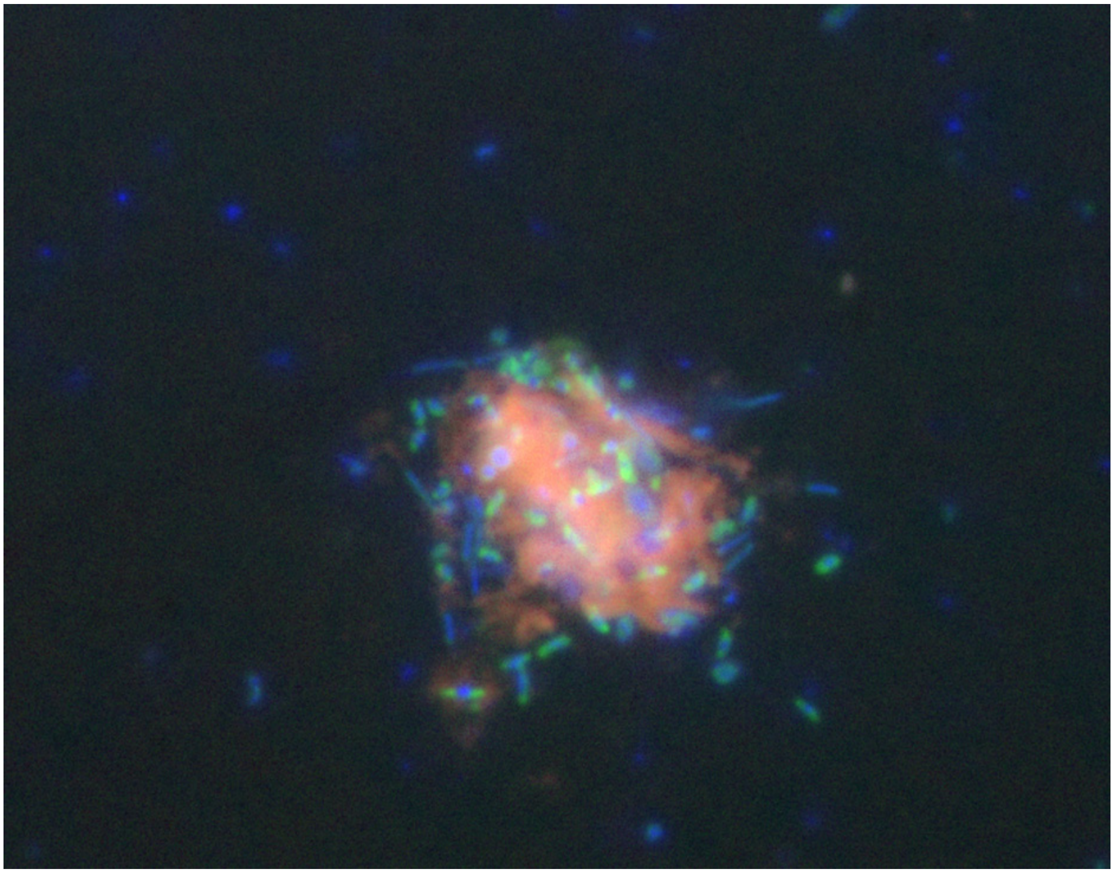


FIGURE 4. *As marine snow falls from the water's surface to the seafloor, oil can become trapped in it. This view taken from a fluoresce microscope shows an oily particle of marine snow (in pink) becoming colonized by oil-degrading microbes (shown in green) and other bacteria (shown in blue). (Montana State University/ Luke McKay)*

INTERACTIONS WITH DISPERSANTS

Dispersants like Corexit 9500A are sometimes used off-shore during oil spills to minimize the amount of oil that reaches the shore, reducing impacts to the habitats and wildlife living there. But how do chemicals from dispersants interact with naturally occurring, oil-degrading microbes? Results from laboratory studies show mixed results, largely depending upon the level of dispersant studied.

Multiple studies demonstrate that dispersants work in conjunction with microbes to break down oil under a variety of temperature conditions. When exposed to temperatures resembling those found in the warm surface or cold deep waters of the Gulf of Mexico, microbes in the lab degrade crude oil from the region faster and more readily when dispersants are used.[16,30,31] Similarly, laboratory studies with Alaska North Slope oil and Arctic environmental conditions show that the breakdown of oil by microbes can be enhanced by as much as 11 percent with dispersant use.[32] Additionally, oil-eating microbes can also break down dioctyl sodium sulfosuccinate, or **DOSS**, a major component of the dispersants **Corexit 9527A and 9500A**, used during the DWH oil spill.[16]

Other research indicates that dispersants can have negative impacts on oil-degrading microbes.[12,33] One laboratory study showed that Corexit 9500A reduces the ability of microbes to stick to oil slicks, which leads to reductions in the growth of oil-degrading microbes on the water's surface.[12] In another example, high levels of Corexit 9500A caused decreased growth and shorter lifespan of certain species of oil-degrading microbes living in beaches and open waters.[33] However, these impacts occur at levels of Corexit hundreds of times higher than the maximum levels estimated near the wellhead during DWH oil spill.[33,34,35]

WHERE DO WE GO FROM HERE?

The Gulf of Mexico Research Initiative (GoMRI) and others continue to develop an understanding of microbes and their role in the breakdown of oil. To learn more about this and the research being conducted on the Deepwater Horizon spill, visit the GoMRI website at www.gulfresearchinitiative.org. Visit the Gulf Sea Grant program website at http://gulfseagrant.org/oilspilloutreach to view our other publications, about dispersants, oil, and other topics.

FIGURE 5. *Oil clean-up in a marsh is shown here. Scientists are studying how microbes that break down oil could potentially be used to aid such clean-up efforts. (U.S. Coast Guard/Petty Officer 3rd Class Derek W. Richburg)*

GLOSSARY

Alkanes — A group of compounds composed of hydrogen and carbon. These occur naturally in petroleum and natural gas, and include methane, propane, and butane. Some alkanes are produced by living organisms.

Amino acids — A collection of 22 compounds, all containing a minimum of nitrogen, oxygen, carbon, and hydrogen. Chains of amino acids make up protein. For this reason, they are sometimes referred to as the chemical building blocks of protein.

Bioremediation — The use of organisms to transform pollutants from a contaminated site into less toxic or non-toxic substances.

Corexit 9527A and 9500A — Dispersants approved for use in U.S. waters used to minimize the presence of surface oil slicks during the Deepwater Horizon oil spill.

Dioctyl sodium sulfosuccinate (DOSS) — A primary component of both dispersant formulas used in the Deepwater Horizon oil spill. It increases the attraction between oil and water molecules and hinders the formation of large oil slicks on the surface of the ocean. DOSS can also be found in consumer products such as detergents, cosmetics, and laxatives and, therefore, can be found in coastal waters.

Dispersants — Chemicals that are used during oil spill response efforts to break up oil slicks and limit floating oil from impacting sensitive ecosystems such as coastal habitats.

Exopolymeric substances (EPS) — Complex mixtures of proteins, fats, sugars, nucleic acids, as well as compounds that do not contain carbon. These sticky mixtures are exuded by microbes and also act as a glue holding together marine snow.

Gene(s) — Unit of DNA, passed from parent to child, that codes for a trait in an organism (for example, coloration, size, stress response).

Lipids — A group of compounds, including natural plant and animal oils, waxes, and fats, that do not dissolve easily in water.

Nutrients — Substances that provide nourishment essential for growth and the maintenance of life.

Oil seeps — Locations where oil and natural gas flow up naturally through cracks in the earth at a slow rate.

Phytoplankton — Microscopic algae that drift or float in bodies of water.

Polycyclic aromatic hydrocarbons (PAHs) — A chemical group found in many sources, including but not limited to oil, tar, ash, coal, car exhaust, chargrilled animal fats, and smoke from burning oil or wood.

Surfactant(s) — Compounds that work to break up oil. Dispersants contain surfactants that break the oil slick into smaller droplets that can more easily mix into water.

Symbiosis — Mutually beneficial relationship between different species of organisms living closely to one another.

Zooplankton — Very small animals, and the immature stages of larger animals, drifting in oceans, seas, and bodies of fresh water.

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SUGGESTED CITATION

Maung-Douglass, E., Graham, L., Hale, C., Sempier, S., Skelton, T., and Swann, L., Wilson, M. (2017). Microbes & Oil – What's the connection? GOMSG-G-18-002.

ACKNOWLEDGMENT

Special thanks to the many external reviewers who contributed to the betterment of this oil spill science outreach publication.

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This work was made possible in part by a grant from The Gulf of Mexico Research Initiative, and in part by the Sea Grant programs of Texas, Louisiana, Florida and Mississippi-Alabama. The statements, findings, conclusions and recommendations do not necessarily reflect the views of these organizations.

GOMSG-G-18-002