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- Top 5 frequently asked questions about the Deepwater Horizon oil spill—Updated 2019

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TOP 5 FREQUENTLY ASKED QUESTIONS ABOUT THE DEEPWATER HORIZON OIL SPILL

— UPDATED 2019 —

Emily Maung-Douglass, Monica Wilson, Christine Hale, Larissa Graham, Melissa Partyka, Stephen Sempier, Tara Skelton, and LaDon Swann

The Deepwater Horizon (DWH) oil spill occurred in April 2010, about 50 miles offshore of Louisiana. Nearly 172 million gallons of oil entered the Gulf of Mexico. The five questions below were the most frequently asked by people who depend on a clean and healthy Gulf of Mexico.

An egret sits atop a boom used by emergency responders to contain oil during the Deepwater Horizon oil spill. (Wolfram Burner)

QUESTION #1: Is Gulf seafood safe to eat?

The DWH oil spill left some consumers with concerns about eating Gulf seafood. During the oil spill, federal agencies, such as the National Oceanic Atmospheric Administration (NOAA), the U.S. Food and Drug Administration (FDA), and the U.S. Environmental Protection Agency (EPA) worked with Gulf of Mexico states to implement a testing program to ensure seafood safety. Additionally, state agencies conducted their own sampling in state waters. Monitoring post spill showed that Gulf seafood harvested from waters open to fishing was safe to eat.
Seafood had to pass a series of tests in order for the waters to be reopened for fishing.\textsuperscript{1,4} In waters free of an oil sheen, scientists collected the edible portion of fish, blue crabs, oysters, and shrimp. If these samples passed a smell and taste test, the scientists ran laboratory tests for \textit{polycyclic aromatic hydrocarbons (PAHs)}, one of the toxic parts of oil, and \textit{dioctyl sodium sulfosuccinate (DOSS)}, a chemical found in dispersants. If the levels of chemicals fell below the FDA's level of concern, the area reopened for fishing. The level of concern determines how much of a certain chemical will harm a human. By testing seafood samples and making sure the chemicals were below these levels, the FDA could determine when Gulf seafood was safe to eat.

Independent studies confirmed this and found no increased health risks for consumers of Gulf seafood.\textsuperscript{3,9,10} Since the DWH oil spill, scientists have continued to improve their ability to detect specific types and levels of chemicals in seafood.\textsuperscript{11} To learn more about the sampling that occurred and to access the data from these sampling programs, read our outreach publication \textit{The Deepwater Horizon oil spill’s impact on Gulf seafood} at gulfseagrant.org/oilspilloutreach/publications.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
\textbf{Test dates} & \textbf{Chemicals tested} & \textbf{Number of samples} & \textbf{Results above the LOC} \\
\hline
\textbf{LOUISIANA} & PAH, DOSS & 7,070 & 0 \\
\hline
\textbf{MISSISSIPPI} & PAH & 624 & 0 \\
\hline
\textbf{ALABAMA} & PAH, DOSS & \sim 2,000 & 0 \\
\hline
\textbf{FLORIDA} & PAH, DOSS & 3,693 & 0 \\
\hline
\textbf{GULF-WIDE FEDERAL/STATE} & PAH, DOSS & \sim 8,000 & 0 \\
\hline
\end{tabular}
\caption{Federal and state agencies tested more than 22,000 seafood samples for PAHs and DOSS in areas where no oil sheen was present. Not a single sample among those chemically tested came back with levels above the level of concern established by the U.S. Food and Drug Administration (Figure 1). In fact, the levels were hundreds to thousands of times lower or undetectable in many cases.\textsuperscript{1,5–8}}
\end{table}

\section*{QUESTION \#2: What are the impacts to wildlife?}

The Gulf of Mexico is a complex \textit{aquatic ecosystem} comprised of many \textit{species} living in connected \textit{habitats}. When oil enters an aquatic ecosystem, it could flow through the \textit{food web} and influence entire \textit{populations} and \textit{communities} of interacting organisms. Food webs, diseases, and many other elements are all involved in understanding how oil spills impact wildlife.\textsuperscript{12} These interactions make it difficult to answer how the DWH oil spill affected wildlife. Scientists use a combination of laboratory and field studies to better understand the DWH oil spill’s effects.

In fish, exposure to oil at levels like those in the surface waters near the wellhead during the DWH oil spill correlates with increases in skin lesions and problems with heart and nervous system development, energy consumption, buoyancy (in embryos), heart function, growth, reproduction, and swimming ability.\textsuperscript{13–19} While the results of these lab and field studies indicate that oil affects individual fish, scientists are still working to understand if populations of fish were affected.

A variety of other animals — such as birds and dolphins — were also impacted by the DWH oil spill.\textsuperscript{16} For example, a mass die-off of a population of bottlenose dolphins living in the Gulf was linked to exposure to chemicals from DWH oil. The loss of these dolphins was from disease and other health effects caused by oil exposure from breathing oil and oil vapors and eating contaminated prey, among others.\textsuperscript{16,20,21} Birds exposed to oil experienced damage to the heart, plumage, liver, and blood, as well as migration problems and death.\textsuperscript{16,22–26}

While it is difficult to predict overall impacts of the DWH oil spill on the Gulf of Mexico, studying food webs sheds some light. In wetlands, certain animals like gulls, wading birds, and snails are especially sensitive to oil. Scientists think that the loss of those important species could throw wetland food webs off balance.\textsuperscript{27} In some reef communities the DWH oil spill reduced the amount
of zooplankton around reefs for months after the spill. The shift changed the diet of predators like red snapper. The long-term investigation into the interaction between species and their environment continues.

View our outreach publications on the effects of the DWH oil spill on a variety of aquatic life, including oysters, dolphins, sea turtles, coral, fish, as well as fisheries and fisheries landings in the Gulf of Mexico at gulfseagrant.org/oilspilloutreach/publications.

QUESTION #3: What cleanup techniques were used, and how were they implemented?

During the DWH oil spill, responders used different methods to remove the oil. Offshore, responders focused on removing the oil using skimmers and controlled burns.

Skimmers are devices that remove oil from the sea's surface before it reaches the coastline (Figure 2). Boats equipped with skimmers of different sizes removed oil near the site of the spill and in nearshore areas, such as beaches, bays, and around marshes. Responders also removed oil on the surface by enclosing it with fireproof booms and burning it.

Dispersants (Corexit 9527A and 9500A) break up the oil at and below the surface. Chemical dispersants not only help to reduce the amount of oil reaching the shorelines but also break the oil into small droplets. The droplets are more available to the microbes that eat oil and naturally remove it from the water. In the Gulf of Mexico hundreds of species of microbes such as bacteria, archaea, and fungi eat oil as part of their natural diet, removing it from the environment. This process is known as biodegradation. Microbes play a key role in the biodegradation of oil in the ocean and can reduce oil's overall environmental impact.

Emergency responders applied roughly 1.8 million gallons of the dispersants Corexit 9527A and 9500A (referred to as Corexit in this document) to break-up the oil and reduce the amount of oil reaching the shoreline. Responders applied dispersants in three ways:

- A remotely operated vehicle (ROV) sprayed dispersants directly into the oil and gas coming out from the wellhead.
- Boats applied dispersants at the surface near the well site and drill rigs to control volatile organic compounds (VOCs) that posed health and safety threats to the crews.
- Planes sprayed dispersants at the surface to disperse oil slicks that were more than five nautical miles from the well site.

Closer to shore, emergency responders focused on protecting the affected shoreline, especially sensitive areas, using skimmers and containment booms. Booms float on the surface of the water and act as physical barriers to floating oil. Booms placed across inlets reduce the risk of oil passing through into sensitive areas. In an ideal situation, booms quickly contain floating oil. However, water currents, waves, and wind can cause oil to make its way over and under the boom.

Once the oil made its way to shore, responders surveyed the area to better define the affected habitat and

Dispersants were federally authorized to be sprayed at distances that must be greater than 2.3 miles from any vessel, more than 3.45 miles from the shoreline or visible marine life, and in areas where the water depth was greater than 33 feet deep.
determine the appropriate method(s) for cleaning the shoreline. Responders recorded those methods as part of the Shoreline Cleanup Assessment Techniques (SCAT) Program. SCAT teams surveyed the shoreline; recorded the amount of oil, type of shoreline, habitat, and animals found in the area; and noted archeological or historic sites. Based on this information, an appropriate cleanup plan was created.

Shoreline cleanup on beaches involved sifting sand, removing surface residual balls (sometimes referred to as tarballs) on the beach, and digging out tar mats. Responders preferred to let most oiled marshes recover naturally, because of concerns about causing more damage during cleanup of these highly sensitive habitats. However, oiling along 44 miles of marsh shoreline was heavy enough to warrant active removal, using careful methods to minimize damage and speed recovery. Marsh cleanup involved minimally invasive techniques, such as swabbing the marsh with materials that absorb oil or low pressure flushing with water.

Check out our outreach publications on dispersants, including their role, fate, and effects on aquatic life during DWH at gulfseagrant.org/oilspilloutreach/publications.

QUESTION #4: Do dispersants make it unsafe for beachgoers to swim in the water?

Dispersants were used in emergency response efforts during the DWH oil spill. While direct contact with full-strength dispersant can cause respiratory and skin irritation, dispersant becomes diluted in surrounding waters. The dispersants used during DWH oil spill are made up of several compounds, including DOSS. Scientists estimated the level of dispersant in the Gulf post-DWH by monitoring DOSS, a common ingredient in over-the-counter household products, to understand if dispersant could pose a threat to beach-going swimmers. During the spill, emergency responders applied dispersant at the wellhead and distances more than 3.45 miles from shore (Figure 3). Teams of scientists sampled areas around the DWH wellhead in May and June 2010 to understand what the highest levels of dispersant in the environment might be. They collected water samples from the surface down to depths of nearly one mile from more than 26 sites near the wellhead. The highest level of dispersant near the wellhead was one part per million as estimated from DOSS levels. This is 100 times lower than the levels of dispersant that are known to cause harm to the human

FIGURE 3. Areas oiled during the Deepwater Horizon oil spill are gray and areas of dispersant application via plane are orange. Boats also sprayed dispersants at the water’s surface and at subsurface depths (not shown on this map). (Environmental Response Management Application)
liver in studies by the EPA, FDA, and National Institutes of Health (100–250 ppm).35,39,40 Scientists often look to the liver to understand how a chemical may effect human health since the liver is key in breaking down foreign chemicals in the body.41 Work continues to better understand the public health implications of dispersant and DOSS.

For more information on the intersection between dispersants and human health, please read our outreach publication, *Is it safe? Examining health risks from Deepwater Horizon oil* at gulfseagrant.org/oilspilloutreach/publications.

**QUESTION #5: Where did the oil go and where is it now?**

Using satellite images, NOAA determined that surface oil from the DWH oil spill reached a maximum area of 29,000 square miles, covering approximately 4.7 percent of the Gulf of Mexico’s surface (Figure 3). During and after the spill, oil mixed with Gulf of Mexico waters and made its way onto the seafloor in some coastal and deep-sea areas. Oil moved with the ocean currents along the continental shelf off Texas and to the coastlines of Louisiana, Mississippi, Alabama, and Florida. The oil reached approximately 1,313 miles of the 3,540 miles of Gulf of Mexico coastline.42 Scientists found evidence of oil southwest of the wellhead at depths between 3,200 and 4,000 feet below the surface in late May and early June.43 The subsurface was an area that had elevated amounts of PAHs compared to other areas.44 Scientists developed seven categories to describe what happened to the oil:

- **Recovered at the wellhead** — oil was captured directly from the wellhead using a riser pipe insertion tube and top hat system.
- **Skimmed** — thin layers of oil were removed from the surface using skimmers.
- **Burned** — setting fire to freshly spilled oil reduced the amount of oil on the water.
- **Chemically dispersed** — chemicals applied to the oil broke the oil into small droplets and made it more available to microbes.
- **Naturally dispersed** — natural mixing, such as waves, caused the oil to break down and mix into the water column.
- **Evaporated or dissolved** — oil evaporated into the atmosphere when it reached the surface or dissolved in the water.
- **Unaccounted for** — scientists are still not certain what happened to a portion of the oil.45

Recent studies show that about three to five percent of the unaccounted oil has made its way onto the seafloor (Figure 4). Oil and oil-derived carbon from the well polluted approximately 1,200 square miles of the seafloor around the well.46,47 Oil on the deep seafloor can persist for a long period of time due to cold temperatures, lack of sunlight, and low oxygen levels — all of which slow the breakdown of oil.47

**FIGURE 4.** Researchers developed a budget calculator to estimate what happened to approximately 200 million gallons of oil ejected from the Macondo wellhead during the Deepwater Horizon oil spill.45–47 (Anna Hinkeldey)
To read more about where the oil from Deepwater Horizon oil spill went in the environment and the use of technology to study the spill, view our outreach publications, Deepwater Horizon: Where did the oil go? and Underwater vehicles used to study oil spills, at gulfseagrant.org/oilspilloutreach/publications.

GLOSSARY

Aquatic ecosystem — Communities of organisms that live in the water and are dependent on each other and on their environment. The main types of aquatic ecosystems are marine, estuarine, and freshwater ecosystems.

Bacteria — A member of a large group of unicellular microorganisms that have cell walls but lack organelles and an organized nucleus, including some that can cause disease.

Community — Groups of different species of organisms interacting with one another and with the environment in a specific region.

Corexit 9527A and 9500A — Dispersants approved for use in U.S. waters and those that were 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.

Food web — A system of linked food chains within an ecological community.

Habitat — The place where an organism, population, or community lives.

Polycyclic aromatic hydrocarbon (PAH) — 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.

Population — Organisms of the same species inhabiting a specified area.

Prey — An animal that is hunted and killed by another for food.

Species — Organisms forming a natural population or group of populations that transmit specific characteristics from parent to offspring.

Volatile organic compounds (VOCs) — Gases released from certain solids or liquids, such as oil. Inhaling these compounds for a long period of time can be harmful to one’s health.

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

REFERENCES


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ACKNOWLEDGMENT

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

SUGGESTED CITATION

WHERE DID THE OIL GO? A DEEPWATER HORIZON FACT SHEET

During the Deepwater Horizon oil spill, approximately 200 million gallons of oil flowed from the Macondo well. Due to the size and scope of the spill, people wanted to know where the oil would travel. Some oil accumulated at the shoreline, on the ocean’s surface, in an underwater plume, and on the seafloor.

RESPONSE ACTIONS
Responders recovered oil at the wellhead, burned, skimmed, and used dispersants on some of the surface oil out at sea, but some oil still lingered in the environment.

NATURAL PROCESSES
After the spill, oil weathered due to environmental exposure. It evaporated, emulsified into foam, naturally dispersed, and/or dissolved. A significant, but unknown, portion was broken down by microbes and the sun.

PATHWAYS TO THE SEAFLOOR
Oil made its way to the seafloor by binding or combining with sand, burned byproduct, or other particles in the water, causing it to sink. Some animals ate oil droplets or particles and then excreted oil-containing fecal pellets, which sank to the seafloor.

OIL AT THE SEAFLOOR
Scientists estimate that 1,235 square miles of the seafloor around the well contained oiled sediments.
1,313 miles of oiled shoreline
Texas, Louisiana, Mississippi, Alabama, and Florida coasts experienced different amounts of shoreline oiling. The oil impacted 1,313 miles of the 3,540 miles of the U. S. Gulf of Mexico coastline.

WANT TO LEARN MORE?
Read Deepwater Horizon: Where did the oil go? and Microbes and oil: What’s the connection? at gulfseagrant.org/oilspilloutreach

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

gulfseagrant.org/oilspilloutreach

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HELPFUL OIL SPILL SCIENCE RESOURCES
While gulfseagrant.org/oilspilloutreach is a great start when looking for oil spill science information, many other sites also contain news and data targeted to specific research and response audiences.

RESEARCH RESOURCES

**Gulf of Mexico Research Initiative (GoMRI)** is a large (>$500 million) funder of oil spill science research, led by an independent, academic 20-member Research Board, who guide the research focus and funding decisions to ensure intellectual quality. Go to gulfresearchinitiative.org to find the latest publications, news, and links to individual consortia webpages.

**Gulf of Mexico Research Initiative Information and Data Cooperative (GRIIDC)** houses all the data that has been collected by GoMRI-funded scientists for free at data.gulfresearchinitiative.org.

**NOAA’s Data Integration Visualization Exploration and Reporting (DiVER)** houses datasets associated with oil spill impacts and post-spill habitat restoration. Click https://www.diver.orr.noaa.gov to find out how to use NOAA’s tools to search, visualize, and download data.

**NOAA’s Environmental Response Management Application (ERMA)** is an online mapping tool that integrates both static and real-time data. Use this tool to view Environmental Sensitivity Index maps, ship locations, weather, ocean currents, and more. ERMA is designed to aid in spill preparedness and planning and to assist in coordinating emergency response efforts. Go to response.restoration.noaa.gov/maps-and-spatial-data/environmental-response-management-application-erm to find out more.
RESPONSE RESOURCES
The United States Coast Guard Interagency Coordinating Committee on Oil Pollution (ICCOPR) is a 15-member Inter-agency Committee that was established by the Title VII of the Oil Pollution Act of 1990. Find out more by clicking https://www.dco.uscg.mil/ICCOPR.

The U.S. National Response Team (NRT) coordinates preparedness, planning, response, and recovery activities for pollutants and contaminants and oversees Regional Response Teams (RRT). Regional Response Teams host local Area Committee Meetings (ACM), which provide members of the public a place to connect with responders. Go to https://www.nrt.org to learn more.

The FEMA Emergency Management Institute Incident Command Resource Center’s website houses Incident Command System (ICS) review documents, training courses, job aids, and more at https://training.fema.gov/emiweb/is/icsresource.

NOAA Office of Response and Restoration (OR&R) plays a role in oil and chemical spills, environmental restoration, and marine debris. They offer training and education opportunities to the public at https://response.restoration.noaa.gov. To contact NOAA Scientific Support Coordinators (SSC), go to https://response.restoration.noaa.gov/about/orr-field-staff.html.

The FOSC’s (Federal On-scene Coordinator) Guide to NOAA Scientific Support, found at https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/fosc-guide.html, lists the scientific support services available from NOAA OR&R’s Emergency Response Division.

The NOAA Final Programmatic Damage Assessment and Restoration Plan (PDARP) report explains the injuries caused by the Deepwater Horizon oil spill. It can be read by clicking http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan.

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During the Deepwater Horizon oil spill, emergency responders documented oil along more than 1,100 miles of shoreline. Oil washed onto and just off Gulf coast beaches. In some places, the sand buried the oil and made cleanup efforts difficult. Ongoing and completed studies are providing information that will enable responders to clean up future spills more effectively and remove the remaining oil from the Deepwater Horizon oil spill.

The Deepwater Horizon oil spill was the worst oil spill in U.S. history with an estimated 172 million gallons of crude oil flowing into Gulf of Mexico waters. Oil washed onto more than 1,100 miles of the Gulf coast despite intensive response efforts to stop the oil from reaching the shore. More than half of the oiled shoreline was sandy beaches. The amount of oil reaching the shore ranged from very light to heavy oiling. The U.S. Coast Guard ended all official cleanup efforts.

Oil is visible in the foreground and surf zone in this image from the Gulf Islands National Seashore, FL, that was taken on July 1, 2010. (NOAA)
efforts in February 2015 (Captain J. P. Nolan, personal communication, February 26 2015). Still, many people are concerned about the impacts of the remaining oil buried on the sandy beaches and surf zone along the Gulf coast.4

WHY WAS CLEAN UP SO CHALLENGING?

You probably know how easily sand moves around if you have ever been to the beach. As the waves wash across your feet, you can see and feel sand moving away from some areas and building up in other areas. Gulf of Mexico beaches move in a similar way. Wind patterns in spring and fall push sand up on the beach and cold fronts during the winter blow from the north and erode sand away.3 Tropical storms and hurricanes move large amounts of sand very rapidly on and off the beach. The movement of sand depends on the direction and strength of the wind and waves.3

During the Deepwater Horizon oil spill, weathered oil floated on surface waters and eventually reached some beaches. This oil was not fresh, liquid oil. The oil mixed with seawater creating a thick, viscous emulsion as it drifted toward shore.3 The color and consistency of the weathered oil changed based on the length of exposure to sun and water. Some scientists described the emulsion as having the consistency of “mousse” similar to whipped orange-colored peanut butter. Some of this thick emulsified oil washed onshore in patches. Then seasonal wind patterns and storms pushed sand over the weathered oil before it could be cleaned-up. The oil was much more difficult to locate and remove once it was buried.3

Storm waves also pushed oil above the high tide line (Figure 1). Some of this oil remained stranded as the tide went out.3,5 The stranded oil patches on the beaches sunk about an inch into the sand and then were covered by wind-blown sand. In some areas, this sand built up on top of this oil and created buried oil patches up to three feet deep.3,5 However, samples of the buried oil collected

HOW DO I REPORT OIL THAT I FIND ON THE BEACH?

If you find what you think is oil, call the National Response Center at 1-800-424-8802. Be ready to provide the date, time, place, and describe what you saw.

In the past, beach-goers have mistaken items such as pieces of plant debris and black shoreline critters for oil that has washed up on the beach. From left: A black tunicate, colonial tunicate, and a skate egg case have often been mistaken for surface residual balls (right) on the shore. (Florida Sea Grant photo)
from above the high tide line had very little oil. More than 90 percent of the weight was from the sand and other materials that had mixed in with the oil.6

Weathered oil also washed into the nearshore and tidal zone (Figure 1). The tidal zone is the area of the beach covered by water at high tide and exposed to air at low tide. Some of the weathered oil mixed with sand and sank in this area. Layers of sand deposited by near shore currents buried the oil and sand mixture. This process created patches of oil within the nearshore and tidal zones (Figure 1).7,8 Emergency responders call large patches of oil that are larger than three feet by three feet in size “oil mats”.5

The patchiness of the oil mats made it hard for emergency responders to determine the location of the buried oil. Over time, emergency responders discovered oil mats along the shore. The oil mats that they found off the barrier islands of Louisiana were as long as 330 feet and up to eight inches thick.3 They also found oil mats at heavily oiled sites in Florida, Alabama, and Mississippi. These mats were under water between the beaches and sand bars near the beach.3

Wind and waves re-exposed buried oil in some areas. Wave energy broke the re-exposed oil mats into smaller pieces. These smaller pieces washed on shore, sometimes onto beaches that had already been cleaned.3 Smaller pieces of broken up oil mats are called surface residual patties or surface residual balls based on their size.3 Some scientists refer to all oil mats and balls as sand and oil agglomerates, a term that does not distinguish them by size.7

Surface residual patties are smaller than oil mats but larger than surface residual balls. They are typically about four inches to three feet in size.5 The patties
form when the energy of waves break larger oil mats into smaller pieces. Surface residual patties can also form when oil washes onshore and sinks into the sand. After the oil spill, emergency responders found surface residual patties in areas with low wave energy. This included areas such as the backsides of barrier islands or along beaches and marshes.5

Pieces of oil that are smaller than four inches are defined as surface residual balls.5 Some might think of surface residual balls as “tar balls”. Tar balls are typically rubbery or extremely hard with little odor or sand. Surface residual balls that have washed up after the Deepwater Horizon oil spill are very different. They are mostly made up of pieces of sand, shell, and other materials (70-95 percent by weight) and are loosely bound by oil.3,5,9 They are fragile, sticky, and a brownish color and have a strong petroleum odor.6,9 Unlike tar balls, surface residual balls are denser than water and roll or bounce along the bottom rather than float.7 Scientists have found them across all tidal zones since they are small and can move around easily.5

**HOW WERE OILED BEACHES CLEANED UP DURING THE DEEPWATER HORIZON OIL SPILL?**

During an oil spill, emergency responders use skimming, booms, burning, and dispersants to clean up oil and protect the shoreline. The methods used depend on the type of oil, location of the spill, and daily weather conditions. Emergency responders use an approach called Shoreline Cleanup Assessment Technique (SCAT) if oil does reach the shoreline.10

During the Deepwater Horizon oil spill, SCAT teams members included federal, state, local, and BP representatives. The SCAT teams conducted regular field surveys to determine the location and amount of oil on the shore.3 SCAT team members recorded the width, the amount, and the thickness of oil that was found on the shoreline. They designated the oiling along the shore as “heavy,” “medium,” “light,” and “very light” using this information (Figure 3). They also develop a Shoreline Clean-up Completion Plan to clean the oil.

**FIGURE 3.** During the Deepwater Horizon oil spill, more than 1,100 miles of shorelines were oiled along the Gulf coast. The amount of oil that observers found on the shoreline ranged from very light to heavy oiling. (Environmental Response Management Application)
up. This plan set cleanup goals and outlined a process determining when cleanup activities were achieved. Emergency responders used a variety of cleanup methods depending on where they found oil and how people and wildlife used the area. In areas that people used, cleanup crews removed as much visible oil as possible using manual and mechanical cleanup techniques. Cleanup was less intensive in other areas, such as national parks and wildlife refuges. This cleanup method reduced potential negative impacts on the environment and culturally important artifacts. Emergency responders worked with the managers of these areas and decided that digging up and removing the oil would cause more harm to wildlife and the environment than just leaving the oil in place. For example, bringing heavy machinery onto beaches to clean lightly oiled areas could compact sand and make it hard for animals, such as ghost crabs, to burrow. In such cases, it was better to leave the oil alone and let it naturally break down than to remove it.

WHAT IS BEING DONE TO REMOVE THE OIL THAT REMAINS?

Cleanup efforts continue in the Gulf of Mexico region five years after the Deepwater Horizon oil spill. Submerged and buried oil deposits remain and can cause re-oiling of the beaches with surface residual balls. Many studies are underway to gain a better understanding of where buried oil is located, how it might be re-exposed, and how it moves along the sandy bottom of the shore.

Scientists are using computer models to study how surface residual balls move around the sandy bottom. They have found that surface residue balls are less mobile during normal wave conditions and are more mobile during storm events when there are large waves, more powerful longshore currents in the surf zone, and strong winds. The models show that surface residual balls of different sizes can be picked up and moved around the surf zone during storms. The models also predicted that surface residual balls can become
TRACING OIL BACK TO ITS SOURCE

How do emergency responders know that the oil found on beaches is from the Deepwater Horizon oil spill? Similar to people, each type of oil has its unique fingerprint. Oil fingerprints differ based on its chemical makeup. Scientists use specialized laboratory equipment to examine the chemicals in the oil that they are trying to identify and compare it to the chemicals found in oil from known sources. Weathered oil is more difficult to fingerprint because some of the chemicals have broken down over time. Scientists focus on certain chemicals that are more resistant to weathering and persist for a long time in these cases. Once they find the oil fingerprint that is identical, they have a match and can determine the source of the oil they are studying.

Scientists made balls out of artificial oil (wax) and sand to study how surface residual balls move around the seafloor. They tracked the movement of these balls in the surf zone, the areas of the beach where waves break. Sand buried the artificial oil and sand balls larger than four inches in diameter in the surf zone. The energy of the breaking waves consistently picked up and moved around artificial oil and sand balls that are smaller than one inch in size. The balls that were one and two inches in diameter also moved along the shore, but less often. Scientists also studied how artificial oil and sand balls move in the swash zone. The swash zone is the area of the beach where water rushes after a wave has broken. Scientists found that artificial oil and sand balls deposited in inlets when currents carry the surface residual balls along the shore. The surface residual balls are washed into inlets during the incoming tide. They remain trapped in the inlets when they are not carried out by the outgoing tide.

A close-up of a surface residual ball found on the beach in Dauphin Island, Alabama. (NOAA photo)
that were smaller than two inches in size were often moved around in this area. These studies supported the model results that smaller surface residual balls are more likely to move around and larger surface residual balls are likely to go through cycles of being buried and unburied.

Scientists discovered that oil moves around even more during major weather events when wind and wave conditions are strong. They monitored beaches during and after Tropical Storm Lee in 2011, Hurricane Isaac in 2012, and Tropical Storm Karen in 2013. All of these storms had strong winds and high wave energy. A few days after each storm, scientists found surface residue balls and patties that had washed onto the beaches. They saw a similar pattern after major cold fronts that also brought strong wind and wave energy.

The number of oil mats and surface residual balls found on beaches has decreased since the oil spill occurred in 2010. However, research results suggest sand and oil agglomerates will continue to wash ashore for decades. Recovering all of the oil may also be difficult. Surface residual balls, for example, are very hard to find in the surf zone once they have broken down to a diameter smaller than the width of a paperclip.

Emergency responders considered the oil removal process complete in Mississippi, Alabama, and Florida in the summer of 2013. The same was true for almost the entire coastline of Louisiana in April 2014. There were six areas in Louisiana, totaling about 2.74 miles, which emergency responders continued to clean. Coast Guard teams and Oil Spill Removal Organizations were on standby to respond to calls of oiling along the Gulf coastline until February 2015 (Captain T. McK. Sparks, personal communication, April 15, 2014).

WHERE DO WE GO FROM HERE?

The Gulf of Mexico Research Initiative (GoMRI) and other research programs continues to fund studies to look at the short-term and long-term impacts of the oiling that occurred on Gulf of Mexico beaches.

The latest information can be found on GoMRI’s website at: http://gulfresearchinitiative.org. To access other oil-spill-related publications or view the references in this publication on Sea Grant Oil Spill Science Outreach Program website: www.gulfseagrant.org/oilspilloutreach.
REFERENCES


SUGGESTED CITATION

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine, and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university-based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10-year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20-member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

### FREQUENTLY ASKED QUESTIONS: OIL EDITION

*Emily Maung-Douglass, Larissa Graham, Christine Hale, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson*

Products made from crude oil power our cars and homes, make up many personal care products, and even help transport us into outer space. This outreach publication explores a few basic aspects of this natural resource, including what it is, its production and consumption, and its detection and release into the environment.

Oil is sometimes released into the coastal and marine environments via natural seeps underwater, like the one shown here. (U.S. Geological Survey/Donna Schroeder)

### WHAT IS OIL?

Oil is often referred to as a “fossil fuel.” As prehistoric marine life died, the decaying matter sank to the sea floor and became covered with sediment. This process continued over millions of years, hardening the deeply buried sediments into rock. Heat transformed the plant and animal remains in the rocks into *crude oil* with a distinct chemical signature unique to the components it was made from as well as the geological conditions.

Crude oil is mainly composed of hydrogen and carbon compounds called hydrocarbons. Several different types of hydrocarbons are present in oil. *Alkanes* are the most abundant and have low chemical toxicity. Some types of alkanes are created by and present in both marine organisms and land plants and can enter the marine environment from those sources. *Polycyclic aromatic hydrocarbons (PAHs)* are another group...
of hydrocarbons found in oil, but also occur in items such as coal, car exhaust, or in charred animal fat. PAHs are typically less abundant in fresh oil than alkanes and can be highly toxic.

Multiple types of crude oil exist and each has its own properties. Heavy crude is thick and gooey due to large, carbon-based molecules and a higher percentage of compounds with oxygen, nitrogen, and sulfur atoms. In most cases, it floats on water despite its gooey nature. Light crude oil contains smaller, carbon-based molecules and flows more easily at room temperature. Crude oil is also classified according to what other elements are present. One undesirable compound in crude oil is sulfur. Sour crude oil has a large amount of sulfur, while sweet crude contains relatively low levels. Traces of nitrogen, oxygen, and metals may also be present in small quantities.

Engineers remove these unwanted compounds through a process called refining. Refining also breaks large molecules into smaller ones so the oil can be more easily utilized. The Deepwater Horizon Oil Spill (DWH) oil is called Macondo 252 (MC252) and is a light, sweet crude.

**HOW IS OIL RELEASED INTO THE MARINE & NEARSHORE ENVIRONMENT?**

Spots where oil naturally leaks into the aquatic environment and, less frequently, on land through cracks and faults in the earth are called oil seeps. Certain types of sea life have adapted to depend on these oil seeps as a source of food. Some microbes consume chemical compounds found in the oil to produce food for themselves and in turn nourish certain types of worms and clams.

More than 42 million gallons of crude oil enter the Gulf of Mexico each year from the region’s more than 900 natural oil seeps (Figure 1). This is the equivalent to...
15 percent of the annual oil production in the United States. Natural oil seeps around the world release about 180 million gallons of crude oil each year, accounting for an estimated 47 percent of the crude oil entering the global marine environment annually.

The remaining 53 percent of oil entering the marine environment makes its way there during operational discharges from production, transportation, and consumption of petroleum (Figure 2). This includes accidental release during activities such as drilling for or transporting oil. It is important to keep in mind that the chemical composition of these various sources can be different. These varying characteristics influence oil’s long-term fate and effects.

**WHO PRODUCES & USES OIL?**

The United States produces an average of 273.8 million gallons of crude oil each day (2009-2014). Fifty-five percent of U.S. production comes from the Gulf of Mexico region, both land-based and offshore, and 39 percent of U.S. Gulf of Mexico’s production comes from offshore. The next top domestic crude oil producers are North Dakota, California, and Alaska (Figure 3).

U.S. crude oil production does not meet demand. Historically, the largest portion of the U.S. trade deficit was petroleum, a broad category that includes both crude oil and products made from it (Figure 4). Petroleum accounted for approximately 10-66 percent of the national trade deficit between 2011 and 2015. The United States utilized an average of 793.2 million gallons of petroleum per day during 2009-2014 (Figure 5).
DOES OIL BREAK DOWN?

Oil breaks down or **weathers** over time. Weathering occurs when oil goes through physical and chemical processes that cause it to “age.” Sunlight, heat, microbes, and oxygen can all trigger and dictate the weathering process. For example, warm water temperatures and microbes can break down many of the carbon-based compounds in oil within a couple of weeks to one month. Cold water conditions slow this process and it may take more than forty days.

Many factors influence the rate at which oil breaks down, including if it is mixed with dispersant. Emergency responders used the dispersants Corexit 9500A and 9527A to minimize the amount of oil reaching the shore and especially low oxygen areas during DWH. Oil-degrading microbes are not abundant in low oxygen environments, such as muddy marshes or areas deep under the surface of sandy beaches. The use of dispersants enhances the breakdown of oil in water by allowing an oil slick to form small droplets more easily consumed by microbes.

Weathered slicks can create solid residues that interact with other particles and sink to the ocean floor or wash ashore with the weathered slicks, common occurrences near seeps and after spills.

**FIGURE 4.** How does society use oil? After the refining process, oil is used in a variety of ways, including transportation, heating, and everyday products. (Florida Sea Grant/Anna Hinkeldey)
The processes that create these solid residues are not fully understood. Recent research suggests that oxygen reacts with many of the chemicals in oil. The compounds produced from this reaction make up most of the mass of weathered oil. Their chemical properties cause them to persist in the environment. More work is needed to increase understanding of the breakdown and ultimate fate of oil in the coastal environment.

**HOW DO SCIENTISTS DETERMINE THE ORIGIN OF OIL FOUND IN THE ENVIRONMENT?**

All oil has a chemical signature unique to its place of origin. Scientists use laboratory equipment to identify and compare the chemical signatures of oil from a spill to oil from known origins. Called oil fingerprinting, this process can help identify the source of oil. It is an invaluable tool since roughly half of the oil entering the coastal and marine environment worldwide comes from natural seeps (Figure 2). Scientists, emergency responders, and regulatory agencies need to identify oil’s source to know if it is a natural or man-made issue.

Matching oil’s fingerprint to its source is not as easy as fingerprinting people. Weathering processes can change an oil’s fingerprint. This decreases the confidence in locating a specific oil source. Scientists are continually...
studying the many compounds in oil to understand what chemicals do not readily degrade so they can accurately identify oil’s source for longer periods.21

A great example of oil fingerprinting in action occurred two years after the DWH disaster. GoMRI-funded scientists wanted to know if the Macondo site was leaking after a surface oil sheen appeared near the wellhead. Scientists compared the sheen’s chemical makeup to samples of MC252 oil, samples from the capped wellhead area, and Macondo wreckage using cutting-edge fingerprinting technologies. The new method analyzed samples for compounds typically found in the drilling fluid lubricants used during oil extraction. These types of chemicals are not naturally found in crude oil. Because the sheen’s chemical signature included compounds that would normally be found in drilling fluid lubricant, the scientists determined the sheen was from the wreckage of the DWH drilling rig and not a leak from the wellhead.26

To learn more about the research being conducted on the Deepwater Horizon spill, visit the Gulf of Mexico Research Initiative website at www.gulfresearchinitiative.org. Visit the Gulf Sea Grant program website at http://gulfseagrant.org/oilspilloutreach to view other publications that provide additional information on the chemistry of oil and oil’s impact on aquatic organisms.

Crude oil has naturally occurring impurities that must be removed before the oil is ready to be made into useable products, such as gasoline. This process is called refining and it takes place at refineries, like the one pictured here. (Jim Bowen)
Oil being weathered, temperature, bacteria present). Processes are influenced by many factors (e.g., type of dispersing, biodegradation, and photooxidation. These includes processes such as oil spreading, evaporation, chemical processes which alter and break down oil. ItWeather (-ing, -s)—A collection of physical and living organisms.

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

Crude oil—Naturally occurring, unrefined oil. Crude oil is refined to produce a wide array of petroleum products (e.g., heating oils, gasoline, diesel, lubricants, asphalt, propane).

Dispersants—Chemicals that are used during oil spill response efforts to break up oil slicks to enhance the breakdown of oil. They can limit floating oil from impacting sensitive ecosystems such as coastal habitats.

Oil fingerprinting—A method that identifies sources of oil using a combination of sophisticated chemical techniques. It helps scientists trace spills to their source.

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

Petroleum—Broadly defined by the U.S. Energy Information Administration as a class of liquid hydrocarbon mixtures. Included are natural gas, crude oil, lease condensate, unfinished oils, refined products obtained from the processing of crude oil, and natural gas plant liquids. Volumes of finished petroleum products include non-hydrocarbon compounds, such as additives and detergents, after they have been blended into the products.

Polycyclic aromatic hydrocarbons (PAHs)—A group of hydrocarbons found in oil, tar, smoke from burning oil, coal, wood, (and ash from burning), car exhaust and cooked (e.g., grilled) animal fats.

Weather (-ing, -s)—A collection of physical and chemical processes which alter and break down oil. It includes processes such as oil spreading, evaporation, dispersing, biodegradation, and photooxidation. These processes are influenced by many factors (e.g., type of oil being weathered, temperature, bacteria present).

REFERENCES
Much of coastal Gulf of Mexico produces both seafood and petroleum, including crude oil. Louisiana holds an annual festival to celebrate both of these commodities. (Louis Dupuy)
DEEPWATER HORIZON: WHERE DID THE OIL GO?

Monica Wilson, Larissa Graham, Christine Hale, Emily Maung-Douglass, Stephen Sempier, Tara Skelton, and LaDon Swann

During the Deepwater Horizon (DWH) oil spill, approximately 200 million gallons of oil flowed from the Macondo well. Of the 200 million gallons, responders recovered 17 percent directly from the wellhead, releasing 172 million gallons of oil into the Gulf of Mexico. Due to the size and scope of the spill, people wanted to know where the oil would travel. Some oil accumulated at the shoreline, on the ocean’s surface, and in an underwater plume. Unexpectedly, a portion of the oil also found its way to the seafloor.

Gulf residents wanted to know the oil’s path and its potential impacts on the marine environment. In 2010, a group of scientists developed an oil budget calculator to estimate what happened to the oil and to provide a status update to the Incident Command. Scientists who developed the tool established seven categories to describe the fate of the spilled oil (Figure 1). For example, responders burned or skimmed some surface oil immediately, but other oil lingered in the environment. The Sea Grant publication Top 5 Frequently Asked Questions about the Deepwater

Oil from Deepwater Horizon washes ashore. (NOAA, Dari Knight)
Horizon Oil Spill details the following categories:

- recovered at the wellhead,
- skimmed,
- burned,
- chemically dispersed,
- naturally dispersed,
- evaporated or dissolved, or
- unaccounted for.

A few points not covered in the original study include the amount of weathering of surface oil. Over time, oil weathers as it interacts with the surrounding environment. It can evaporate, emulsify, naturally disperse, dissolve, or be broken down by microbes (called biodegradation) or the sun. The study also did not calculate the amount of oil recovered by the Vessels-of-Opportunity program and the amount that sank to the bottom.

Oil seeps occur naturally in the marine environment, so microorganisms in the ocean have evolved to be able to consume, or eat, oil. In the Gulf of Mexico hundreds of species of microbes such as bacteria, archaea, and fungi degrade oil. This is known as biodegradation. Microbes play a key role in the biodegradation of oil in the ocean and can reduce the overall environmental impact.

Oil at the water’s surface

Because oil is less dense than water, most spilled oil floats on the water’s surface. Currents, tides, river discharge, waves, and wind can move this surface oil, affecting where it winds up. Scientists use computer models to track the movement of oil at the water’s surface and predict its path.
Scientists also used satellite imagery called synthetic aperture radar (SAR) to calculate the area affected during the 87 days oil flowed freely into the Gulf. Results indicated surface oil reached a cumulative area of 57,000 square miles (Figure 2).9 Scientists found that winds and large river outflow from the Mississippi River kept a portion of surface oil offshore.10 More oil could have traveled offshore in the Loop Current but was trapped in a large eddy on the northern part of the Loop Current. The eddy remained stationary for several months, keeping the oil from reaching South Florida.11,12

**Evaporation**

Oil weathers over time as it interacts with the surrounding environment. The amount of weathering, the type of oil spilled, and the conditions during and after a spill influence how oil will move. Evaporation is an important part of the weathering process for most oil spills.4,5,13 Typical crude oils can lose up to 45 percent of their initial volume due to evaporation in the first few days following a spill.13 A significant fraction of the leaked DWH surface oil evaporated.4,5

**OIL ON THE SHORELINE**

During the DWH oil spill, a portion of the surface oil moved under the influence of the wind and ocean currents to make its way to the shore. Texas, Mississippi, Alabama, and Florida coasts all experienced shoreline oiling to different degrees (Figure 3). The oil impacted approximately 1,313 miles (37 percent) of the 3,540 miles of Gulf of Mexico coastline.

Table 1 lists the amount of shoreline oiled by state. Louisiana received 64 percent of the oil that made it to shore. The two shoreline habitats primarily affected were beaches (46 percent) and coastal wetlands (52 percent). The remaining two percent included all other shoreline types.14

**OIL BELOW THE SURFACE WATER**

Approximately one month after the spill began, scientists aboard the R/V Pelican first found evidence of an oil plume just under the water’s surface, called a subsurface plume. Certain chemical compounds in oil emit a light that allow them to be detected by fluorescence techniques. Using colored dissolved organic matter (CDOM) fluorometers, scientists discovered the subsurface oil plume. They found elevated levels of CDOM at water depths greater than 3,280 feet and as far as eight miles from the wellhead. They took water samples from areas with elevated levels of CDOM and found elevated levels of polycyclic aromatic hydrocarbons (PAHs). The PAH concentrations confirmed that the elevated levels of organic matter (CDOM) were related to oil contamination.15

![FIGURE 2. During the Deepwater Horizon oil spill, the extent and amount of oiling on the sea surface varied across the Gulf of Mexico. Colors indicate the average volume of oil in each cell area, with the highest concentrations (red) occurring near the wellhead.](Reprinted from MacDonald et al., 2010)
Using similar techniques other scientists analyzed over 5,000 water samples to track the deep water plume. In addition to looking for oil droplets, they searched for other evidence of contamination at the plume depth, including elevated PAHs, dissolved gas, fluorescence, and lowered dissolved oxygen levels. Water samples containing oil droplets were found as far as 96 miles from the wellhead. Other samples containing elevated fluorescence and low dissolved oxygen signals indicated the presence of oil as far as 256 miles from the wellhead (Figure 4). Other scientists confirmed the subsurface plume using the autonomous underwater vehicle (AUV) Sentry (Figure 5). They collected and tested water samples and found the subsurface oil plume between depths of 3,380 and 4,265 feet in late May and early June of 2010. Although more than 22 miles in length and existing for months after the oil spill, the subsurface plume was not a river of oil floating under water. The plume was simply an area that had elevated amounts of PAHs compared to other areas. The subsurface plume trapped approximately 35 percent of the spilled oil, but scientists are uncertain of the plume’s ultimate fate.

### OILED WASTE MATERIAL

Approximately 100 million pounds of oiled waste materials were removed from sand beaches during response activities (adapted from Michel, 2015)

<table>
<thead>
<tr>
<th>State</th>
<th>Prior to June 2011 (pounds)</th>
<th>June 2011 - February 2014 (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas</td>
<td>17,454</td>
<td>0</td>
</tr>
<tr>
<td>Louisiana</td>
<td>76,062,800</td>
<td>15,176,296</td>
</tr>
<tr>
<td>Mississippi</td>
<td>3,886,415</td>
<td>113,061</td>
</tr>
<tr>
<td>Alabama</td>
<td>2,569,200</td>
<td>930,656</td>
</tr>
<tr>
<td>Florida</td>
<td>Not available</td>
<td>66,276</td>
</tr>
</tbody>
</table>

### OIL ON THE SEAFLOOR

Estimating the total amount of oil that made its way to the seafloor is difficult. Deep sea currents move the deposited oil, causing it to accumulate in dips and depressions on the seafloor. Marine animals that live on the bottom bury
it, move it, and change its distribution. Scientists used different chemical techniques to understand how much oil made it to the seafloor. They estimated that an area of approximately 1,235 square miles around the Macondo well had been polluted with different amounts of oil and oil-derived carbon from the spill. While oil on the seafloor had not been included in the original oil budget, recent studies show that about three to five percent of the oil discharged from the well made its way to the seafloor.20-22

**Sedimentation of oil**

Although oil normally floats on the surface, it can make its way to the bottom when it attaches to other, heavier particles in the water. Sedimentation occurs when the oil and particles land on the seafloor.23 This may occur near a river or in shallow areas. Rivers flowing into the Gulf can introduce sediment and other sticky materials that attach to the oil. For example, large volumes of water from the Mississippi River contain small particles that could have combined with the oil.24 Certain biological processes may also form sticky particles, called marine snow, that can

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**FIGURE 4.** Scientists took offshore water samples to track the deep plume, mapping surface oil spreading out from the wellhead in red and the deep plume going towards the southwest in yellow/green (a). In a three-dimensional underwater model (b), a column of oiled samples rises from the wellhead to the surface while the deep plume extended 256 miles southwest from the wellhead. Colors relate to the phases of each sample’s oil—samples with Deepwater Horizon oil droplets (red); dissolved oil without oil droplets (blue); or containing poorly defined oil fingerprints but with other evidence of oil such as dissolved oxygen or fluorescence (yellow/green).16 (Adapted from Payne and Driskell, 2015)

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**FIGURE 5.** The autonomous underwater vehicle (AUV) Sentry confirmed the deep subsurface oil plume between depths of 3,380 and 4,265 feet. The plume was more than 22 miles in length.17 (Woods Hole Oceanographic Institution/ Will Koeppen)
capture the oil droplets and cause them to sink. Marine snow may contain tiny algae, microbes, mucous web-like threads, pieces of small decaying animals, feces, and other bodily waste that may carry contaminants from the surface to the bottom (Figure 6).²⁵

During the DWH spill scientists learned that marine snow trapped the oil, carrying it downward to the seafloor where it accumulated.²⁶ The oil along with ash from on-site burning became part of marine snow. The sinking of marine snow contributed to the sedimentation of oil from the spill. This event has been termed Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA).²⁷

Scientists believe that MOFFSA-related activities caused some of the oil to accumulate on the seafloor.²⁴ Researchers continue to work to better understand where the oil went, how long it might stay there, and its impacts on the marine environment. The Gulf of Mexico Research Initiative (GoMRI) funds these ongoing studies. Emerging information can be found on GoMRI’s website at http://gulfresearchinitiative.org. To access other oil spill-related publications or view the references in this publication on Sea Grant Oil Spill Science Outreach Program website: www.gulfseagrant.org/oilspilloutreach.

Potential pathways for oil to sink to the seafloor

**FIGURE 6.** Oil can take many paths to reach the ocean floor. (Florida Sea Grant/Anna Hinkeidey, adapted from Deepwater Horizon Natural Resource Damage Assessment Trustees)
Polycyclic aromatic hydrocarbons (PAHs) naturally through cracks in the earth at a slow rate. Oil seeps marine organisms. Weathering, microbial degradation, and ingestion of oil by Oil-derived carbon — Oil-derived chemicals from the surface waters to the deep ocean. Marine snow — A shower of biological material falling from the surface waters to the deep ocean. Oil-seeps — Areas where oil and natural gas flow up naturally through cracks in the earth at a slow rate. Polycyclic aromatic hydrocarbons (PAHs) — One of the many chemical groups found in oil, tar, smoke from burning oil, coal, wood, or decaying vegetation; used to identify oil in the environment. Sedimentation — Occurs when particles (or sediment) suspended in a liquid settle and get deposited on the bottom. Synthetic aperture radar (SAR) — Satellite- or aircraft-borne radar system used to create images of ground features, terrain, and oceans. Weather (red, -ing, -s) — A collection of physical, chemical, and microbial processes that alter and break down oil. It includes processes such as oil spreading, evaporation, dispersing, biodegradation, and photooxidation. These processes are influenced by many factors (e.g., type of oil being weathered, temperature, bacteria present).

**REFERENCES**


**GLOSSARY**

**Autonomous underwater vehicle (AUV)** — Programmable robotic vehicles that can drift, drive, or glide through the ocean without being controlled by humans.

**Colored dissolved organic matter (CDOM)** — Dissolved organic matter in the water that consists of broken down plant parts, such as leaves, algae, or phytoplankton.

**Eddy** — A current having a rotary or circular motion.

**Emulsify** — Occurs when water and oil combine, with one being suspended in the other. For crude oils, it refers to the process where sea water droplets become suspended in the oil by mixing due to turbulence.

**Fluorescence** — A substance absorbing light that re-emits the light as a different color.

**Fluorometer** — An instrument used to measure re-emission of light by a substance.

**Loop Current** — A warm ocean current that flows northward between Cuba and the Yucatan Peninsula, moves north into the Gulf of Mexico, loops east and south before exiting to the east through the Florida Straits and joining the Gulf Stream to flow between Florida and the Bahamas.

**Marine snow** — A shower of biological material falling from the surface waters to the deep ocean.

**Oil-derived carbon** — Oil-derived chemicals from weathering, microbial degradation, and ingestion of oil by marine organisms.

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

**Polycyclic aromatic hydrocarbons (PAHs)** — One of the many chemical groups found in oil, tar, smoke from burning oil, coal, wood, or decaying vegetation; used to identify oil in the environment.

**Sedimentation** — Occurs when particles (or sediment) suspended in a liquid settle and get deposited on the bottom.

**Synthetic aperture radar (SAR)** — Satellite- or aircraft-borne radar system used to create images of ground features, terrain, and oceans.

**SUGGESTED CITATION:**


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**OIL SPILL SCIENCE OUTREACH TEAM**

**Christine Hale**
Texas Sea Grant College Program  
chris.hale@tamu.edu

**Larissa Graham**
Mississippi-Alabama Sea Grant Consortium  
larissa.graham@auburn.edu

**Emily Maung-Douglass**
Louisiana Sea Grant College Program  
edouglass@lsu.edu

**Stephen Sempier**
Mississippi-Alabama Sea Grant Consortium  
stephen.sempier@usm.edu

**Tara Skelton**
Mississippi-Alabama Sea Grant Consortium  
tara.skelton@usm.edu

**LaDon Swann**
Mississippi-Alabama Sea Grant Consortium  
swanndl@auburn.edu

**Monica Wilson**
Florida Sea Grant, UF/IFAS Extension  
monicawilson447@ufl.edu

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OIL SPILL SCIENCE
SEA GRANT PROGRAMS OF THE GULF OF MEXICO

THE SEA GRANT and GOMRI PARTNERSHIP
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PREDICTING THE MOVEMENT OF OIL

Monica Wilson, Larissa Graham, Christine Hale, Emily Maung-Douglass, Stephen Sempier, Tara Skelton, and LaDon Swann

When oil spills occur, one of the first questions is “Where will the oil go?” Pollutants, such as oil, float on the surface and move through and along with the water. Computer models are tools that help predict the path of pollutants. They help minimize oil spill impacts by estimating the landfall and movement of oil. Plans for protecting the environment, society, and the economy require reliable forecasts that predict where oil will spread in the event of a spill.

Photos like this one, taken during a U.S. Coast Guard flyover in May of 2010, helped scientists and responders keep track of the Deepwater Horizon oil’s location. (David Rencher)

The Deepwater Horizon (DWH) oil spill was the largest spill in U.S. history. About 172 million gallons of crude oil entered the Gulf of Mexico waters, causing an unprecedented threat to marine life and the environment. Determining the spill’s potential impacts and planning response strategies required getting information unique to the situation because no two oil spills are alike. Each spill occurs in a different location under different circumstances. The type and amount of oil, the proximity of oil to sensitive resources, the season, the weather, and the water currents all combine to make each spill a unique event.

Oil spill models predict the movement of oil and possible landfall locations. They
calculate how oil weathers as it spends more time in the water, how it spreads, and the rate at which it evaporates. These forecasts help responders develop cleanup strategies based on more accurate estimates of how long spilled oil will remain in the environment, where it will go, and how it will change over time.

Response efforts for oil or other chemical spills must be quick, effective, and relevant to the event. In the case of the DWH spill, oil was on the surface and at extreme depths. Models predicted the movement of oil both at and below the surface to guide response efforts and direct ships assessing the situation during the spill (Figure 1).

WHAT ARE MODELS AND HOW DO THEY WORK?

Computer models are tools used to simulate what might or what did happen in a given situation. A common example of a computer model is a weather forecasting model. It calculates what the weather might be in the next few days or over the week. Other models also simulate ocean currents, tides, waves, and mixing in the ocean, which all affect the movement and spread of pollutants through the sea. The predictions depend on the information that enters the model, or inputs. Some examples of inputs to ocean models include bottom depth, wind measurements, and river inflow. The information that comes out can include water level, current speeds, water temperature, and salinity.

To improve the quality of computer models, scientists compare model predictions to direct observations in the field (Figure 2). If the model predictions do not match what is actually occurring in the field, the model is re-examined and modified until it produces more reasonable results. Some models may be compared with data and corrected while an event is occurring. This process is called data assimilation.

Combining multiple models helps scientists understand how different environments interact. One example is when meteorological models are paired with ocean circulation models to understand events such as approaching storms, hurricane paths, and El Niño. In the case of an oil spill model, which simulates the fate and transport of oil pollution, several model components are needed.

COMPONENTS OF AN OIL SPILL MODEL

- Meteorological models simulate the present and predict future behavior of the atmosphere (wind, temperature, precipitation).
- Ocean circulation models simulate the motion of water, such as ocean currents.
- Trajectory models simulate how particles move up and down and horizontally in the water.
- Chemical models (or “Fate models”) estimate the changing state of pollutants as they move through the water.

MODELING CHALLENGES

Several factors reduce the ability of models to predict oil movement:

- Errors in forcing — Oil spill models rely on forecast modeling to supply forces that make the ocean move.
These forces include winds, tides, temperature, and precipitation. Forecast models’ errors increase with time. The longer the model predicts into the future, the larger the errors get and the less reliable the forecast becomes.

- Errors in estimating the amount of oil and its properties — During the DWH oil spill, the amount of oil released into the Gulf was not well known. Modelers had to make assumptions about how much oil entered the environment, which could impact the accuracy of the model.
- Response techniques — Application of dispersants, burning oil, and skimming oil added uncertainties to the fate and transport of the oil spill model.
- Lacking understanding of how and why oil changes over time — The fate of oil in the ocean depends on many factors:
  - spreading caused by ocean currents, waves, and dispersants;
  - chemical changes in oil that take place when oil is weathered; and
  - biodegradation that occurs when bacteria break down the oil.3,7

MODELS USED TO UNDERSTAND THE DEEPWATER HORIZON OIL SPILL

During the DWH oil spill, the National Oceanic and Atmospheric Administration (NOAA), university researchers, and other agencies used numerous models to predict where the oil was and where it was going.7,8

Beginning in late April, 2010, NOAA’s Office of Response and Restoration modeling team began generating daily forecasts for the DWH oil spill. NOAA produced forecast maps twice a day from April 23 to May 19. These maps
showed the surface location of oil and predicted where it would go next. Scientists produced forecasts for where surface oil would be at 12-, 24-, 36-, 48-, 60-, and 72-hour intervals to support daily response plans. All forecasts ended on August 23, 2010, when no more evidence of floating oil appeared and no recoverable oil could be seen in flights over the area for three weeks.7,12,13

**COASTAL PREDICTIONS**

Models also predicted how oil would move in the nearshore environment. Early in the spill, emergency responders were most concerned that oil would reach coastlines from Louisiana to the Florida Panhandle. Other forces were at work, however. By May, the nearby Mississippi River was swollen with spring rains, playing an important role in influencing where the oil went. The model simulations, satellite data, and on-site observations helped scientists understand the relationship between the river’s outflow and the movement of surface oil. They learned that when winds were weak, the increase in the river’s outflow helped protect the coast by pushing the oil away from the shoreline.14

Some of the oil that was not collected or dispersed made its way to the northern Gulf of Mexico coastline. Oil mixed with suspended sediment and formed sand and oil agglomerates.

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**NOAA’S OFFICE OF RESPONSE AND RESTORATION USES TWO PREDICTIVE MODELS:**

**General NOAA Operational Modeling Environment (GNOME)**

- Predicts possible route oil may follow in or on a body of water.9
- Produces spill trajectories that support response operations.
- Uses satellite images and flight observations to set starting values for predictions (Figure 3).10

**Automated Data Inquiry for Oil Spills (ADIOS)**

- Predicts how different types of oil break down and change over time in the marine environment.
- Incorporates a database of more than one thousand types of crude oils and refined products so that it can quickly estimate the pollutant’s expected behavior.
- Includes the changes of oil over time due to weathering.11
ates that sank to the seafloor. Wave action caused these agglomerates to break up into smaller, more mobile pieces known as surface residual balls (SRBs).\(^{15}\) Scientists use models to predict how SRBs move along the Alabama and western Florida coast (Figure 4). SRBs continue to show up on beaches years after the spill.\(^{16}\)

**OFFSHORE PREDICTIONS**

The Loop Current is a warm current that flows northward between Cuba and the Yucatan Peninsula, moves into the Gulf of Mexico, and then exits through the Florida Straits. The Loop Current sheds rings of warm water, known as eddies, that separate from the main current.\(^{17}\) Keeping track of the Loop Current and its eddies became important during the DWH oil spill. If oil entered the Loop Current, it could have been transported as far away as the Florida Keys, Cuba, or the Bahamas.

In May 2010, a portion of oil entered a large eddy on the northern part of the Loop Current (Figure 5). NOAA began producing maps to provide daily updates of the location of the Loop Current and its major eddies. These maps also provided the location of floating oil relative to the Loop Current. The forecasts predicted the likelihood of oil being

**FIGURE 4.** A computer model predicted the movement of surface residual balls (SRBs) during calm conditions (top) and storm conditions (bottom). Pink indicates SRBs are mobile; blue means they are immobile.\(^{27}\) (Adapted from Plant, Long, Dalyander, Thompson, & Raabe, 2012)

**FIGURE 5.** One computer model produced this map showing the path of the Loop Current and associated eddy. Colors indicate sea surface temperature (SST). The oil slick is shown in gray. The black star represents the location of the oil well. White dots represent wind stations. Blue dots represent drifter positions from April 26 to May 27.\(^{18}\) (Reprinted from Walker et al., 2011)
sent to the Florida Straits and other parts of the Gulf.\textsuperscript{12,18} Oil never reached the Florida Keys because the eddy remained stationary for several months.\textsuperscript{12,13,18}

**HOW GOOD WERE THE OIL SPILL MODELS?**

It is important to keep in mind that no two models are alike. Each model has its own unique features, inputs, and properties that can make their predictions vary from one another. During DWH, a number of computer models existed for the Gulf of Mexico. Scientists tested some of these models to see how well they represented the path of the oil. Researchers from NOAA’s Emergency Response Division used satellite images as guides to help them run four different models. Essentially, they made an outline of the oil slick from the images, filled it with particles that represented the oil, and then let the model predict the path of the oil (Figure 6). No one model consistently gave the best estimate. Because a spill impacts many different marine environments such as bays, estuaries, shallow, and deep areas, it is difficult to represent the water circulation in all regions. Multiple model trajectories are needed to get an understanding of the movement of the oil.\textsuperscript{7}

**OTHER BENEFICIAL USES FOR MODELS**

These are examples of other ocean-related models in use today.

**Search and Rescue**

The U.S. Coast Guard uses the Search and Rescue Optimal Planning System (SAROPS) for search planning. It helps predict the location of persons or objects lost at sea.\textsuperscript{19}

**Sea-Level Rise, Hurricanes, and Storm Surge**

Models have become increasingly important to help predict hazards to coastal communities. As the world’s population continues to grow and move toward the coast, modeling the impacts of sea-level rise and storm surge are important for storm preparation and recovery.\textsuperscript{20} Models have also been applied for hurricane forecasts as well. Additionally, scientists use hindcasts for the development of coastal risk assessments and the design of levee protection systems.\textsuperscript{21}

**Navigation**

NOAA’s Operational Forecast System (OFS) shares existing conditions and makes short-term forecasts of water levels, salinity, temperature, and waves. The information is used by the maritime community for planning safe navigation through estuaries and bays.\textsuperscript{22}

**Flushing of Coastal Waters**

Circulation models estimate flushing and residence time within an estuarine system. They can calculate how long water particles and pollutants will remain in an area. They also predict the effects of channel deepening and widening on the movement of water in an estuary.\textsuperscript{23} The models can describe how water moves between an estuary and the ocean through tidal inlets. This can help predict the water quality in an estuary.\textsuperscript{24}
The use of computer models can simulate real-world events, providing powerful predictive tools that can be applied to serve specific needs. Oceanographic models calculate the effects that winds and waves have on water circulation, increasing the understanding of how water and pollutants move within an area. The Gulf of Mexico Research Initiative continues to fund modeling studies as well as observational studies that improve the accuracy of existing models. Emerging information can be found on GoMRI’s website at http://gulfresearchinitiative.org. To access other oil-spill-related publications or view the references in this publication on Sea Grant Oil Spill Science Outreach Program website: www.gulfseagrant.org/oilspill-outreach.

GLOSSARY

Biodegradation — The natural breakdown of a substance, especially by bacteria.

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.

Eddies — Currents having a rotary or circular motion.

Estuarine system — A partially enclosed body of water where freshwater from rivers and streams mixes with salt water from the ocean; the areas of transition between the land and sea.

Hindcast — A model that is run for a time period in the past to understand what has previously occurred.

Loop Current — A warm ocean current that flows northward between Cuba and the Yucatan Peninsula, moves north into the Gulf of Mexico, loops east and south before exiting to the east through the Florida Straits and joining the Gulf Stream to flow between Florida and the Bahamas.

Meteorological models — Models that describe the current and future behavior of the atmosphere (wind, temperature, precipitation) over large geographic areas.

Ocean circulation models — Models that describe the physical processes in the ocean.

Refined products — Products that have had unwanted chemicals (impurities) removed.

Residence time — Average amount of time a water parcel spends in an area.

Salinity — The average concentration of dissolved salts in a body of water.

Sand and oil agglomerates — A term that refers to oil mats, surface residual balls, and surface residual patties and does not distinguish them by size.

Skimming — Using special tools to remove oil from the sea’s surface before it reaches the coastline.

Spill trajectories — Show how and where a spill will move in or on the water.

Storm surge — Rising water levels caused by high wind events such as hurricanes or winter storms.

Surface residual balls (SRBs) — Pieces of oil that washed up after the Deepwater Horizon oil spill and were mostly made up of pieces of sand, shell, and other materials loosely bound by oil.

Trajectory — The path followed by a parcel of water or pollutant, such as oil, in the water column or water surface.

Weather (-ed, -ing, -s) — A collection of physical, chemical, and microbial processes that can alter and break down oil. It includes processes such as oil spreading, evaporation, dispersing, biodegradation, and photooxidation. These processes are influenced by many factors (e.g., type of oil being weathered, temperature, bacteria present).

REFERENCES


**SUGGESTED CITATION**


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**OIL SPILL SCIENCE OUTREACH TEAM**

**Christine Hale**  
Texas Sea Grant College Program  
chris.hale@tamu.edu

**Larissa Graham**  
Mississippi-Alabama Sea Grant Consortium  
larissa.graham@auburn.edu

**Emily Maung-Douglas**  
Louisiana Sea Grant College Program  
edouglas@lsu.edu

**Stephen Sempier**  
Mississippi-Alabama Sea Grant Consortium  
stephen.sempier@usm.edu

**Tara Skelton**  
Mississippi-Alabama Sea Grant Consortium  
tara.skelton@usm.edu

**LaDon Swann**  
Mississippi-Alabama Sea Grant Consortium  
swanndl@auburn.edu

**Monica Wilson**  
Florida Sea Grant, UF/IFAS Extension  
monicawilson447@ufl.edu

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UNDERWATER VEHICLES USED TO STUDY OIL SPILLS

Monica Wilson, Larissa Graham, Christine Hale, Emily Maung-Douglass, Stephen Sempier, Tara Skelton, and LaDon Swann

Scientists use a variety of oil detection technologies to determine the location of the oil released, to see how it spreads, and to identify chemicals in the oil. Remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and submarines help to locate oil and monitor its impacts below the water’s surface and on the seafloor.

REMOTELY OPERATED VEHICLES

ROVs are underwater robots used to explore the deep ocean. They are connected to a ship with cables. The first tethered ROV, Poodle, was developed in 1953. The U.S. Navy advanced the technology by developing robots to recover objects from the ocean floor, such as nuclear bombs. Also designed for industrial purposes, the oil and gas industry created ROVs to assist, develop, and examine underwater pipelines. They also perform structural tests of offshore platforms and help with numerous other underwater tasks. Scientists use them to explore the deep areas where divers cannot reach. ROVs are also being used for shallow water operations.1,2
How do ROVs work?

ROVs are controlled with a joystick onboard a boat. They receive their power and send their data through a tether, a direct hard-wire communication cable between the ROV and those onboard. ROVs can be equipped with tools such as cameras, lights, robotic arms, claws, cutting blades, water samplers, and instruments that measure temperature, depth, and salinity. The cameras take still photos and videos of the underwater environment. The robotic arms retrieve small objects, cut lines, or attach hooks to larger objects.

During the Deepwater Horizon (DWH) oil spill, ROVs inspected the rig, treated the underwater oil plume with dispersants, and studied the impacts of the oil on the seafloor environment. On April 22, 2010, ROVs diving near the wellhead – located about a mile below the ocean’s surface – found hydrocarbons leaking from the riser pipe. As ROVs explored the pipe and attempted to activate the blowout preventer, scientists discovered other oil leaks. The ROVs supplied videos of oil exiting the wellhead. They also collected samples of the oil and injected dispersants directly into the oil coming out of the wellhead.

Scientists used ROVs to examine oil’s impacts on deep-sea coral communities. Approximately six months after the DWH spill, the ROV Jason II’s mounted camera took close-up images of 43 corals approximately seven miles southwest of the wellhead. A manipulator claw and the cutting blade collected samples of coral and the brittle stars attached to them. Scientists used the images and samples to assess the oil’s impact on the corals (Figure 1).

In another study, scientists used ROVs to locate and observe corals in the Gulf of Mexico’s mesophotic zone. How do ROVs work?

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zone between 50 and 100 meters’ depth. Mud samples collected by the ROV showed elevated levels of contaminants on the seafloor. Scientists studied images of specific coral locations over time to evaluate their health and condition before and after the DWH oil spill. They found that rates of injury to coral climbed from 4 to 9 percent before the spill to 30 to 50 percent after the spill. To learn more about the impacts of oil on the Gulf coral communities, read the Sea Grant publication *Corals and oil spills*.

**AUTONOMOUS UNDERWATER VEHICLES (AUV)**

AUVs are battery-powered, programmable robots that can move or glide through the ocean without an operator. Unlike an ROV, an AUV does not have a cable between it and the research vessel. Similar to ROVs, they conduct underwater missions such as detecting and mapping shipwrecks, studying the depths of the seafloor, and locating obstructions that could be hazardous to vessels. AUVs are efficient and productive because of propulsion and navigation systems that allow them to move independently and accurately in any direction in the water. AUVs can also be equipped with a variety of sensors and instruments that provide information and take measurements as they move through the water. Typical AUV sensors and instruments include the following:

- Side-scan sonar uses soundwaves to create pictures or images of the sea floor.
- Cameras take photographs and videos of the location being surveyed.
- Multibeam sonar uses soundwaves to provide information about the seafloor’s depth.
- Conductivity, temperature, depth (CTD) and water quality sensors measure a variety of water quality properties such as temperature, salinity, depth, pH, and oxygen levels.
- Acoustic Doppler Current Profilers (ADCP) measure the ocean currents.
AUVs conduct surveys in an array of depths, from 16 feet to about 20,000 feet below the surface. Scientists plan and download their program to the AUV prior to the launch and deploy the vehicle from the surface to begin its mission. The vehicle returns to the surface to be recovered by a research vessel once its mission is complete or it begins to run out of battery power.\textsuperscript{12}

In response to the DWH oil spill, scientists deployed the AUV Sentry on two research cruises to track the underwater oil plume and to map and photograph deep-sea animals. Sentry was equipped with multiple sensors including a mass spectrometer that helped detect the underwater oil plume. Scientists discovered the underwater oil plume\textsuperscript{14} at a depth of 3,280 feet and later explored its extent.\textsuperscript{15,16} Using Sentry the underwater plume was mapped and calculated to be more than 22 miles in length.\textsuperscript{15} During the first dive Sentry followed preplanned routes designed to repeatedly cross the oil plume at a constant depth. Sentry collected information and sent it back to the surface using sound waves, similar to short messages sent through text messaging. The second dive was similar. However, this time the engineers changed Sentry’s pre-planned path during the mission. As soon as the mass spectrometer on Sentry did not show the presence of any hydrocarbons, the engineers commanded it using soundwaves to return towards the plume (Figure 2).\textsuperscript{12} On another cruise, Sentry also took pictures of the ocean floor, mapping and surveying it to help scientists locate coral communities near the wellhead. Scientists used this information to plan their dives with ROVs and the submersible Alvin for follow-up sampling and observations.\textsuperscript{8,12}

Gliders, vehicles that move up and down in the water by changing their buoyancy, are another form of AUV. They have wings that help them glide through the water. Presently, gliders provide data from the surface to 3,200 feet in depth although deeper versions are now in development. They can take anywhere from three to six hours to complete a cycle from the surface to a specified depth and back.\textsuperscript{17} Gliders can also carry various instruments, such as cameras and sensors that can observe oil plumes.\textsuperscript{18} They
HUMAN OCCUPIED VEHICLE (HOV)

HOVs are submersibles capable of carrying scientific observers to study the ocean depths. An on-board pilot controls the HOV, which is not attached to a ship or vessel by any cables. The Alvin and the Challenger are HOVs that study the deep sea marine environment.

Alvin explores marine communities at extreme depths. It can plunge to a maximum depth of 14,764 feet. Alvin has seven thrusters that allow it to hover in the water, maneuver over rugged terrain, or rest on the seafloor. It is capable of collecting data throughout the water, producing maps, and taking photographs. After DWH, Alvin took close-up images and collected water and coral samples for lab analyzation. Alvin was only used in areas where the vehicle could get close to coral communities without causing them any harm. During November and December of 2010, scientists conducted sampling from a number of discharge features along the continental slope of the Gulf of Mexico. Data collected from such missions helps improve ocean circulation models, which then helps monitor the location of pollutants, such as oil from the DWH oil spill.
SO MANY CHOICES — WHAT’S THE DIFFERENCE?

Determining which technology to use can depend on the environment being studied, the amount of time a scientist has, the advantages and disadvantages of the technology, and the cost to operate the equipment. 4,13,22,23

<table>
<thead>
<tr>
<th>Submersible</th>
<th>Operation Cost</th>
<th>Operation Effort</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Deep Sea ROV</td>
<td>Approximately $15,000/day (not including ship cost)</td>
<td>More people involved due to constant transmission of data and video</td>
<td>Available in a variety of sizes</td>
<td>Cable entanglement/management</td>
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<td>Intensive for the entire science party due to collaboration throughout the mission</td>
<td>Easy to deploy</td>
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<td>Can stay submerged for days, not battery limited</td>
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<td>Can be used on a wide range of research vessels</td>
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<td>Mobility allows close up examination of seabed</td>
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<td>Constant transmission of real-time data</td>
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<td>AUV</td>
<td>Approximately $500 - $10,000/day (not including ship cost)</td>
<td>Data comes in periodically when vehicle surfaces and computers can download data</td>
<td>Does not require any human control</td>
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<td>Allows vessel/scientists to conduct other tasks while AUV is in the water performing its mission</td>
<td>Operates free of cables, which increases efficiency and speed</td>
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<td>Run times as short as a few hours to as long as months</td>
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<td>Pre-programmable and can be commanded to change on the fly</td>
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<td>Gives limited real time data through acoustic links</td>
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<td>Can be equipped with multiple sensors</td>
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<td>Large boat not necessary to operate</td>
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<td>HOV Alvin</td>
<td>Approximately $45,000/day (includes ship cost)</td>
<td>Intensive for the two to three scientists inside the submersible</td>
<td>Gives scientists opportunity to visit the seafloor in person</td>
<td>Requires support of the R/V Atlantis</td>
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<td>Less intensive for those onboard while they wait for the submersible to return</td>
<td>Can be equipped with many different instruments to aid in observations and research</td>
<td>Limited operation time (5 hours total)</td>
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<td>Gets very cold inside (50°F)</td>
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<td>Cramped conditions for scientists on board</td>
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<td>Difficult to deploy</td>
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of Mexico. While aboard *Alvin*, they witnessed natural oil seeps in the Gulf, observing gas and oil seepages as rising bubbles. They used *Alvin* to collect sediment cores at the bottom of the Gulf of Mexico and water samples from active gas seeps to test for radium isotopes, which can serve as tracers to detect oil in the environment. Technology played a large role in studying the DWH oil spill and this publication only featured a small subset of the breadth of technology used. It is always evolving and scientists are constantly finding new ways to use technology in their research. The Gulf of Mexico Research Initiative (GoMRI) funds these ongoing studies. Emerging information can be found on GoMRI's website at [http://gulfresearchinitiative.org](http://gulfresearchinitiative.org). To access other oil spill-related publications or view the references in this publication on Sea Grant Oil Spill Science Outreach Program website: [www.gulfseagrant.org/oilspilloutreach](http://www.gulfseagrant.org/oilspilloutreach).

### Glossary

**Blowout preventer** — A large valve used to seal, control, and monitor oil and gas wells to prevent the well from releasing oil or gas.

**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.

**Hydrocarbons** — Compounds composed of carbon and hydrogen atoms. Most hydrocarbons naturally occur in crude oil and natural gas and are formed from decomposed organic matter.

**Mass spectrometer** — An instrument used to identify the kinds of chemical particles present in a substance.

**Mesophotic** — A low light environment at depths of 100 to 500 feet below the ocean’s surface.

**pH** — A measure of the acidity or alkalinity of a solution.

**Riser pipe** — A pipe that connects the oil platform to an underwater oil well.

**Salinity** — The average concentration of dissolved salts in a body of water.

**Submersible** — A small vehicle designed to operate underwater.

### References


**SUGGESTED CITATION:**

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university–based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10–year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization and remediation technologies. GoMRI is led by an independent and academic 20–member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

**IN THE AIR AND ON THE WATER: TECHNOLOGY USED TO INVESTIGATE OIL SPILLS**

Monica Wilson, Christine Hale, Emily Maung-Douglass, Stephen Sempier, Tara Skelton, and LaDon Swann

Oil detection and monitoring are important for managing marine resources and minimizing potential environmental impacts. New technologies complement traditional ship, satellite, and mooring-based data collection techniques, allowing scientists to study all aspects of oil spills. Along with underwater vehicles, unmanned surface and aerial vehicles, as well as satellites, are used to study oil spills at and above the ocean’s surface. These technologies allow scientists and responders to understand how oil moves on the ocean’s surface. Some have advanced into operational use by the spill response community and others are being tested as response tools.

Unmanned surface/aerial vehicles and satellites help scientists understand the movement of currents and pollutants at the ocean’s surface (graphic not to scale). (Anna Hinkeldey)

**UNMANNED SURFACE VEHICLES**

Unmanned surface vehicles (USVs) operate on the surface of the water without any onboard operators. Scientists are developing new ways to use USVs as research tools. USVs are a cost-effective technology with a wide range of applications, including scientific research, environmental missions, ocean resource...
The Saildrone, a type of unmanned surface vehicle, can carry an array of instruments that allow scientists to take atmospheric and oceanic surface and subsurface measurements. (ECOGIG)

exploration, and military uses. Some USVs are lightweight and compact, which makes them easy to maneuver and deploy in shallow water where ships cannot operate effectively. They also have the potential to carry instruments and sensors to conduct monitoring and sampling. Due to USVs not requiring a crew on board, there are minor threats of collisions at sea, the costs of maintenance and operation are lower, and they can perform longer and more hazardous missions than manned vehicles.

**Saildrones**

Saildrones are exactly what the name describes, sailing drones. They float on the surface of the water to conduct oceanography, fishery, and marine mammal studies. Powered by wind and solar energy, they have solar panels on the hull and wing to provide power for command, control, communications, and sensor operations. Scientists launch Saildrones from shore, docks, or platforms. They stay at sea for extended lengths of time while reporting and collecting real-time data with a collection of weather- and water-related sensors.

Natural oil seeps are locations where oil leaks naturally into the ocean through cracks and faults in the ocean floor. Scientists recently used a Saildrone to study oil from a natural seep in the Gulf of Mexico on the surface of the ocean. The study’s objective was to estimate how long the oil slick remained on the surface and to determine the importance of winds and surface currents on the movement and fate of the surface oil. Scientists launched the Saildrone from a platform in Louisiana and directed it to a natural oil seep 230 miles offshore. Once it located the seep, it surveyed the area for three weeks and then sailed back to the platform. The instrument was equipped with an anemometer and an autonomous Remote Optical Watcher (ROW). A sensor that uses fluorescence to detect the presence of oil on the surface of the water, an ROW sends an alarm when it detects oil at a level above a specified threshold. Observations collected by the Saildrone confirmed the changes in wind speed and direction predicted by the computer model during the study were correct. The costs of this operation were much lower and data quality higher compared to other methods.

**Drifters**

Drifters study ocean circulation patterns by providing scientists with real-time information about how surface currents move. They float on the surface of the water, come in many different sizes, and contain GPS units to track their position as they move with the water. Modern drifters are quite inexpensive so they can be deployed in large numbers, which can reveal the highly complex nature of ocean surface currents. The data gathered from these devices helps scientists develop and evaluate predictions from computer models.
Scientists compare the data from the drifters and the model to make sure the model is predicting what is happening on the water’s surface. The computer models help predict climate, weather patterns, currents, and where pollutants might go when dumped or spilled into the ocean. To learn more about computer models and how scientists use them to track oil, read the Sea Grant publication *Predicting the movement of oil*.

In 1989 and 1991, scientists used drifters during four experimental oil spills on the Norwegian coastline. Experimental oil spills are planned, controlled spills that allow scientists and responders to observe the movement of oil in a non-threatening manner. These experiments allow them to study the impacts of weather and sea conditions on the oil and help guide strategies for oil spill planning and response. Scientists deployed nine drifters to help track the movement of the experimental oil and see if the computer model used to map ocean currents represented the oil’s movement correctly. They found that the movement of the oil and drifters depended on the weather and sea conditions as well as the condition of the oil. When wind and sea surface were calm, the motions of the surface oil and the drifters were similar. As winds increased and small breaking waves began to appear on the sea surface, the properties of the oil changed. This change caused the oil and drifters to move away from one another.

More recently, two experiments used 1,400 drifters to understand the currents of the Gulf of Mexico. During the first experiment, scientists deployed 300 satellite-tracked surface drifters in the northeastern Gulf of Mexico over the course of a week. Drifters reported their location every five minutes for six months. During this experiment, Hurricane Isaac came through the Gulf of Mexico. This gave scientists an opportunity to collect data and study the impacts of hurricanes on ocean surface currents. Results showed that during Hurricane Isaac, the movement of water particles was six times larger than prior to the hurricane.

During the second experiment, scientists deployed 1,100 drifters to trace the small-scale currents in the open ocean environment — the largest experiment of its kind. Scientists designed the drifter to be compact to make it easier to conduct research from small boats in shallow coastal areas such as harbors, lakes, rivers, and estuaries. The experiment successfully measured small-scale ocean currents across a large geographical area using drifters (Figure 1). It also provided information that has allowed scientists to learn more about the speed and movement of surface currents. Computer
What happened to all those drifters that went into the ocean?

Normally, scientists search for and recover as many drifters as possible after an experiment has ended. However, sometimes it is not possible to collect all the drifters due to the length of time they have been in the water and the distances that they have traveled. This causes some to remain in the ocean. Scientists kept this in mind when developing the CARTHE drifter. It is the first environmentally-friendly drifter, built with 85 percent biodegradable material and 15 percent nontoxic electronics. The drifter’s body is made of a biodegradable material. Its fasteners are constructed with steel, so they eventually rust away in the ocean. The tubing is natural rubber and the battery packs do not contain lead or mercury and so are not classified as hazardous waste.9

Scientists invented an environmentally friendly, biodegradable drifter to conduct ocean current experiments. (CARTHE)

models use this information to help make them more accurate when tracking pollutants in the water.

In another study, scientists used two USVs to collect marine mammal acoustic data. The goal of the project was to improve monitoring methods as well as to investigate the impacts of the Deepwater Horizon (DWH) oil spill on nearby marine mammal populations. Each of the vehicles towed tools used to capture a range of sounds made by dolphins, beaked whales, and pygmy and dwarf sperm whales. Because USVs are very quiet, a very wide range of frequencies could be recorded at very long ranges compared to other methods. Scientists identified approximately 30 marine mammals during their study and will continue to monitor activity in the Gulf of Mexico.10

**UNMANNED AERIAL VEHICLES**

Unmanned aerial vehicles (UAVs) are becoming widely used for scientific research, law enforcement, security, natural disaster, environmental monitoring, flood damage assessment, and urban planning.11,12 They include unmanned aircrafts/drones, multirotor helicopters, and balloons/blimps of different sizes and shapes.12 UAVs offer a cost-effective way for operators to return to or continue to survey specific sites from the air, observe changes to the environment over long periods of time, and conduct surveys in hard-to-reach areas.11-13 Strict limits on where and how UAVs can be flown present challenges for use, particularly in the U.S.12 UAVs have proven to be a reliable technology well-suited for aerial investigation and oil spill response.13,14

Scientists control UAVs using remote controls or pre-program them to fly freely, reducing the risk to humans.11,12 Like USVs, UAVs can be equipped with many different sensors, cameras, GPS equipment, and other meteorological instruments.11,12 During spill response, UAVs assist in locating the source of a spill to determine proper response action and deliver high quality, real-time information.11,13 They capture aerial views, detect and monitor marine animals affected by spills, and offer information to aid in shoreline clean-up.12

Drones

Scientists used drones and rhodamine dye to examine the surf zone in the Florida Panhandle, putting the dye in the water to see how it moves. For six days, scientists flew drones directly above the surf zone to capture the beach’s response to storms and day-to-day changes. They used two drones so they could have one fully
charged and ready to fly over the same location as soon as the other drone’s battery began to reach its lower limit. This practice minimized gaps in their data and allowed them to capture multiple images that showed the movement of dye in the surf zone. The drones helped give scientists a better understanding of how water and pollutants move (Figure 2).

**Blimps and Balloons**

Blimps and balloons are low-flying, slow, long-endurance aircrafts that provide a stage to observe an area for a long period of time. Helium gas keeps them floating steady through the air. Blimps and balloons can include cameras, thermal infrared sensors, GPS equipment, and several other meteorological sensors. Tethered to a boat out in the water or to a platform on land, they can be easily and rapidly deployed while being controlled wirelessly.

One of the biggest drawbacks from in situ burning is that it creates air pollution. During clean-up efforts of the DWH oil spill, scientists used a helium-filled balloon called an aerostat to monitor air quality changes from the smoke plumes caused by burning oil. The smoke produced by in situ burning may contain high concentrations of particles and toxic gases, impacting the health of those who are exposed to them. Scientists launched an aerostat into the plumes of 27 surface oil fires over a period of four days. Its instruments sampled emissions for pollutants and continuously measured carbon dioxide. Studies such as this one provide a great representation of emission factors from these smoke plumes and help to insure the safety of responders.

**SATELLITES**

Satellites are man-made objects placed into orbit around the Earth or another body in space. Scientists use them for communications, photography, mapping, and navigation, among other things. Satellites equipped with remote sensors gather information about objects or areas from a distance, providing scientists with a new way to study the oceans. These sensors record natural energy, such as sunlight, reflected from the Earth’s surface. The remotely-sensed data captured by satellites allow scientists to study shoreline changes, ocean surface, ocean currents, waves, winds, phytoplankton, and sea surface temperature. Remote sensing plays an important role in oil spill response efforts. By using remote sensing instruments, oil can be monitored at all times. Knowing the location of a slick and its movement helps responders plan accordingly and lessen the impacts of the oil.

During the DWH oil spill, satellites tracked the movement of oil. NOAA’s Satellite Analysis Branch supplied more than 300 oil spill analyses using satellite imagery and data sets to map the location of the surface oil. The data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) and Medium Resolution Imaging Spectrometer (MERIS) helped determine the location and size of the surface oil slick. These satellite images, paired with computer models, created a system for tracking the oil.

Scientists monitored the oil using satellite synthetic aperture radar (SAR). A radar mounted on a satellite, SAR produces a series of high-resolution remote sensing images. This technology identifies and monitors sea surface oil over large remote areas. It can ‘see’ oil during...
the day or at night, through cloud cover or fog — not a common feature on most satellite sensors. During DWH, satellites took the first SAR image on April 23, 2010 (Figure 3). By that time, the oil had spread toward the northern Gulf coastline. When the wellhead was sealed on July 15, 2010, satellites had already passed over the Gulf more than 700 times, giving responders many images to monitor the spill. SAR data helped scientists calculate the total amount of surface oil and predict where it might move. To do this, they analyzed 166 SAR images collected by multiple satellites. The scientists compared these SAR results to calculate the amount of oil coming from the well and observe the impacts of response techniques. From these images, scientists determined that over the 87 days, the oil slick covered a surface area of approximately 4,300 square miles.

Scientists also use SAR images to get an accurate estimate of oil slicks caused by natural seeps, production and transportation of oil, and spills in the Gulf. They reviewed 177 pollution reports from 2001 to 2012 and, using 137 SAR images, found that oil slicks caused by the production and transportation of oil are often larger than reported.

More recently, scientists used another satellite instrument known as Visible Infrared Imaged Radiometer Suite (VIIRS) to track an oil tanker’s pathway and location. On January 6, 2018, an Iranian oil tanker collided with a grain freighter in the East China Sea, causing major fires and oil spills. After the collision, nighttime imagery collected by VIIRS helped to monitor the drifting tanker as well as the fires associated with the collision. Once the tanker sank, the instrument showed three separate fire sources the following night, indicating the drifting of floating oil on the water’s surface.

Technology continues to evolve and help scientists test, discover, and view the environment from different perspectives. The Gulf of Mexico Research Initiative (GoMRI) funds several of these ongoing studies. Emerging information is available on GoMRI’s website at http://gulfresearchinitiative.org. To access other oil spill-related publications or view the references in this publication on Sea Grant Oil Spill Science Outreach Program website, www.gulfseagrant.org/oilspilloutreach.

**FIGURE 3.** The first synthetic aperture radar (SAR) image of the DWH oil spill, taken on April 23, 2010, shows oil on the surface (black) moving toward the coast. The white outline shows the extent of oil on April 25, 2010. The red circle indicates the location of the wellhead.23

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**GLOSSARY**

**Anemometer** — An instrument that measures and records wind speed and direction at the water’s surface.

**Carbon dioxide** — A colorless, odorless gas found in our atmosphere.

**Fluorescence** — A substance absorbing light that re-emits the light as a different color.

**In situ** — Observations made at the location or original place of an incident.

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

**Remote Sensor** — A sensor attached to a satellite or aircraft that collects data and detects/classifies objects or areas on Earth.

**Rhodamine dye** — A harmless, water-soluble dye used as a water tracer.

**Small-scale** — Ocean currents that occur on spatial scales on the order of 100 meters to 10 kilometers, and times scales of day(s).

**Surf zone** — The area of the beach in which waves break.
TECHNOLOGY PROS AND CONS

Scientists must consider a number of factors when determining which unmanned surface or aerial vehicle will best suit their study.

<table>
<thead>
<tr>
<th>Unmanned Surface Vehicles</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Saildrones                | • Long range and duration for data collection of up to 12 months  
                          • Fast — travel up to 10 knots (11.5 mph)  
                          • Durable — sturdy, long-lasting, and reusable  
                          • Collect high quality data in real-time  
                          • Can endure rough weather conditions  
                          • Wind and solar powered, no use for batteries  
                          • Can include many sensors | • Cannot sample water at depth  
                          • Require specialist to operate |
| Drifters                  | • Come in many different sizes, allowing deployment from multiple locations  
                          • Contain GPS units to track position | • Difficult to recover after deployment  
                          • If not biodegradable, can pollute the ocean environment  
                          • Must deploy many at a time |

<table>
<thead>
<tr>
<th>Unmanned Aerial Vehicles</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Drones                  | • Can be equipped with many sensors  
                          • Come in many sizes | • Strict limits on where and how they can be flown  
                          • Duration limited by battery power  
                          • Sensors compact due to limited space  
                          • Cannot operate in windy conditions  
                          • Difficult to operate at night |
| Blimps and Balloons    | • Observe changes over long periods of time from various altitudes  
                          • Can be equipped with many sensors  
                          • Free of vibration, which is better for images | • Height of flight limited by length of cable and flight path restrictions  
                          • Use helium to stay inflated so occasionally need to be brought down and refilled |

REFERENCES

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OIL SPILL SCIENCE OUTREACH TEAM

Christine Hale
Texas Sea Grant College Program
chris.hale@tamu.edu

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Missy Partyka
Mississippi-Alabama Sea Grant Consortium
m.partyka@auburn.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
ladon.swann@usm.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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SUGGESTED CITATION

STAFFORD ACT OF 1988
The Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1998 was intended to establish an orderly means of providing federal natural disaster assistance to state and local governments.1 The Stafford Act authorizes the delivery of federal aid to communities and individuals during declared major disasters or emergencies, such as hurricanes or terrorist attacks. A major disaster can be characterized as any natural catastrophe or — regardless of cause — any fire, flood, or explosion that produces severe damage in the United States. An emergency is defined as an instance where state, local, and non-governmental disaster relief efforts require federal assistance to alleviate damage, loss, hardship, or suffering.1 The President may declare a major disaster or emergency when not enough state or local resources are available.2

Three types of assistance are authorized by the Stafford Act:

- **Individual assistance** — Provides immediate direct and financial assistance to individuals for housing and other disaster-related needs.
- **Public assistance** — Provides assistance to state and local governments and certain private nonprofit organizations for emergency work and for repair or replacement of disaster-damaged facilities.
- **Hazard mitigation** — Provides grants to state and local governments for actions taken to prevent or reduce long-term risk to life and property from natural hazards.1

When a major disaster or emergency is declared, the National Response Framework will likely be activated.

Some Gulf beaches required extensive cleanup after the Deepwater Horizon oil spill. Federal laws clarify how response efforts work and who pays for them. (Louisiana Sea Grant)

The National Response Framework outlines planning assumptions, policies, concept of operations, and organizational structures. It also describes resources federal agencies can use to support initial emergency lifesaving functions if state and local government response capabilities are overwhelmed.1 The involvement of the Federal Emergency Management Agency (FEMA), the agency that administers disaster relief, depends on the scope and cost of the disaster and whether federal employees must be reassigned to manage it.2
OIL POLLUTION ACT OF 1990

Federal response to oil spills dates back to 1924, when the first Oil Pollution Act (OPA) was established. OPA ‘24 was amended by the Clean Water Act, which was the primary federal statute governing oil spills prior to OPA ‘90. OPA ‘90 expanded the existing Clean Water Act. It created new requirements regarding oil spill prevention and response. 3

OPA strengthens the federal government’s ability to prevent oil spills, ensures that oil is cleaned up, and restores any natural resources impacted by a spill.2 It requires shippers, offshore producers, storage facilities, and the federal government to develop oil discharge response plans for local areas.4,5 OPA significantly increases the range of covered damages and assigns liability to a responsible party for all cleanup costs.3 The federal government ensures responsible parties restore the environment and pay the public for its losses, overseeing a spill’s compensation until natural resources fully recover.2

Responsible parties are liable for removal costs and damages that result from the incident and a range of other costs, including:
- injuries to natural resources,
- loss of real personal property,
- loss of subsistence use of natural resources,
- lost government revenues resulting from destruction of property or natural resource injury, and
- lost profits and earnings resulting from property loss or natural resource injury, and costs of providing extra public services during or after spill response.3

OIL SPILL LIABILITY TRUST FUND

If the responsible party is unable or unwilling to pay, the Oil Spill Liability Trust Fund (OSLTF) pays for removal cost, natural resource damages, and other economic and property damages. The OSLTF is funded by environmental taxes on petroleum, penalties for discharges of petroleum in violation of the Clean Water Act, and funds recovered by the OSLTF from responsible parties. It contains a maximum limit of one billion dollars per incident, with a sub-limitation of 500 million dollars for natural resource damage assessments and claims associated with an incident.3,6

Costs include any actions necessary to mitigate injury to public health or welfare. OPA sets responsible party liability limits in place that differ based on the source of the spill. Some spills may incur a simple dollar amount cap, while others have unlimited liability for cleanup costs with limits on other damages.3,6

When a spill happens during a coastal storm, oil spill response falls within the larger storm response. The National Contingency Plan, the federal plan for responding to hazardous material releases, could be used under the National Response Framework to address an oil or chemical spill during a storm. The liability of responsible parties remains the same.

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gulfseagrant.org/oilspilloutreach

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STORMS AND SPILLS

Coastal storms can trigger oil and chemical spills. Learn what to do if a storm causes a spill near you.

HOW DO STORMS CAUSE OIL SPILLS?

Strong winds and flood waters can damage coastal oil facilities, like storage tanks or refineries, and make boats leak fuel. High tides, rain, and winds raise water levels and cause storm surge, which can damage levees, bridges, roads, homes, businesses, industrial facilities, and pipelines. Coastal storms are a major concern during ongoing oil spills. When a storm's path crosses an existing spill, storm surge can carry oil or oil-covered debris onto the coastline or beyond. However, storms can also help disperse existing oil spills when high winds and rough seas mix the water's surface, breaking up the oil slick before it comes ashore.

WHAT ARE THE POTENTIAL IMPACTS OF STORM-DAMAGED OIL RIGS AND VESSELS?

In most cases, damaged vessels have oil on board and need to be removed from the water. In addition to potentially leaking oil, sunken oil drilling platforms also pose safety risks for boats out on the water. During Hurricane Rita, several oil platforms sank in the Gulf. Months later a barge struck a sunken platform and caused nearly two million gallons of oil to spill into the surrounding waters.

WHAT CAN BE IN A STORM’S FLOOD WATERS?

Potential sources of pollutants following flooding from a storm include raw sewage, bacteria, oil, heavy metals, pesticides, toxic chemicals, gasoline, decaying vegetation, and other materials. Eating, drinking, or touching contaminated water can cause illness and infection. Lingering floodwaters after a hurricane increase health risks to residents and rescuers. While pollution in flood waters eventually dilutes, taking extra precautions, such as practicing good hygiene and avoiding standing water, can prevent problems.

WHO SHOULD I CONTACT TO REPORT A SPILL?

Residents should read resources from FEMA, NOAA, and USCG to find out how to best prepare for a storm and help minimize the chances of a spill. However, if a chemical release or oil spill does occur, contact the National Response Center 24 hours a day at 1-800-424-8802. Be prepared to include the following:

- your name, location, organization, and telephone number;
- date, time, and location of incident;
- source and cause of the release or spill; and
- types and quantities of materials spilled.

Not sure when to report an oil or chemical spill? Check out the spill reporting requirements on EPA's website at https://www.epa.gov/emergency-response/when-are-you-required-report-oil-spill-and-hazardous-substance-release.
1989

HURRICANE HUGO

Caused two major oil spills on the island of St. Croix, U.S. Virgin Islands, by damaging a discharge line near the bottom of a storage tank and causing it to release one million gallons of oil.8

2005

HURRICANES KATRINA AND RITA

Passed through the center of the Gulf of Mexico’s oil industry within a month’s time of one another, causing dozens of major oil spills and thousands of smaller spills due to direct wind action and flooding.9 During Hurricane Katrina, dikes surrounding oil tanks at the Murphy Oil refinery in St. Bernard Parish, Louisiana, filled due to storm surge and failed, releasing approximately 1.05 million gallons of oil into nearby neighborhoods.1,2,10 Storm surge from Hurricane Rita swept oil storage tanks into nearby yards.

2012

HURRICANE ISAAC AND TROPICAL CYCLONE SANDY

Impacted two coastal regions. During Isaac, Gulf residents reported 158 oil spills and 171 objects possibly containing hazardous materials to the U.S. Coast Guard. These objects ranged in size from several gallons to 60,000 gallons.11 Sandy caused oil, hazardous materials, and oil-covered debris to spread across waterways and ports along the Mid-Atlantic.11,12

2017

HURRICANE MARIA

Crashed through the U.S. Virgin Islands and Puerto Rico. It brought strong winds and heavy rains to the islands causing catastrophic damage and flash flooding. Though Maria did not produce any large-scale pollution events, thousands of damaged vessels were left behind, causing small pollution incidents. Responders removed about 12,500 gallons of fuel and oil waste in the U.S. Virgin Islands and 16,000 gallons of oily water in Puerto Rico.13

SPILLS FROM PAST STORMS

REFERENCES


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June 2018
Work or play along the Gulf coast? Know what to do in the event of an accidental spill.

**MAINTAIN** your boat’s engine, making sure that fuel lines are attached and undamaged. Faulty lines are the source of many small spills.

**TAKE CARE** when fueling. Whether at the dock or on the water, accidents occur due to distracted operators missing or overfilling the tank or hands-free fueling clips not operating correctly.

**PROTECT** yourself in the event of an oil or fuel leak while boating. Turn off electricity to prevent sparking and always have a fire extinguisher on board. Avoid inhaling fumes and keep gloves available if you must handle toxic chemicals.

**PURCHASE** oil absorbent cleanup materials at boating stores and keep on board to prevent and contain spills.

*Oil absorbent booms, sheets (bottom), and pads can be kept on your boat to catch leaks under the engine or to contain and remove oil at the surface of the water (back). Bilge socks (top) trap any oily overflow on board, making safe disposal easy. (MASGC/Tara Skelton)*

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**BE PREPARED**

Absorbent pads remove oil safely. Never use household detergents, as they harm sea life and can incur large fines.

*(Florida Sea Grant)*
WHAT TO DO IF YOU SEE A SPILL

**ALERT** the authorities. By law, you must notify both the National Response Center and the state agency of any spill, no matter how small.

**SOAK UP** oil from the water using the cleanup materials described on the previous page.

**STORE** all used oil and oily absorbent materials in a closed container labeled “Used Oil.”

**DISPOSE** of used oil and oily absorbent materials at authorized locations:

- Local governments often host regional “Household Hazardous Waste Day” events.
- Some businesses like supercenters, oil change stations, and other types of automotive centers take used oil.

MAKE THE CALL

Boaters must report all spills to the National Response Center at **1-800-424-8802** and to the state hotline.

- ALABAMA: 1-800-843-0699
- FLORIDA: 1-800-320-0519
- LOUISIANA: 1-877-925-6595
- MISSISSIPPI: 1-800-222-6362
- TEXAS: 1-800-832-8224

LOCATE AN OIL DISPOSAL SITE

Go to the following website to find out where in your community to dispose of used oil.

**EARTH 911** — [http://search.earth911.com/](http://search.earth911.com/)

Use the search term ‘motor oil’ and your zip code to find the nearest oil recycling location.

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After alerting the authorities, use the oil-absorbing products you have on board to remove toxic chemicals from the water (above). If it is a smaller spill, officials may tell you to clean it yourself to the best of your ability. If larger, they may send help. By law, all waste oil, including oiled absorbent materials, must be disposed of safely in designated locations (right).
The 2010 Deepwater Horizon oil spill left many tourists and residents questioning if oil and the dispersants used to keep oil from reaching the shore could make them sick. Scientists studied the health risks of lingering chemicals from the spill.

**ARE BEACHES SAFE TO VISIT?**
Scientists tested oil samples and looked at risks that could occur from having the oil on your skin, eating it accidentally, or breathing the fumes while at the beach. Learn more about what they found on the next page.

**IS THE WATER SAFE FOR SWIMMING?**
Scientists tested offshore and nearshore waters for chemicals found in oil and dispersants. Learn more about the results of their studies on the next page.

**IS GULF SEAFOOD SAFE TO EAT?**
Multiple government agencies tested more than 22,000 seafood samples for chemicals found in oil and dispersants. Learn more about these samples on the next page.

**IF YOU COME IN CONTACT WITH OIL OR TAR AT THE BEACH —**
- Wash the area with soap and water, baby oil, or cleaning paste sold at auto parts stores.
- Do not use solvents, gasoline, kerosene, diesel fuel, or similar products on your skin. These products are worse for your health than the oil.
Oil washed onto nearly 600 miles of Gulf Coast beaches in 2010. Scientists collected oil samples from sandy beaches after the spill to see if lingering chemicals were at levels harmful to humans. They also tested sites in heavily oiled areas five years later to look at longer-term effects. In both cases, studies suggested that exposure to weathered oil, impacted sand, or tar balls after the oil spill would not have a negative effect on humans. The amount of sandy oil pieces found on beaches has decreased since 2010. However, a small amount of oil remains because what is left is hard to find and remove.

Scientists sampled coastal waters for chemicals found in oil during the spill and through the following summer. When scientists added up the total amount of all harmful oil chemicals they found, the level was 10 times lower than levels known to harm humans. During the spill, emergency responders applied dispersant at the wellhead and to oiled surface waters more than 3.45 miles from shore. The highest level of the main dispersant chemical of concern was 100 times lower than the levels known to cause harm to the human liver.

During the spill, federal and state agencies tested samples to ensure seafood was safe to eat. Seafood had to pass visual, smell, taste, and chemical tests in order for the waters to be reopened for fishing. By making sure the chemicals were below harmful levels, the U.S. Food and Drug Administration (FDA) could determine when Gulf seafood was safe to eat.

Oil contains many chemicals, some that are harmful and some that are not. The highest level of cancer-causing chemicals in seafood was more than 400 times lower than the levels the FDA considers unsafe. According to the FDA, the dispersants used during the spill were not likely to build up in seafood and were low in human toxicity. All seafood samples tested for dispersant chemicals were below the FDA level of concern.

Since the Deepwater Horizon oil spill, scientists have improved their ability to detect specific types and levels of chemicals in seafood that are of concern when an oil spill occurs.

REFERENCES
CREATING HEALTHY COMMUNITIES TO OVERCOME OIL SPILL DISASTERS

How are communities impacted by disasters?

**Natural disasters** can devastate communities. Community members can be displaced from their homes and become overwhelmed figuring out how to rebuild their lives. Despite these challenges, community members tend to respond to natural disasters in a more positive way than human-caused disasters. They come together and help one another rebuild their lives.¹²

**Human-caused disasters**, such as accidental oil spills, tend to break down even the strongest communities. Impacts to human health, the environment, and the economy – whether real or perceived – may lead to additional stress and anxiety among community members.¹²³

“What when hurricanes happen ... it pull[s] people together—there is nothing to gain by exploiting the situation. I have seen the BP experience bring out the worst in people ... It has divided ... this community ... because it brought competition and jealousy ... ”¹²

What can we do to help communities during and after an oil spill?

**Worry and stress rises**
The mental health of residents can be negatively impacted by an oil spill, especially for those directly affected. People in the oil, fishing, and tourism industries may lose their source of income and face uncertainty about how long the loss may last.³ Oil spills also come with physical health risks, which can be real or perceived.⁴⁵

**Pointing fingers is common**
During a human-made disaster, blame and distrust can extend farther than just the responsible party. Certain groups might be more distrustful of leaders due to prolonged or uncertain impacts, cleanup efforts, and bad feelings over past regulations.²⁶

**Compensation causes conflict**
Compensation programs can lead to confusion and competition. Residents can perceive others’ payments for lost income as unfair. They also may compare their claims, compete for funds, and become stressed about financial uncertainty - all which can hinder recovery.¹²
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.

MASGP-18-010

GOMSG-G-18-001

Help yourself and others

- Call the Disaster Distress Helpline at 1-800-985-5990 or text TalkWithUs to 66746.
- The Department of Homeland Security lists resources about health, safety, coping, and helping others: https://www.ready.gov/recovering-disaster
- Peer listening provides a support network during a disaster: http://masgc.org/peer-listening

Get accurate, up-to-date information

Contact or follow these agencies:
- Your local Sea Grant program can provide science-based information: http://seagrant.noaa.gov/
- NOAA’s Office of Response and Restoration works with the US Coast Guard during oil spills: https://response.restoration.noaa.gov/about/orr-field-staff.html
- NOAA Incident News tracks the status of oil spills around the nation: https://incidentnews.noaa.gov/

Clarify the compensation process

- The National Pollution Funds Center lists the process for submitting oil spill claims: https://www.uscg.mil/Mariners/National-Pollution-Funds-Center/Claims/

REFERENCES


ACKNOWLEDGMENT

Special thanks to the many external reviewers who contributed to the betterment of this oil spill science outreach publication.
THE DEEPWATER HORIZON OIL SPILL’S IMPACT ON GULF SEAFOOD

Larissa J. Graham, Christine Hale, Emily Maung-Douglass, Stephen Sempier, LaDon Swann, and Monica Wilson

Even five years after the Deepwater Horizon oil spill, consumers have concerns about whether Gulf seafood is safe to eat. Federal and state scientists tested more than 22,000 seafood samples during the oil spill and did not find a single sample where levels of chemicals from oil or dispersants were unsafe. Scientists are still conducting studies to ensure that the seafood harvested from the Gulf is safe to eat.

Scientists have found that eating seafood is good for people’s health and recommend that most people eat two servings of seafood, about the size of the palm of your hand, each week. However, experts encourage pregnant women, young children, elderly individuals, and those with certain health conditions to avoid eating some types of seafood. This includes seafood that is raw, partially cooked, or that which tends to be high in mercury concentrations. Fish with high mercury include tilefish, shark, swordfish, and king mackerel.

If seafood is good for our health, then why are there recommended limits to the amount of some types of seafood we should eat? Seafood, like other foods that we eat, can be exposed to contamination through the natural environment, pollutants, oil and chemical spills, and processing and handling procedures. The U.S.
Food and Drug Administration (FDA) provides guidelines for the types and amount of seafood that we should eat. For most people, the risk of ingesting low levels of contaminants from food is not a concern because their body can break the chemicals down.²³

**CONCERNS AFTER THE DEEPWATER HORIZON OIL SPILL**

During the Deepwater Horizon oil spill, about 172 million gallons of Louisiana sweet crude oil spilled into Gulf of Mexico waters. In addition, a total of 1.84 million gallons of Corexit, a dispersant, was used to break up oil at the sea surface and at the wellhead almost a mile below the water’s surface.⁴⁻⁷,⁸ The release of oil and use of dispersants raised public concern about eating seafood from the Gulf of Mexico despite federal and state reassurance that seafood was safe to eat. Federal and state agencies temporarily closed fishing waters in areas where oil was found or was predicted to travel based on currents and wind conditions.⁹ At one point, 88,522 square miles or 36 percent of U.S. Gulf of Mexico waters were closed to fishing.¹⁰

Oil contains many chemicals, some that are harmful in small doses and some that are not. Certain **polycyclic aromatic hydrocarbons**, or PAHs, for example, can cause mutations, developmental defects, or cancer in wildlife and humans.⁹ Crude oil and drilling fluids that are used to extract oil contain different types of metals, such as arsenic, mercury, copper, and lead, and scientists have found many of these metals at elevated levels in the sediments in oil spill zones.¹¹ These chemicals and metals can build up in marine organisms and reach levels of concern that make seafood unsafe to eat.¹¹

According to the FDA, the dispersants that were used during the Deepwater Horizon oil spill have low potential to build up in seafood and are low in human toxicity, so there was likely little public health risk associated with eating seafood exposed to dispersants.⁹ However, dispersants break up oil slicks into smaller droplets, which can cause an increase of oil in the water column. Wildlife can take up these smaller droplets, potentially increasing the exposure to PAHs.¹²

![Image](https://example.com/image.png)

**FIGURE 1.** During an oil spill, different types of marine life that we eat as seafood will be exposed to varying levels of oil-derived chemicals based on where they live, feed, and breed and how mobile they are.¹¹ Some aquatic animals are better at breaking down chemicals such as polycyclic aromatic hydrocarbons (PAHs) than others.¹¹ Credit for images: ©1992, Diane Rome Peebles (flounder image) and Jane Hawkey, Chip Chenery, Tracey Saxby, and Dieter Tracey, IAN Image Library (all other images; ian.umces.edu/imagelibrary)/.

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<td><strong>Finfish</strong></td>
<td>More mobile</td>
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<td></td>
<td>• Are mobile and can swim away from contaminated areas.</td>
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The following table outlines the mobility and potential build up for different types of seafood:

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**FIGURE 1.** During an oil spill, different types of marine life that we eat as seafood will be exposed to varying levels of oil-derived chemicals based on where they live, feed, and breed and how mobile they are.¹¹ Some aquatic animals are better at breaking down chemicals such as polycyclic aromatic hydrocarbons (PAHs) than others.¹¹ Credit for images: ©1992, Diane Rome Peebles (flounder image) and Jane Hawkey, Chip Chenery, Tracey Saxby, and Dieter Tracey, IAN Image Library (all other images; ian.umces.edu/imagelibrary)/.

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ROUTES OF EXPOSURE TO CHEMICALS

Chemicals from oil or dispersants can contaminate seafood in a variety of ways. An animal can eat oil droplets or eat other animals that have been exposed to chemicals. Chemicals can also be absorbed through the skin or gills or attach to the skin of an animal. The amount of a chemical that an animal comes in contact with depends on many things, such as how the organism feeds and where it lives (Figure 1). Once contaminants are in an organism’s system, they can build up, or bioaccumulate, over time. An organism can reduce the amount of bioaccumulation by processing, breaking down, and removing the chemicals through their waste or, in some organisms, chemicals can leave the body through processes in their organs and tissues (Figure 1). Vertebrates, such as fish, and invertebrates, such as crabs, oysters, and shrimp, have the ability to break down the chemicals in oil, but some do it better than others. Invertebrates break down petroleum chemicals more slowly and not as well as other animals. This inefficiency can cause PAHs to accumulate in their tissues. Finfish, on the other hand, can rapidly break down and remove PAHs from their bodies. However, it is important to note that organs, such as the liver and gall bladder which help remove chemicals from a fish’s body, may have higher levels of PAHs than muscle and other tissues (Figure 1).

AGENCIES DEVELOP A PLAN TO ENSURE SEAFOOD SAFETY

During the Deepwater Horizon oil spill, federal agencies, such as the National Oceanic Atmospheric Administration (NOAA), FDA, and U.S. EPA, worked with the Gulf of Mexico states to develop and implement a program to ensure Gulf seafood safety.

First, the FDA set a level of concern for PAHs and dioctyl sodium sulfosuccinate (DOSS), a chemical that is found in dispersants, for different types of seafood. The level of concern determines how much of a certain chemical will harm a human. By testing seafood samples and making sure the chemicals are below these levels of concern, the FDA can determine if Gulf seafood that might have been exposed to oil or dispersants is safe to eat. The levels of concern were calculated based on the average weight and age of consumers and amount of seafood people eat and how often they eat it. 

CRITIQUES TO THE FDA LEVEL OF CONCERN

Some groups of people are at higher risk to the effects of chemical exposure than others. For example, a healthy adult that eats fish twice a week will not have the same health risk as a young child with a lower body weight, an elderly adult with compromised health, or a person who eats fish for every meal. Due to these differences, risk assessments often err on the side of caution or scientists conduct additional assessments for these subpopulations. During the oil spill, some scientists had concerns about FDA’s protocol for reopening fishing areas. They suggested that average consumer body weight and how much seafood Gulf coast residents eat daily were not accurate. They also suggested that more studies should be conducted to look at the health risks for children and pregnant women and that the levels of concern should be more conservative to protect people falling outside of the averages used in the FDA’s protocol.
FIGURE 2. Federal and state agencies set up a method for sampling, testing, and reopening closed harvest waters. Waters were reopened when they had no visible oil present and seafood samples that were collected passed sensory and chemical testing. Credit for images: Kim Kraeer, Lucy Van Essen-Fishman, Jane Hawkey, Tracey Saxby, Diana Kleine, and Jason C. Fisher, IAN Image Library (ian.umces.edu/imagelibrary).
Separate levels of concern were set for shrimp and crabs, oysters, and finfish because consumers eat varying amounts of these types of seafood.\textsuperscript{16, 17}

The federal and state agencies then developed a set of guidelines for sampling, testing, and reopening fishing grounds in both federal and state waters (Figure 2).\textsuperscript{9, 16} Seafood was not tested from an area until signs of fresh oil from the Deepwater Horizon spill were no longer visible.\textsuperscript{9} Filets of finfish, edible blue crab tissue, whole oysters, and the edible parts of shrimp were all tested. A sample could be made of one animal or multiple animals. A legal size fish, for example, could be tested alone or smaller fish from the same area could be combined to make a complete sample. Multiple oysters, shrimp, and blue crabs were also combined, by seafood type, to make a complete sample. The samples had to pass a smell and taste test and a chemical test to be sure that PAHs and DOSS were below the FDA’s level of concern.\textsuperscript{16}

According to the guidelines, officials would reopen the sampled areas that passed all of the tests.\textsuperscript{16}

Due to public concern, the FDA also tested crabs, oysters, and shrimp in some harvest waters for elevated levels of mercury, arsenic, cadmium, and lead.\textsuperscript{20} The NOAA Mussel Watch program, a long-term program that monitors the amount of metals and other contaminants in seafood, also conducted two rounds of sampling in 2011. Scientists tested oysters for levels of arsenic, cadmium, lead, mercury, copper, nickel, selenium, and vanadium and then compared these levels to 30 years of data that had been collected previously through this program.\textsuperscript{20} Officials reopened all federal waters by April 19, 2011, based on visual, sensory, and chemical testing of seafood samples.\textsuperscript{21} Some areas in state waters remained closed after this date. Heavily oiled areas in Barataria Basin in Louisiana, for example, were not reopened to fishing until June 2015 because of oil contamination.
Through the multi-agency program, more than 8,000 seafood samples were collected and tested. All chemical tests for PAHs and DOSS were much lower than the established level of concern that was set by FDA or not detected at all (Table 1). The FDA’s additional testing for metals showed that there were not elevated levels of metals in crabs, oysters, shrimp, or mussels.

Four of the states in the Gulf of Mexico received funding to conduct their own sampling in state waters (Figure 3). The states tested finfish, shrimp, crabs, and oysters for PAHs and DOSS. Of the more than 13,500 samples tested, not a single sample contained PAHs or DOSS above the FDA’s level of concern.

Independent scientific studies also indicated that seafood was safe to eat in addition to the state and federal seafood testing. One study collected reef fish from commercial sites that were open to fishing. Scientists tested the seafood samples for PAHs, DOSS, and metals (lead, cadmium, mercury, arsenic, and selenium). All PAH levels in the 96 samples were below the FDA’s levels of concern. Dispersants were not detected in any samples, and metal levels were undetectable or similar to levels reported pre–DWH oil spill.

Some scientists were concerned with the health risk to Vietnamese–American communities that may eat more seafood and were suspected to fall outside of the average body weight used to determine the level of concern for PAHs. Scientists contacted consumers to ask about their seafood consumption and potential health risks and also testing shrimp from reopened fishing grounds to measure levels of PAHs. The study determined that the Vietnamese–American consumers weighed less than the average body weight used in calculating the FDA’s levels of concern. It also found that the consumers ate more than three times the amount of shrimp used in the FDA’s risk assessment.
FIGURE 3. Federal and state agencies tested seafood for polycyclic aromatic hydrocarbons (PAHs) and dioctyl sodium sulfosuccinate (DOSS), a chemical in dispersants after the Deepwater Horizon oil spill. Finfish, shrimp, oysters, and crabs were sampled in the federal program and by all state programs. Florida also tested clams and lobsters. Of the more than 22,000 seafood samples tested, none contained PAH or DOSS concentrations above the Food and Drug Administration Level of Concern (LOC).25, 26, 27, 28, 29

for the underestimates in weight and level of seafood consumption, this study did not find any health risks based on the low levels of PAHs that were detected in the shrimp samples.19

Scientists are still studying Gulf coast residents and testing the seafood that they catch or buy at the market. These studies are looking at long-term health impacts so the results may not be out for some time.

ONGOING STUDIES CONTINUE TO MONITOR SEAFOOD

Federal and state monitoring and independent studies have shown low levels of PAHs, DOSS, and metals in seafood from the Gulf of Mexico. The Gulf of Mexico Research Initiative (GoMRI) has funded studies to look at the short-term and long-term impacts on fish populations and human health. Emerging information can be found on GoMRI’s website, http://gulfresearchoptivity.org.

To learn more about how oil and dispersants impact aquatic life and how these organisms break down these chemicals, refer to our other publications, which can be found on the Oil Spill Science Outreach Program website at http://gulfseagrant.org/oilspilloutreach.
REFERENCES


SUGGESTED CITATION

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university-based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10-year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20-member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

The impacts of the Deepwater Horizon oil spill stretched beyond the Gulf of Mexico’s waters, plants, animals, and habitats. It affected the mental health of some residents along the Gulf Coast. The impacts varied based on what kind of job a person had, how attached they were to the place they lived, and how many disasters they had lived through prior to the spill.

Scientists have found that the oil spill had an impact on the mental health of some coastal residents, cleanup workers, and those that relied on the Gulf for income. (NOAA)

The Deepwater Horizon oil rig exploded on April 20, 2010, killing 11 workers and injuring others. Oil flowed from the wellhead for 87 days before emergency responders could cap it. During this time, approximately 172 million gallons of crude oil flowed into Gulf of Mexico waters.¹ ² ³

The oil spill affected coastal communities of the Gulf of Mexico in many ways. Some people who relied on the Gulf for work lost income and business...
opportunities during the oil spill. Other coastal residents and cleanup workers were directly exposed to oil and witnessed the impact it caused to the shoreline and Gulf waters.\textsuperscript{2,4,5,6}

After the oil spill, several studies examined the mental health impacts of the oil spill on people living along the Gulf Coast. Scientists documented short-term mental health impacts, but the long-term impacts have been harder to identify. Scientists are also developing new ways to determine how exposure to disasters, such as oil spills, impacts the physical and mental health of communities.\textsuperscript{7}

**COASTAL RESIDENTS FEEL THE EFFECTS OF THE OIL SPILL**

*Scientists start to document impacts*

The oil spill affected the mental health of some residents living along the Gulf Coast.\textsuperscript{4,6,8-15} However, the level of impact varied across the spectrum. Negative mental health impacts were most common in people whose work, family, or leisure life was impacted by the spill. Residents reported feeling depressed, anxious, and suffering from post-traumatic stress disorder.\textsuperscript{3,15,16,18,19}

Impacts were strongest immediately after the spill and decreased over time.\textsuperscript{8} Levels of depression, mental illness, and stress that some residents experienced were above the national average even two years after the spill.\textsuperscript{9}

Scientists saw that even some residents in oil-free Gulf communities were anxious or depressed. These residents worried about the oil spill’s impact on the environment, human health, and seafood safety.\textsuperscript{10,16}

*Loss of income results in stress and anxiety*

The oil spill impacted the fishing and seafood, tourism, and oil and gas industries. Government agencies closed oiled waters to recreational and commercial fishing; visitors canceled their vacations; and the government stopped offshore drilling projects for six months.

Residents that relied on these industries for their source of income or had lost income because of the oil spill were more likely to feel anxious or depressed,

\textbf{In Mississippi}, some coastal residents experienced worsened financial situations, social relationships, and health issues including more mentally unhealthy days compared to residents in the rest of the state.

\textbf{In Alabama}, some coastal residents felt stress, anxiety, and depression and had more mentally unhealthy days compared to residents in the rest of state. Residents were also worried about air quality, safe seafood and their income or economic future.

\textbf{In Louisiana}, the oil spill disrupted the work, school, and social life of some coastal residents, which resulted in symptoms of anxiety, depression, and posttraumatic stress.

\textbf{In Florida}, some coastal residents felt anxious and depressed especially if they experienced income loss from the spill. These feelings were observed even in areas where oil did not reach the shore.

\textbf{Regionally}, some coastal county residents reported decreased income, lost jobs, and a disruption in their work or family life, which resulted in mental health distress in themselves and their children. People that relied on the jobs connected to the Gulf were more likely to suffer from negative mental health symptoms after the oil spill.

Of these industries, negative impacts were more common in fishing communities.
drink more, or have more thoughts of suicide than other residents.\textsuperscript{5,6,8,10-13,16-22} Residents living below the poverty line were more likely to suffer from depression, anxiety, and stress than those with higher incomes.\textsuperscript{20}

Mental health impacts from income loss were not limited to adults. Parents that had income loss due to the spill were 1.5 times more likely to report new physical or mental health problems in their children. When digging deeper, scientists found that these health problems were not only due to the oil spill. These families also faced economic pressures independent from the oil spill and lacked access to programs to help overcome adversity. Scientists believe that these factors may also have contributed to mental and physical health problems.\textsuperscript{17}

The oil spill hits the fishing industry hard

People with ties to fishing were more likely to have higher levels of stress than others who also relied on the Gulf for a source of income.\textsuperscript{8,12,13,18,19,22} State and federal agencies closed fishing grounds while they monitored the spread of the oil slick and tested seafood samples to ensure safety. Many people who worked in the fishing and seafood industries were out of work during this time. Officials reopened all federal waters by April 19, 2011, based on visual, sensory, and chemical testing of seafood samples.\textsuperscript{24} However, some heavily oiled areas in Barataria Bay in Louisiana state waters were not re-opened to fishing until June 2015 because of oil contamination.

The fishing industry also had other concerns in addition to the closure of fishing grounds. Members wondered about the long-term effects on fish populations and whether consumers would believe that seafood was safe to eat.\textsuperscript{8,22} A year after the spill, scientists saw that residents in counties with strong ties to fishing were more stressed and more worried about their economic futures than people in counties with strong ties to tourism. The tourism industry appeared to be recovering after the spill whereas questions lingered about how long it would take the fishing industry to do the same.\textsuperscript{18,19}

CORROSIVE COMMUNITIES AND RESILIENT COMEBACKS

Competition leads to negative feelings

“There are people that are abusing the system and everybody coming out of the woodwork to try to get that money. They try to get their hands on that money, which is sickening really to the people that actually need it and aren’t getting what they deserve.” – Study participant, After the BP Deepwater Horizon oil spill: Financial and health concerns among coastal residents and commercial fishers.\textsuperscript{22}

The oil spill was not the first disaster to hit residents that lived along the Gulf Coast. These communities were hit hard by natural disasters, such as Hurricane Katrina and Hurricane Rita in 2005. The Deepwater Horizon oil spill was different. It was not a natural disaster but a technological, man-made disaster.

Natural disasters tend to create therapeutic communities. These types of disasters are typically deemed
“nobody’s fault” and people come together to support one another and rebuild.\textsuperscript{25} Technological disasters, on the other hand, tend to lead to \textbf{corrosive communities} as victims try to fix blame. Victims can become suspicious and cynical toward those they feel are responsible for the disaster.\textsuperscript{25}

BP, the \textbf{responsible party}, implemented a claims process after the oil spill to help offset some economic losses.\textsuperscript{23,27} BP also created the \textbf{Vessels of Opportunity} program to hire fishing crews to assist with cleanup efforts. These programs were created to ease stress by reducing or eliminating economic concerns. However, in some cases, the effects of the compensation process led to corrosive communities.\textsuperscript{10,27}

Some residents were frustrated with the claims process and did not trust it. They felt that the amount of compensation people were given was determined at random, even with identical claim statements. Other residents felt as though the selection for the Vessels of Opportunity program was arbitrary and should hire fishing crews that were out of work. Many residents complained about “spillionaires,” who they felt unfairly profited from payment. These inequalities led to conflict, jealousy, and competition between members of some communities.\textsuperscript{10,25}

\textbf{Community attachment can help and harm}

Community attachment, or how close community members feel to one another and the place where they live, can play into the amount of time that it takes a community to recover after a disaster. Community attachment can be a good thing because it implies that a strong and caring network is in place that can help people recovery from disaster. A group of scientists talked with residents who had a strong attachment to their communities. A year after the spill, they found that these residents were recovering more quickly than other residents that were not as attached to their communities.\textsuperscript{8}

However, community attachment can also cause strain. Scientists saw that residents more attached to their community and part of the fishing and seafood industries had a harder time recovering after the spill. They felt angry, worried, anxious, depressed, sad, nervous, and afraid even a year after the spill.\textsuperscript{8} This may be because residents tied to the fishing industry were still facing hardships. The attachment to their community also may have
made them less likely to want to leave their home, even when the oil spill was threatening their way of life. Additionally, their social network was probably made up of others that felt the same way. This could have contributed to a cycle of negative outlooks and stress.\textsuperscript{12}

\textbf{Gulf of Mexico communities overcome diverse disasters}

A person’s ability to “bounce back” after a hard time, also known as resilience, can lead to quicker recovery after a disaster. The personal impact of a disaster will depend on several factors. These factors include how exposed people are to a disaster, the ways they cope with adverse situations, and the type of community they live in.\textsuperscript{6} Many studies have described the impact that the oil spill had on people who lived through other disasters, such as Hurricane Katrina.\textsuperscript{14,28-30} Scientists are also examining how biological factors, such as the brain, play into the impact on and recovery of a person exposed to a disaster.\textsuperscript{26}

Individuals with low income or less social support were more likely to experience negative impacts in the years after both natural and man-made disasters. The same was true for those who practiced their religion daily, either alone or with others in prayer groups. Those who worshipped daily were nine times more likely to suffer from post-traumatic stress symptoms than those in their community who did not practice religion. These people were not necessarily suffering because they were lonely or isolated. Instead, scientists believe they may have begun practicing religion after the disaster for comfort, a sense of meaning, and perhaps in an effort to heal. Informal religious activities may be common after a disaster, especially if wind or water has destroyed church buildings.\textsuperscript{30}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{HurricaneKatrina.jpg}
\caption{The fishing industry suffered much damage from Hurricane Katrina in 2005. (NOAA)}
\end{figure}
Scientists interviewed residents in southeastern Louisiana that were impacted by the Deepwater Horizon oil spill and also lived through Hurricane Katrina and other traumatic experiences. People that suffered from anxiety, depression, or post-traumatic stress during Katrina were more likely to experience the same feelings after the oil spill. However, residents that experienced multiple disasters were able to rebound faster and had better mental health outcomes in the long run. Scientists suggest that past disasters have taught these residents to adapt and cope with hard times.14

Scientists asked Alabama residents if they thought they recovered from setbacks quickly and how well they adapted to change. Residents who did not view themselves as being able to overcome difficult times had a harder time after the oil spill. They reported more symptoms related to depression and post-traumatic stress disorder.28

Other factors can influence how well a resident recovers after a disaster. Feeling a sense of purpose or meaning in life, or the belief that they are living their life in a way that stays true to their core values, can help people recover after disasters.29 Residents that had higher levels of resilience and meaning in life had fewer negative mental health symptoms after the oil spill than residents with lower levels.29

**TAKING THE NEXT STEPS**

The Gulf of Mexico Research Initiative (GoMRI), the National Institute of Environmental Health Sciences, the National Academy of Sciences, and other organizations continue fund research to look at the mental health impacts of the oil spill and how communities are recovering. Information about ongoing studies funded by GoMRI can be found at [http://gulfresearchinitiative.org](http://gulfresearchinitiative.org). Other publications focusing on the oil spill can be found on the Sea Grant Oil Spill Science Outreach website at: [www.gulfseagrant.org/oilspilloutreach](http://www.gulfseagrant.org/oilspilloutreach).
REFERENCES


GLOSSARY

**Corrosive communities** — Communities in which individuals’ lack of social connectedness due to fears, stress, anxiety, and conflict after a disaster impedes the communities’ ability to recover.

**Resilience** — The ability for a community or individual to respond to, withstand, and recover from adverse situations.

**Responsible party** — The person, business, or entity that owns the vessel or facility that caused the spill and, therefore, is liable for the cost of removal and damage. The term does not imply criminal negligence.

**Therapeutic communities** — Communities in which individuals pull together in a coordinated and connected way after a disaster to restore their community to pre-disaster conditions.

**Vessels of Opportunity** — A program that was implemented by BP after the Deepwater Horizon oil spill to provide limited employment opportunities to those in the Gulf region that had lost income or were out of work due to the oil spill.

*Workers decontaminate after cleaning oiled booms in Port Fourchon, Louisiana. (NOAA)*


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**SUGGESTED CITATION**


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**OIL SPILL SCIENCE OUTREACH TEAM**

**Christine Hale**  
Texas Sea Grant College Program  
chris.hale@tamu.edu

**Larissa Graham**  
Mississippi-Alabama Sea Grant Consortium  
larissa.graham@auburn.edu

**Emily Maung-Douglass**  
Louisiana Sea Grant College Program  
edouglass@lsu.edu

**Stephen Sempier**  
Mississippi-Alabama Sea Grant Consortium  
stephen.sempier@usm.edu

**Tara Skelton**  
Mississippi-Alabama Sea Grant Consortium  
tara.skelton@usm.edu

**LaDon Swann**  
Mississippi-Alabama Sea Grant Consortium  
swannnl@auburn.edu

**Monica Wilson**  
Florida Sea Grant, UF/IFAS Extension  
monicawilson447@ufl.edu

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MASGP-16-030  
GOMSG-G-16-006
OIL SPILLS AND HARMFUL ALGAL BLOOMS: DISASTERS WITH SHARED CONSEQUENCES FOR COMMUNITIES

Melissa Partyka, Emily Maung-Douglass, Christine Hale, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson

Natural and human-caused disasters like harmful algal blooms and oil spills are a part of life for many coastal communities. In the immediate aftermath of the Deepwater Horizon oil spill, people were concerned that the spill might trigger blooms of harmful algae and questioned whether residual oil in the environment generated blooms in following years. Though the causes of these two types of disasters are different, their potential impacts to local communities and economies have similarities.

Weathered oil on the surface of water can look reddish and may be mistaken for a red tide. (GISR/ Du and Kessler)

WHAT ARE HARMFUL ALGAE AND HOW DO THEY FORM BLOOMS?

Algae are plant-like organisms that mostly live in water. Found in both fresh and marine waters, algae range in size from microscopic to macroscopic (for example, seaweed or any algae large enough to be seen by the naked eye). Algae occupy the base of marine and freshwater food chains and produce much of the world’s oxygen supplies. ‘Harmful algae’ can cause negative effects to humans and wildlife, including poor beach conditions, reduced oxygen in the water, fish kills, and foodborne illnesses. When algae populations grow to very large numbers, they form a ‘bloom.’ Harmful Algal Blooms (HABs) are typically caused by
microscopic **phytoplankton**, a diverse group of mostly algae.

Algae, like plants, need nutrients such as nitrogen and phosphorus to grow. While the reasons for individual HAB events vary across years and locations, nutrients from lawns, sewage, and agricultural operations can run off into nearby water sources and travel to the coast. Some algae use these abundant nutrients to grow rapidly. Sometimes algae that are beneficial can bloom to such large concentrations, or at the wrong time of the year, that they become harmful (for example, large rafts of sargassum washing onshore).

Deepwater Horizon oil spill began, questions emerged about potential impacts on marine life, including algae. Early field and laboratory studies indicated that oil and dispersants had the potential to kill some types of algae while encouraging the growth of others, some of which could be harmful. Though evidence exists that Deepwater Horizon impacted algal populations, there is no proof that the spill led to HAB events in the Gulf of Mexico. The types of plankton that appeared to be the most affected by this spill were zooplankton grazers, microscopic animals that eat algae. When zooplankton disappear from the environment, the algae they graze on can grow very rapidly. However, data from research in the field and the lab suggest that grazers have limited ability to stop or control a bloom of K. brevis by themselves. What is clear is that oil spills can greatly alter algal communities and so potential connections warrant continued attention.

**WHETHER FROM HABS OR OIL SPILLS, COMMUNITIES FEEL THE IMPACTS**

**What causes oil spills?**

Oil spills are usually accidents. While the human errors that lead to accidents like oil spills can be managed and reduced through regulations and training, accidents do still occur, and they are hard to predict. The Bureau of Safety and Environmental Enforcement (BSEE) is the lead federal agency charged with improving safety and ensuring environmental compliance by the offshore oil and gas industry. When accidents do occur, BSEE, along with the U.S. Coast Guard, may conduct investigations into the causes of accident.

**Do oil spills cause HABs?**

Unlike human-caused accidents like many oil spills, HABs are, in general, naturally occurring events. However, harmful algal blooms have been measured after oil spills in the past, though the relationship between the two events is not always clear. Shortly after the

**BLOOMS OF ALGAE ARE NATURAL IN MANY AQUATIC SYSTEMS**

Not all algae blooms are harmful! Less than 1% of algal blooms actually produce toxins and many play key roles in coastal food webs. In fact, annual algae blooms are periods of great biological activity in most of the world’s oceans. These blooms can attract huge schools of algae-feeding fish, which then attract larger fish and even migrating whales. When blooms of algae die, they sink to the ocean floor and may become buried. After many millions of years these buried algae could become coal, natural gas, or oil. The Gulf of Mexico is rich in oil and natural gas reserves because of its history with large algae blooms.
Oil spills and HABs share similarities

Although oil spills and harmful algal blooms are very different types of events, they do share several things in common, including how they might look on the water surface (Figure 1), and environmental settings that can help to spread them from place to place (Table 1). Even with many factors in common, there is a distinct difference — HABs are living organisms that can grow and reproduce as long as conditions are right. Once an oil spill is stopped, the oil will only break down, not grow.

Both types of disasters can contribute to marine mammal strandings, lead to fish kills, result in fisheries closures, and cause illness in humans following direct exposure (Table 2). The outcomes following exposure to HABs and oil spills can be highly variable and often depend on whether exposure is chronic, occurring repeatedly over time, or acute. Acute, intense exposure happens when concentrations of algae or oil are at their peak or the dose is very high. Symptoms of acute exposure often appear within hours or days. Symptoms

### Table 1. Oil spills and HABs share many things in common including how wind and weather can move both blooms and spills through the water. The environment can help to break down toxins or encourage blooms to grow.

<table>
<thead>
<tr>
<th>ENVIROMENTAL FACTORS</th>
<th>DURATION OF EVENT</th>
<th>PERSISTENCE IN THE ENVIRONMENT</th>
<th>FORECASTING</th>
<th>RESPONDING AGENCIES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OIL SPILLS</strong></td>
<td>Weather (temperature, sunlight, wind), currents</td>
<td>Minutes to year</td>
<td>Oil and chemicals may remain in sand or marshes months to years if buried or submerged</td>
<td>Short-term movement of surface oil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HABs</strong></td>
<td>Weather (water temperatures, salinity, sunlight, and wind), nutrients, currents, competition</td>
<td>Days to years</td>
<td>Toxins may remain in seafood or seagrass for days to weeks after bloom has ended</td>
<td>Pre-bloom: favorable conditions; mid-bloom: daily movement and impacts</td>
</tr>
</tbody>
</table>

**FIGURE 1.** Responders placed booms off the coast of Florida (left) to prevent oil from reaching the beach following the Deepwater Horizon spill (USEPA). A red tide event (right) off the coast of Texas resembles oil approaching shore. (NOAA)
of chronic or low-dose exposure to toxins may not be seen for months or years. For example, people exposed to chemicals associated with oil for long periods, either by breathing or skin contact, can develop cancer.\textsuperscript{13}

**Seafood safety and impacts to sea life**

Chemicals and toxins in the seawater from oil spills and HABs can affect the quality and safety of many types of seafood harvested from impacted areas. Exposure may also lead to the immediate death of sea life as seen with fish kills. HAB events usually cause immediate effects when living things are rapidly exposed to very high concentrations of toxins. Toxins produced by harmful algae can also bioaccumulate in the flesh of fish and shellfish during periods of regular exposure.\textsuperscript{14}

Consumption of HAB toxins from contaminated seafood—primarily oysters, clams, and mussels—can cause a variety of illnesses in humans.\textsuperscript{15} The type, duration, and severity of symptoms depends on the type of harmful algae and the toxins they produce, along with the overall health of the individual.\textsuperscript{16} In severe cases, exposure to toxins from HABs can cause death.\textsuperscript{17}

In seafood, toxins from HABs are odorless, tasteless, and cannot be destroyed by cooking or washing.\textsuperscript{18} To prevent these toxins from making their way into the public market, the U.S. Food and Drug Administration has set up seafood harvesting and testing guidelines.\textsuperscript{19} In the Gulf of Mexico, state scientists regularly monitor shellfish growing waters for the presence of multiple harmful algae species like *K. brevis* and *Pseudo-nitzschia*. These species occur naturally in the environment, so closures only occur when concentrations are above certain levels. Once closed, shellfish cannot be harvested until chemical testing on shellfish meat is done to show concentrations of toxins are below recommended exposure levels.\textsuperscript{19}

Similar criteria as for HAB-related closures—that is, chemical thresholds for safety—exist for seafood harvesting in places that might have experienced oil spills (Table 3).\textsuperscript{20}

**Polycyclic Aromatic Hydrocarbons** (PAHs) are a group of compounds found in crude oil; some of these compounds can cause human health impacts. The Gulf of Mexico is home to hundreds of seeps that release over 40 million gallons of crude oil and natural gas every year.\textsuperscript{21} With oil leaking naturally into the environment, and runoff from petroleum uses on land flowing into the Gulf, low levels of PAHs are commonly detected in water, fish, and shellfish samples in the Gulf of Mexico.\textsuperscript{22,23} These low levels are not considered harmful to human health. However, PAHs may accumulate in seafood in concentrations higher than considered safe following an oil spill. To protect consumers, food safety standards are in place for oil, including fisheries closures, sensory testing, and chemical analysis. For more information on how seafood is tested following oil spills, see the outreach publication *The Deepwater Horizon oil spill’s impact on Gulf seafood*.\textsuperscript{49}
Coastal disasters can have multiple impacts on local economies

Coasts that experience HABs and large oil spills may suffer economic losses for several reasons. People may become worried and change their travel plans or avoid buying seafood during a HAB or spill event over concerns about exposure to hazards. Following the Deepwater Horizon oil spill, many travelers reported cancelling or postponing their vacations out of concern about not being able to participate in marine-based recreation such as fishing or beach-going. According to the Deepwater Horizon Natural Damage Assessment, the public lost over 16 million days of recreational activity (e.g., boating, fishing, beach-going, etc.) following the spill.

In Florida, officials estimate that prolonged HABs can lead to losses of millions of dollars per month for the lodging and restaurant sectors alone, even in the most rural communities. Loss of seafood consumer confidence following both types of events can have long-lasting economic impacts for coastal fishing communities, especially when questions of seafood safety receive broad news coverage. But economic impacts can also include things like the medical costs of human health problems, government expenditures and relief, and the costs of administering shellfish closures.

PREDICTING DISASTERS ON OUR COASTS

Technology used to track oil can help predict movement of HABs

Researchers and government agencies used a combination of satellite imagery, climate data, and ocean circulation models to help track and predict the movement of oil following Deepwater Horizon. These same data are regularly used to predict HAB events. Sea surface temperature and underwater mixing are known to influence both types of events. Multiple studies have found that the position of the Loop Current within the Gulf of Mexico plays a role in the occurrence and severity of red tide events along Florida’s west coast. For example, more major red tides (those with K. brevis cell concentrations at one million cells per liter of seawater) occur when the Loop Current extends further to the north (Figure 2). In 2010, the position of the Loop Current moved further south during the months following the Deepwater Horizon oil spill, both helping to prevent oil from reaching the beaches of western Florida and potentially preventing a red tide event that year. Scientists hope to use the location of the Loop Current to predict the occurrence of major blooms in the future.

While researchers used some of the same data and tools to track oil following Deepwater Horizon as they now use for HABs, the approaches are not necessarily identical. The majority of oils are relatively buoyant, often rising to the surface of the water and forming slicks visible in satellite imagery. HABs are also often seen at the surface. However, many types of algae can move up and down through the water, which changes how they look from space. Also, river water flowing into the ocean can carry soil and plant matter that can make hunting for any algae from space challenging, much less one specific type of algae (Figure 3). To tell the difference between floating oil, algal blooms, and other things that can color...
the water, scientists use different types of sensors and parts of the light spectrum. To learn more about how scientists use technology to track oil on the ocean surface see the outreach publication *In the air and on the water: Technology used to investigate oil spills.*

**WHILE OIL SPILLS HAVE BEEN DECREASING, HABS COULD BE INCREASING IN FREQUENCY**

The 2010 Deepwater Horizon oil spill was a large and devastating event in the Gulf of Mexico. Despite this extreme event, data compiled for BSEE indicate that the rate of offshore oil spills from tanker collisions, pipeline failures, and drilling rigs has declined significantly over the past 40 years. Worldwide, even with an increase in rates of oil extraction, large oil spills (more than 215,000 gallons) caused by tanker collisions are down from a high of nearly 80 per decade in the 1970s to fewer than seven in the past 10 years. In fact, 2019 tied with 2012 for the lowest volume of oil lost to the environment from tanker spills (~265,000 gallons) recorded in the last five decades.

Red tides have been occurring in the Gulf of Mexico for nearly 200 years. The first documented case of red tide off the coast of Florida was in 1844, according to the Florida Fish and Wildlife Conservation Commission’s database, [http://myfwc.com/research/redtide/](http://myfwc.com/research/redtide/). Though these blooms have occurred naturally for centuries, scientists believe that they could increase in frequency as the effects of climate change begin to be felt. Experiments are ongoing to help predict how sea level rise, increased rainfall, and warming ocean temperatures might affect algae blooms in the future.

**Want more information?**

Major events like oil spills, HABs, and large storms are likely to continue affecting our coasts. Scientists continue to study the impacts of these events on coastal environments and the communities that live there. Information on oil spills in the Gulf of Mexico and across the U.S. can be found at NOAA’s *Incident News* and *Office of Response and Restoration* webpages. For more research about oil spill impacts, go to the Gulf of Mexico Research Initiative (GoMRI) website, [gulfresearch.org](http://gulfresearch.org). Resources like the Harmful Algal BloomS Observing System, or HABSOS, and the NOAA HAB forecasting system are free to the public and continue to improve their content. Additional publications on oil spills and impacts to coastal communities can be found on the sea Grant Oil Spill Science Outreach Program website, [www.gulfseagrant.org/oilspilloutreach](http://www.gulfseagrant.org/oilspilloutreach).

**GLOSSARY**

**Bioaccumulate** — To accumulate or build-up chemicals in the tissues of an organism. In the aquatic world, the bioaccumulated chemical can enter an organism via several methods, including their food, gills, and other tissue membranes.

**Dinoflagellates** — Single-celled algae that have whip-like tails to swim through the water.

**Fish kill** — A population or community of fish that dies off in a localized area.

**Loop Current** — A warm ocean current that flows northward between Cuba and the Yucatan Peninsula, moves north into the Gulf of Mexico, loops east and south before exiting to the east through the Florida Straits and joining the Gulf Stream to flow between Florida and the Bahamas.

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

**Plankton** — Very small and microscopic organisms that drift or float in bodies of water. Consisting of algae, protozoans, and the eggs and larval stages of larger animals, they are an important part of food webs.

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

**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

OIL SPILL SCIENCE OUTREACH TEAM
Dani Bailey
Texas Sea Grant College Program
danielle.bailey@tamu.edu

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Missy Partyka
Mississippi-Alabama Sea Grant Consortium
m.partyka@auburn.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
ladon.swann@usm.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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.

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FREQUENTLY ASKED QUESTIONS: DISPERSANTS EDITION

Chemical dispersants break oil into smaller droplets, limiting the amount of oil that comes into contact with wildlife and shorelines. Many people question how they work and whether they are safe for people and animals.

WHAT ARE DISPERSANTS AND WHAT DO THEY DO?

Dispersants are a mixture of compounds whose components work together to break oil slicks into small oil droplets (Figure 1). The small droplets are then broken down by evaporation, sunlight, microbes, and other natural processes.\(^1\) Dispersants work under a wide range of temperature conditions. Their components and dispersed oil can be broken down by microbes as well.\(^2\)

WHEN AND WHERE ARE DISPERSANTS USED?

There is no ‘one-size-fits-all’ technique for oil spill response.\(^3\) Decision-makers must weigh the environmental costs of each technique depending upon the scenario. Typically, responders use combinations of clean-up tools — including sorbents, booms, skimmers, burning, and dispersants — depending upon the incident.\(^3,4\) For example, booms can concentrate oil in an area for removal by skimmers, but they often fail in rough sea conditions and are less effective in open water. Where dispersant use is permitted, and environmental conditions (e.g., waves) indicate it could be effective, dispersants may better protect animals and habitats. Dispersants are rarely used; but when they are, they are typically applied at the water’ surface. However, during the Deepwater Horizon oil spill, responders also used dispersants directly at the source of the underwater blowout.\(^5\)

WHAT IMPACTS DO DISPERSANTS HAVE ON SEA LIFE?

For sea life, oil can cause problems, including damage to internal organs and blood cells, difficulty with body
Dispersants protect sea life and their habitats from being oiled by reducing large oil slicks to small droplets. Lab studies show that high levels of dispersants can lower the survival rate of aquatic life who encounter them. However, scientists found that the levels of dispersant that can harm animals or people are not found in the environment, even after incidents like the Deepwater Horizon oil spill. Dispersants alone are unlikely to pose risk for sea life.

While dispersant prevents some sea life from being oiled, it may increase exposure for others tens to hundreds of times by moving oil compounds into the water. In lab studies, oil-dispersant mixtures cause a variety of negative impacts to marine life,

**WHAT ARE EXISTING POLICIES?**

The National Contingency Plan, as mandated by the Clean Water Act, describes which dispersants may be considered for oil spill clean-up, the types of waters where they may be used, and how much may be applied in those waters. Only products that have undergone effectiveness and toxicity testing may be listed.

**REFERENCES**


**SUGGESTED CITATION**


**HOW WERE DISPERSANTS USED DURING DEEPWATER HORIZON?**

After receiving federal authorization, emergency responders applied 1.8 million gallons of dispersants Corexit 9500A and 9527A to the water’s surface and underwater at the point of the blowout. Airplanes sprayed dispersants only in daylight. Application could not occur in areas less than 33 feet deep, within 2.3 miles of any vessel, or within 3.45 miles of shoreline or visible marine life. Including problems with egg hatching, heart health, growth, and early development. These studies in the laboratory show that impacts can vary depending on the species, age at time of exposure, oil and dispersant concentrations, and environmental factors like water temperature and salinity. While oil-dispersant mixtures can be problematic to sea life in lab studies, scientists see population declines in some wild animal populations but not others. Scientists continue investigating the differences between studies done in the lab and the ever-changing conditions in the wild.
RESPONSES OF AQUATIC ANIMALS IN THE GULF OF MEXICO TO OIL AND DISPERGANTS

Emily S. Maung-Douglass, Larissa J. Graham, Christine Hale, Stephen Sempier, LaDon Swann, and Monica Wilson

As the Deepwater Horizon (DWH) oil spill unfolded, concern grew over the potential impacts of oil and chemical dispersants to aquatic animals. Scientists are able to use biological markers to detect if an animal was exposed to oil. Research indicates that the fate of oil-based compounds in exposed animals depends greatly upon the age and species, as well as environmental conditions.

In April 2010, the Deepwater Horizon oil rig caught fire and sank off the coast of Louisiana. Over the next 87 days the Deepwater Horizon oil spill released approximately 200 million gallons of oil from the Macondo well. Oil spill responders applied chemical dispersants Corexit 9500 and 9527. These dispersants were used to increase the natural breakdown of oil, reduce the number of oiled animals and limit on-shore oiling. Funding agencies like the Gulf of Mexico Research Initiative (GoMRI) sponsor research to better understand the responses of marine and coastal animals to oil-dispersant mixtures. This outreach publication summarizes research results related to the effects of oil and dispersants on aquatic animals that live in the Gulf of Mexico (Figure 1).

FIGURE 1. The moon jellyfish is a species of jellyfish native to the Gulf of Mexico. Jellyfish are one example of animals that are unable to break down and eliminate PAHs from their bodies. (A. Vasenin)
**Polycyclic Aromatic Hydrocarbons (PAHS)**

Crude oil is a mixture of thousands of compounds. Alkanes (such as methane and ethane) are usually the most abundant compounds in oil and have relatively low toxicity. Polycyclic aromatic hydrocarbons (PAHs) are also present in crude oil. PAHs are found in oil and tar. They are formed in burning of gas, oil, coal, wood, and charring of animal fat. Dispersants break up oil slicks into relatively small oil droplets that bacteria can more readily degrade. While applying dispersants to oil increases the rate at which oil droplets diffuse into the water column, dispersants also increase concentration of PAHs in the water. PAHs cause concern because they can remain in the environment for a long period of time. Some of them cause mutations, developmental problems, and/or cancer in wildlife and humans.

**Physiological Responses**

Animals respond to chemicals like PAHs from oil in several ways. Chemicals that are not easily broken down are often stored (a process known as bioaccumulation) in the body’s tissues. Chemicals that bioaccumulate in the body have the potential to be passed to predators higher in the food chain or passed from a mother to her young. A mother passes the PAHs to her eggs through the glycolipoprotein that will form the egg yolk. If these eggs hatch then the offspring from the eggs will have elevated PAH levels.

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**FIGURE 2.** Diagram of possible ways polycyclic aromatic hydrocarbons (PAHs) from oil enter aquatic animals and animal responses (i.e., uptake, bioaccumulation, metabolism, excretion). Image credit: Florida Sea Grant/Anna Hinkeldey with contributions from D. Tracey, J. Thomas, T. Saxby (IAN-UMCES Image Library).
Some animals can break down foreign chemicals such as PAHs using their body’s metabolism processes (Figure 2). Metabolism occurs when the animal’s body activates or inactivates certain genes through gene expression. CYP1A is an important gene that enables animals to breakdown PAHs and other foreign compounds. Some of these breakdown products are easily excreted. This process prevents foreign chemicals from being stored in the animal’s tissues. Other breakdown products are more toxic and can cause cancer in the animal. Scientists study changes in CYP1A expression levels in animals to determine if they have encountered a toxic substance like oil. Scientists are able to confidently estimate oil exposure by doing experiments in the lab and comparing the lab results with the results collected in the field.

**Four Key findings related to aquatic animal responses to Corexit and oil mixtures**

**Some animals accumulate PAHs**

Many aquatic animals cannot breakdown and remove PAHs once these compounds enter their bodies. This causes PAHs to accumulate in their tissues. Copepods are aquatic animals related to insects and are about the size of a pinhead (Figure 3). Copepods accumulate PAHs when exposed to oil. However, they are also able to release some PAHs in their waste. Levels of PAHs in jellyfish (Figure 1) exposed to oil are 1.4-3.1 times higher than in jellyfish not exposed to oil. PAH levels in jellyfish also increase with level of oil exposure. The PAHs can travel through the food web when other animals eat the contaminated copepods, copepod waste, or jellyfish.

Scientists monitoring wild Gulf coast coquina clams found that levels of PAHs in the clams were variable the year after DWH. The variability may have been due to the patchy distribution of the oil that came to shore. PAH levels in the clams were higher than the PAH levels in the surrounding sands. This suggests that the clams accumulate PAHs in their tissues. PAH levels in the clams declined during the two years after the spill. This indicates that PAH levels were declining at the beach locations where the clams were tested.

Clams and their relatives (e.g. oysters, mussels) tend to be stationary. They are also relatively slow at breaking down and excreting foreign chemicals. This causes these animals to bioaccumulate foreign compounds in their tissues. These factors make this group of animals good indicators of environmental pollution. For more than twenty years NOAA’s Mussel Watch program has tested the tissues of oysters and mussels to monitor the presence of foreign chemicals (e.g., PAHs, metals) in the environment. Post-DWH, GoMRI-funded scientists collected wild oyster samples (Figure 4). They compared them to samples the Mussel Watch program had previously collected in the Gulf. PAH levels were similar to those found during the ten years before the DWH oil spill. Other GoMRI-funded scientists tested oysters from Mississippi and Alabama. Samples were taken during and after the DWH oil spill to determine if oysters accumulated oil in their shells. They found no measurable traces of oil-based compounds in the oyster shells.

**Fish break down oil-based compounds in their bodies – and that can be used to detect exposure to oil.**

Fish are able to breakdown and eliminate PAHs from their bodies by expressing the CYP1A gene. Scientists
can determine if a specific area has been oiled by examining Gulf killifish (Figure 5). This fish will turn up CYP1A gene expression if they experience oil. Gulf killifish do not travel far from their homes. So if a killifish has high levels of CYP1A gene expression then it is likely that the area had oil. Grand Terre, Louisiana, is a location that was heavily oiled from the DWH oil spill. Fish collected in Grand Terre after the DWH oil spill had higher levels of CYP1A gene expression than fish collected from that location before the oil came to shore or fish from locations that did not have oil. In August 2011, more than a year after the well was capped, scientists still found higher levels of CYP1A gene expression in killifish sampled from Grand Terre than in killifish from unoiled locations. The elevated levels indicate that oil and/or oil components remained in Grand Terre for at least one year after the DWH oil spill.

Effects differ based on stage of life and environmental conditions

An animal’s response to oil and dispersant may change with age. Newly hatched spotted sea trout (Figure 6) exhibited stress from chemically dispersed oil while slightly older juvenile spotted sea trout did not. The skin of newly hatched fish allows more chemicals to pass through it than the skin of older fish. This may make younger fish more sensitive to chemically dispersed oil compared to older fish.

**FIGURE 6.** Adult spotted sea trout, like the one pictured here, are recreational sport fish. GoMRI-funded scientists are studying the young of this species. Image Credit: Raver Duane (U.S. Fish and Wildlife Service)
Environmental factors can influence the impacts of oil and dispersants on animal health too. These factors include the amount of salt in the water (salinity) and ultraviolet rays from sunlight. Animals living in salt marshes encounter a wide range of salinities. The salinity in a marsh can change within hours due to tides and weather events. Oil and dispersant mixtures at low salinities were more toxic to Gulf killifish than the mixtures at higher salinities. Scientists concluded that the fish were either more sensitive at low salinities or less capable of breaking down PAHs in low salinity environments. Long-term exposure to PAHs can make some fish and their offspring tolerant to PAHs. However, when fish spend energy becoming more resistant to PAHs they can become more sensitive to other environmental factors like UV light and low oxygen. Finally, in some cases, other environmental stressors can affect animals more than PAHs or oil exposure. For example, salinity has a greater impact on the reproductive health of oysters than oil exposure. Scientists continue to explore the relationships between environmental factors and aquatic animal health.

**Oil exposure can impair vital development and bodily function**

Oiled sediments and PAHs impact the ability of fish eggs to hatch, the development of the fish and how well the fish functions. Few killifish eggs hatched when exposed to sediments from heavily oiled areas. If they did hatch, it took longer for them to hatch. The fish that did hatch were smaller than expected and developed heart problems. Heart problems included reduced heart rate and the development of a fluid filling the sac surrounding the heart. These heart problems might be due to PAHs changing the normal function of the heart tissue. Mahi-mahi (Figure 7) juveniles exposed to PAHs or hatched from eggs exposed to PAHs could not swim as fast as juveniles that were never exposed to PAHs. Reduced swimming...
speed could translate into fewer young surviving into adulthood, leading to reduced reproduction rates and population levels.

The energy needed to break down foreign chemicals (i.e., PAHs and dispersants) can come at the cost of growth. For example, both newly hatched and juvenile spotted sea trout exposed to either dispersant or PAHs were significantly smaller than unexposed individuals. This indicates that the fishes’ bodies used energy to breakdown the dispersant and PAHs instead of putting growth.

FIGURE 7. Mahi-mahi are large, predatory fish that spawn in the Gulf of Mexico. The adult form of the species (pictured here) is popular in recreational fishing circles. The young of the species are studied by GoMRI-funded scientists (J. Weiss)
that energy toward growth. However, these effects do not appear to be permanent in juveniles. Within several weeks after exposure, the body size of the juveniles exposed to dispersants and PAHs became similar to individuals who had never been exposed to these chemicals.

To learn more about the research being conducted on the Deepwater Horizon spill, visit the Gulf of Mexico Research Initiative website at www.gulfresearchinitiative.org. Visit the Sea Grant oil spill outreach program website at: http://gulfseagrant.org/oilspilloutreach to view other publications related to this theme.

**GLOSSARY**

**Alkanes** - A group of compounds composed of hydrogen and carbon. Have carbon atoms in chains linked by single bonds and that have the general formula \( C_nH_{2n+2} \). Occur naturally in petroleum and natural gas, and include methane, propane and butane.

**Bioaccumulation** - The accumulation or build-up of chemicals in the tissues of an organism. In the aquatic world, the bioaccumulated chemical can enter an organism via several methods, including their food, gills, and other tissue membranes.

**Corexit** - A modern dispersant approved for use in US waters that was used to minimize the presence of surface oil slicks during the Deepwater Horizon oil spill.

**CYP1A** - Gene that helps the body metabolize, or breakdown, foreign chemicals (e.g., PAHs).

**Gene(s)** - Unit of DNA that codes for a trait in an organism (e.g., coloration, size, stress response). Passed from parent to child.

**Gene expression** - A gene that is expressed is ‘turned on’ or ‘turned off’. Expression can also be turned up or down, similar to a volume knob on a stereo, producing a response within the body.

**Glycolipoprotein** - A molecule that has the properties of sugar, lipid (fat), and protein (e.g., vitellogenin, the protein that will form an egg’s yolk).

**Metabolism** - The breakdown of chemicals by the body (e.g., metabolism of foreign chemicals).

**Polycyclic aromatic hydrocarbon (PAH)** - A group of hydrocarbons commonly found in oil, tar, burned wood and animal fats. More than 100 PAHs exist and some are known to cause cancer, birth defects, mutations, or death.

**Salinity** - The average concentration of dissolved salts in a body of water.
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.
THE SEA GRANT and GOMRI PARTNERSHIP

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university-based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10-year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization and remediation technologies. GoMRI is led by an independent and academic 20-member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

OIL SPILL SCIENCE
SEA GRANT PROGRAMS OF THE GULF OF MEXICO

CHEMICAL DISPERSONANTS AND THEIR ROLE IN OIL SPILL RESPONSE

Larissa J. Graham, Christine Hale, Emily Maung-Douglass, Stephen Sempier, LaDon Swann, and Monica Wilson

Nearly two million gallons of dispersants were used at the water’s surface and a mile below the surface to combat oil during the Deepwater Horizon oil spill. Many Gulf Coast residents have questions about why dispersants were used, how they were used, and what impacts dispersants could have on people and the environment.

On April 20, 2010, an explosion on the Deepwater Horizon oil rig killed 11 people. The rig was located 42 miles southeast of Venice, Louisiana. The ruptured wellhead had released an estimated 4.9 million barrels of Louisiana sweet crude oil before responders capped it on July 19, 2010. Some of this oil was collected at the site of the wellhead. Scientists estimate that the remainder of the oil, or about 4.1 million barrels (172 million gallons), were released into Gulf of Mexico waters.1,2,3,4,5

Emergency responders attempted to clean up the oil and prevent it from reaching the shoreline by skimming and burning the oil at the surface. They also applied nearly two million gallons of dispersants to break up the oil. This spill was the largest application of dispersants in U.S. history.4
HOW DID RESPONDERS USE DISPERSANTS DURING THE DEEPWATER HORIZON OIL SPILL?

Responders used two types of dispersants, Corexit 9500A and Corexit 9527A, during the Deepwater Horizon oil spill. Both are on the federal guideline list of dispersants that can be used during a spill. Responders first applied Corexit 9527A until they exhausted the supply. Then they switched to Corexit 9500A and continued using it throughout the cleanup efforts. There are many different Corexit formulas and product types. When we use the word “Corexit” in this publication, we are referring to Corexit 9527A and 9500A.

During the spill, responders sprayed approximately one million gallons of dispersants over close to 300 square miles of oiled surface waters (Figure 1). Responders spraying dispersant from airplanes could not apply them within 2.3 miles of any vessel, within 3.45 miles of the shoreline or visible marine life, or in areas with water depths less than 33 feet deep. Responders sprayed dispersants from boats in areas close to the wellsite where crews were working. According to the U.S. Coast Guard, this method reduced the amount of dispersant in the air, increasing the safety of the working environment. The same U.S. Coast Guard report states that emergency responders applied 98 percent of the dispersants more than 11 miles offshore.

For the first time in U.S. history, responders used dispersants at very deep depths. They applied approximately 771,000 gallons of Corexit 9500A nearly one mile beneath the sea surface at the source of the leak. They did this using a remotely operating vehicle to inject dispersant at the site of the wellhead.

HOW DO DISPERSANTS BREAK UP OIL?

A typical commercial dispersant contains solvents and surfactants. Solvents help keep the chemicals mixed and help them dissolve into the oil. Surfactants allow oil and water to mix easily.
By allowing oil and water to mix, the oil slick breaks into many smaller oil droplets. The smaller droplets mix into the water column and then are eventually carried away by currents, attach to particles in the water column and settle to the bottom, or evaporate. Nature’s “oil-eating” microbes are found in our oceans and have adapted over time to use most of the chemicals in oil as food. In the process, they naturally remove oil from the environment. Smaller oil droplets are more available to these “oil-eating” microbes than large oil slicks (Figure 2).

WHEN DO RESPONDERS USE DISPERSONTS TO CLEAN UP OIL?

Responders consider trade-offs when determining the most effective cleanup method(s) that should be used during an oil spill. Applying dispersants was just one of many strategies that emergency responders used at the Deepwater Horizon site during the spill. Other response activities included burning the oil at the water surface and mechanically recovering it using skimmers or other equipment.

Emergency responders may use dispersants when other cleanup methods may not be as practical. For example, the spill is very large, the water may be too rough for other methods, or the spill may be too far away from land to use mechanical recovery equipment. Under these conditions, responders may choose to apply dispersants to break up an oil slick. They may also choose to use dispersants because they can be deployed rapidly by aircraft, cutting down on the response time.

Dispersants and other response methods can prevent an oil slick from reaching the shoreline. This can reduce the
oiling of coastal wildlife and sensitive habitats, such as coastal wetlands, mangroves, and beaches. Once these habitats are oiled, they are very difficult to clean without causing further damage to the area.8

However, dispersants are not always effective. When oil is dispersed, it is removed from the water’s surface and harder to clean up mechanically.8 Dispersants may not work well on some types of oil and spraying them on patchy oil slicks can be inefficient.7,8 They also do not work well under very windy conditions because they can drift in the wind during application or waves can wash them off the slick. When this happens, the dispersant cannot penetrate, mix with, and break down the oil.7

Applying dispersants beneath the water’s surface, at the site of the wellhead, was a new technique used during the Deepwater Horizon oil spill. One reason that this method was approved was related to the health of response workers and the ease of application. Deep sea application would minimize human contact with dispersants and could also occur at night and during foul weather. This technique may have been more effective at dispersing the oil because Corexit was injected right into the wellhead. This also allowed for a quicker response time because dispersants could be applied at night and in foul weather.1

HOW DID AGENCIES REGULATE AND MONITOR DISPERSANT USE?

The National Contingency Plan (NCP) establishes the framework to authorize dispersant use. This plan outlines which dispersants emergency responders can apply during a spill and how dispersant use will be monitored.9

Emergency responders use Special Monitoring of Applied Response Technologies (SMART) guidelines to monitor surface dispersant use. SMART guidelines do not look at the effects or impacts of dispersed oil. Instead, they provide information about how to apply dispersants and how well they are working.10

Responders use the SMART monitoring program to determine if dispersants are effectively breaking up oil and, if so, how quickly.4 The U.S. Coast Guard, National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA), U.S. Centers for Disease Control and Prevention, and the U.S. Bureau of Safety and Environmental Enforcement were all part of developing this program.4 During the Deepwater Horizon oil spill, trained observers flew over the oil slick to see if the dispersant was working to break up the oil. Sampling teams collected water samples to measure the amount of dispersed oil in the water column. Agencies used this information to modify how they were applying the dispersant.4

In 2010, the U.S. EPA collected air samples off the coast of Louisiana for four days after the aerial application of dispersants. They tested the air for two chemicals, 2-butoxyethanol and propylene glycol. Scientists took samples 30 minutes after dispersant application and did
The U.S. EPA also collected onshore air quality samples along shoreline sites in Louisiana, Mississippi, Alabama, and Florida. They tested these samples for two dispersant chemicals that were most likely to be in the air in measurable amounts after spraying, 2-butoxyethanol and dipropylene glycol monobutyl ether. They found low levels of both chemicals in the air, but all were below levels that are likely to cause negative health effects. All of the data from these monitoring efforts are available on U.S. EPA’s website at http://www.epa.gov/bpspill/dispersant-air-sampling.html.

According to the U.S. Coast Guard’s On-Scene Coordinator Report, the U.S. EPA and the U.S. Coast Guard were satisfied with how dispersants were used during the Deepwater Horizon oil spill. These agencies stated that dispersants had been an important tool for reducing the oil spill’s impact and had prevented more damage to marshes, wetlands, beaches, and coast’s economy. They also stated that the information collected during the spill supported continued application of dispersants.

### CAN DISPERSANTS HARM MARINE ANIMALS?

The dispersants that emergency responders use today are less harmful to the environment than the more toxic products used prior to 1970. However, they still contain chemicals that can have a negative impact on aquatic life (Tables 1 & 2).

The U.S. EPA was concerned that dispersants could hurt aquatic wildlife and so, in May 2010, they directed BP to scale back on the use of dispersants. To understand how dispersants could affect aquatic wildlife, the U.S. EPA conducted independent toxicity studies in the laboratory.

The U.S. EPA tested eight approved dispersants, including Corexit 9500A, on two aquatic species: Gulf mysid, a small shrimp, and the inland silverside, a fish that resides in coastal waters in the Gulf of Mexico. These laboratory tests looked at the acute toxicity of dispersants. Determining the acute toxicity of a substance can help scientists determine the lethal concentration. However, knowing the acute toxicity...
does not help scientists understand the effects that the substance can have on the reproduction, growth, or development of an animal. Corexit 9527A was not tested during these studies because the dispersant was no longer being used in response efforts.

The laboratory experiments showed that none of the dispersants, when tested alone, were more toxic to the shrimp or silversides than oil. Corexit 9500A and another dispersant (JD-2000) were less toxic to silversides than the other dispersants that were tested.6

The U.S. EPA was also concerned about how oil mixed with dispersant could affect aquatic life. They conducted additional studies and found that Corexit 9500A, when mixed with oil, had similar toxicity as the seven other dispersants that were tested.6 Oil alone and oil mixed with each of the dispersants that were tested had similar toxicity to shrimp, except when oil was mixed with one of the dispersant tested (Nokomis 3-AA). The combination of oil and this type of dispersant was more toxic to the shrimp than oil alone.6

The extent of damage that dispersants, dispersed oil, and oil can have on aquatic life is still under debate. Some peer-reviewed research studies have found dispersants to be less toxic than oil alone, and other studies have shown that dispersants or oil plus dispersant are more toxic than oil alone.7

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**The On-Scene Coordinator Report**

This report documents the response efforts during the Deepwater Horizon oil spill. It provides a timeline of the spill and the efforts to address the potential impacts to public health related to the spill. This report is available at [http://masgc.org/assets/uploads/publications/873/2_coordinator_report_dwh.pdf](http://masgc.org/assets/uploads/publications/873/2_coordinator_report_dwh.pdf).
WHAT STUDIES ARE STILL ONGOING?

Many questions remain about the impacts of dispersants and dispersed oil on the ecosystem, environment, and human health. The Gulf of Mexico Research Initiative (GoMRI) and other research programs are looking at alternative dispersant use and technology, how dispersants react with oil under various conditions, the environmental impacts of dispersants, and the impacts that dispersants have on human health.

<table>
<thead>
<tr>
<th>CAS #</th>
<th>Chemicals in Corexit 9500A and Corexit 9527A</th>
<th>Other substances that contain this chemical a,b,c</th>
<th>Potential health effects to humans based on animal tests d</th>
</tr>
</thead>
<tbody>
<tr>
<td>577-11-7</td>
<td>Di(2-ethylhexyl) sodium sulfosuccinate (DOSS)</td>
<td>Certain cosmetics, gelatin, chocolate powder, beverages, laxatives</td>
<td>Causes eye, skin, and respiratory tract irritation. May be harmful if absorbed through the skin or inhaled. Harmful if swallowed. May cause gastrointestinal irritation with nausea, vomiting, and diarrhea.</td>
</tr>
<tr>
<td>111-76-2</td>
<td>2-Butoxyethanol (Found in Corexit 9527A only, not Corexit 9500A)</td>
<td>Certain cleaners, soaps, cosmetics, lacquers, paints</td>
<td>Causes eye and skin irritation. May be toxic to blood, kidneys, liver, and central nervous system. Repeated or prolonged exposure to the substance can produce target organs damage, including injury to red blood cells, kidney or the liver. May cause adverse reproductive effects, birth defects, or cancer. Severe over-exposure can result in death.</td>
</tr>
<tr>
<td>57-55-6</td>
<td>Propylene glycol</td>
<td>Cosmetics, preservatives in food, medicines</td>
<td>Causes mild eye, skin, respiratory, and gastrointestinal irritation. May affect the behavior or central nervous system, brain, metabolism, blood, respiration, cardiovascular system, endocrine system, urinary system, and liver. Prolonged or repeated inhalation may affect behavior, central nervous system, and spleen. May be toxic to central nervous system. May mutate genetic material or cause adverse reproductive effects and birth defects.</td>
</tr>
<tr>
<td>64742-47-8</td>
<td>Distillates, petroleum, hydrotreated light</td>
<td>Cleaners, paints, varnishes</td>
<td>Causes skin irritation. Repeated skin contact has resulted in irritation and skin cancer in animals. May cause drowsiness or dizziness. May be fatal if swallowed or enters airways.</td>
</tr>
<tr>
<td>29911-28-2</td>
<td>Dipropylene glycol monobutyl ether</td>
<td>Cleaners, degreasers, paints</td>
<td>The chemical, physical, and toxicological properties of this chemical have not been thoroughly investigated.</td>
</tr>
<tr>
<td>1338-43-8</td>
<td>Sorbitan, mono-(9Z)-9-octadecenoate</td>
<td>Skin cream, air freshener</td>
<td>Not classified as a hazardous substance or mixture.</td>
</tr>
<tr>
<td>9005-65-6</td>
<td>Sorbitan, mono-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivatives</td>
<td>Baby bath, mouth wash, face lotion</td>
<td>Not classified as a hazardous substance or mixture.</td>
</tr>
<tr>
<td>9005-70-3</td>
<td>Sorbitan, tri-(9Z)-9-octadecenoate, poly(oxy-1,2-ethanediyl) derivatives</td>
<td>Insect spray, food additive</td>
<td>Not classified as a hazardous substance or mixture.</td>
</tr>
</tbody>
</table>

TABLE 2. The chemicals that are found in Corexit 9500A and 9527A, the two dispersants that were used during the Deepwater Horizon oil spill.13 The Chemical Abstracts Service number (CAS) or unique identifier for each chemical substance, toxicity level based on tests on animal subjects, and the potential health effects are listed for each chemical. This information was provided by the Food and Drug Administration (a), U.S. Department of Health and Human Services (b), Agency for Toxic Substances and Diseases Registration (c), and Material Safety Data Sheets (d).

More information about these ongoing studies can be found on GoMRI’s website at http://gulfresearchinitiative.org. Other publications focusing on dispersants are on the Sea Grant Oil Spill Science Outreach website at www.gulfseagrant.org/oilspilloutreach.
REFERENCES


GLOSSARY

Acute toxicity - Adverse (negative) effects after an organism is exposed to one or more doses of a substance over a short time period (often, less than 72 hours).

Corexit 9527A and 9500A – dispersants approved for use in US waters and those that were used to minimize the presence of surface oil slicks during the Deepwater Horizon oil spill.

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

Microbes – very tiny organisms including bacteria, fungi, archaea, and protists. Some microbes (bacteria and archaea) are the oldest form of life on earth.

National Contingency Plan (NCP) – a federal document that outlines response efforts for oil spills and other hazardous substance spills.

Special Monitoring of Applied Response Technologies (SMART) – a cooperative monitoring program that is used during oil spill response efforts to determine if dispersant application is effective.

Surfactants – compounds that work to break up oil. Dispersants contain surfactants that break the oil slick into smaller droplets that can more easily mix into the water column.

SUGGESTED CITATION


OIL SPILL SCIENCE OUTREACH TEAM

Christine Hale
Texas Sea Grant
chris.hale@tamu.edu

Larissa Graham
Mississippi-Alabama Sea Grant
larissa.graham@auburn.edu

Emily Maung-Douglass
Louisiana Sea Grant
edouglass@lsu.edu

Stephen Sempier
Mississippi-Alabama Sea Grant
stephen.sempier@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant
swanndl@auburn.edu

Monica Wilson
UF/IFAS Florida Sea Grant Extension
monicawilson447@ufl.edu

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PERSISTENCE, FATE, AND EFFECTIVENESS OF DISPERGANTS USED DURING THE DEEPWATER HORIZON OIL SPILL

Monica Wilson, Larissa Graham, Chris Hale, Emily Maung-Douglass, Stephen Sempier, and LaDon Swann

The Deepwater Horizon (DWH) oil spill was the first spill that occurred in the deep ocean, nearly one mile below the ocean’s surface. The large-scale applications of dispersants used at the surface and wellhead during the Deepwater Horizon oil spill raised many questions and highlighted the importance of understanding their effects on the marine environment.

Emergency responders used a large amount of dispersants during the 2010 DWH oil spill. They applied approximately 1.8 million gallons of chemical dispersants (Corexit 9527A and 9500A, referred to as Corexit in this document) to surface waters that were oiled from April 22 through July 19.1 They also injected roughly 771,000 gallons of dispersants directly into the flow of oil and gas from the Macondo wellhead (Figure 1).1,2 Before this event, scientists did not know how effective dispersants were when used in the deep ocean.2,3 Most studies were based on sea surface spills and predicted where the oil would go and how long it would stay in the environment. Deep waters have higher pressures and lower temperatures that can cause dispersed oil to behave differently than it does on the surface.
HOW DISPERSANTS WORK

Chemical dispersants break large oil slicks into small oil droplets. The smaller droplet size affects how the oil moves in the water and how it interacts with the environment. The natural processes that remove oil from the environment occur more easily when oil is in the form of small droplets. For example, ultraviolet light from the sun, evaporation, and bacteria that feed on oil can remove it from the water more easily when dispersants are used. However, dispersants can accelerate the mixing of oil from the surface into the water column, which increases marine life’s exposure to the oil.

PERSISTENCE OF DISPERSANTS

To understand how long dispersants remain in nearshore and offshore environments, scientists measured the concentration of dioctyl sodium sulfosuccinate (DOSS). DOSS, or dioctyl sodium sulfosuccinate, is one of the surfactants in Corexit 9527A and 9500A. DOSS, and other surface-active agents, lowers the tension between oil and water particles allowing them to mix (emulsify). DOSS is a common ingredient in consumer products, such as detergents, cosmetics, and laxatives, and therefore, can end up in lakes, rivers, and coastal waters through stormwater runoff or our wastewater systems.

Nearshore waters

Nearly four years after the spill, scientists found DOSS in oiled samples collected on Gulf of Mexico beaches. Scientists collected tar balls and sand patties between June 2012 and January 2014 from Florida, Alabama, Mississippi, and Louisiana shores. DOSS was found in these samples. However, the amount of oil and DOSS in different samples was patchy and inconsistent.
because the oil washing up on the beach was from offshore oil mats.\textsuperscript{7}

DOSS found in the nearshore environment is not always linked to the use of dispersants. Although scientists have used DOSS to track Corexit in the environment, DOSS does not always have a direct link to Corexit (see page 2). After the oil spill, the community of Orange Beach, Alabama, conducted its own water sampling to determine if DOSS was present in nearshore and inland waters. DOSS was found in the water samples, but it did not come from the dispersants used during DWH. The amount of DOSS in the samples was higher than expected given the samples’ distance from where responders sprayed the dispersants. The more likely source of DOSS was from stormwater pollution from nearby communities, which use detergents, cosmetics, laxatives, and other everyday products that contain DOSS.\textsuperscript{8}

\textit{Offshore waters}

Another study found deep-sea coral communities covered in brown clumps of material containing oil from the well. The
corals were located 4,500 feet below the surface and up to seven miles from the wellhead. Scientists sampled the coral communities six months after the DWH oil spill and found DOSS was still present. The breakdown of DOSS is slower in deeper waters where lower temperatures delay the uptake by bacteria and sunlight cannot penetrate.

**EFFECTIVENESS**
Both chemical and environmental factors determine how well dispersants break up oil. The type of oil, the amount of oil, how weathered the oil is, the type of dispersant, and how the dispersants are applied to the oil can influence how well dispersants work. Physical properties of the water, such as temperature, water salinity, and wave energy, may also affect the dispersants’ effectiveness. Dispersants are less effective on oils that have:

- Higher viscosity, the oil is thick and doesn’t flow easily;
- Weathered causing the oil to become more viscous or have a thicker consistency;
- Cooled significantly below their pour point, which is the lowest temperature at which a liquid remains pourable, or;
- Emulsified, when two liquids such as oil and sea water combine and mix.

**SURFACE APPLICATION OF DISPERSANTS**
During the DWH oil spill, responders applied chemical dispersants to the oil slick at the sea surface using planes and boats. This method exposed the dispersants to direct sunlight, which could have caused some of the ingredients in them to be less effective. To understand what happened to the dispersants in the environment, scientists tested four ingredients found in Corexit (2-butoxyethanol, dioctyl sodium sulfosuccinate (DOSS), dipropylene glycol butyl ether, and propylene glycol) to determine whether sunlight affected them. They discovered that the exposure to direct sunlight did not directly affect the dispersants. However, the sunlight altered other chemical components in the water, which caused the Corexit to degrade.

Floating or submerged materials, such as sea sand, mangrove leaves, seaweed, and seagrass, also influence the effectiveness of dispersants. In lab studies, scientists tested the role of different natural materials on dispersant effectiveness. When small amounts of
floating oil were present, natural materials (such as seaweed) that float on the surface adsorbed the oil. The dispersant was less effective because there was less oil in the water column to disperse. However, when there was a large amount of floating oil, wave action moved the seaweed and similar materials causing the oil to be mixed into the water column. This made the dispersant more effective at breaking down the oil (Figure 2).  

**DEEP-WATER APPLICATION OF DISPERGANTS**

Before the DWH oil spill, responders had never used dispersants in deep water to break up oil. While responders were applying Corexit almost one mile below the sea surface, the federal government started a monitoring program to test the effectiveness of the dispersant. They also monitored how the dispersant was affecting the environment, water and air quality, and human health. Results from the program indicated that the dispersant was effective at breaking up oil and reducing the amount of oil that reached the surface. According to the U.S. Environmental Protection Agency (EPA), applying the dispersant at depth meant a smaller amount of dispersant was needed compared to what would be needed to disperse the same amount of oil once it reached the surface. It also reduced the amount of oil reaching the ocean surface and minimized human contact with dispersants. The monitoring plan developed and used during the DWH oil spill is available on U.S. EPA’s website and listed in the reference section.

Some scientists have been unable to determine whether applying a dispersant at depth was successful in breaking down oil into smaller droplets (Figure 3). Studies show that DOSS, and possibly other chemicals

![FIGURE 3. Graphic showing the theoretical fate of the oil with and without subsurface dispersants and what occurred during the DWH oil spill. In theory, if no dispersants were applied at the wellhead, oil would have become trapped in an underwater plume and risen to the surface (left image). If dispersants were applied at the wellhead, oil would not rise to the surface but would become fully contained in an underwater plume (middle image). During the DWH oil spill, the oil behaved in both ways. Dispersants were applied at the surface and at the wellhead, some oil became trapped in an underwater plume and the rest rose to the surface (right image). (Kujawinski)](image-url)
found in Corexit, became trapped in the deep plumes. There were two competing explanations for this entrapment:

1. Dispersants were highly effective. Corexit was found in small oil droplets trapped in the plume. If DOSS was deposited in these small oil droplets, then it would suggest that the dispersant was highly effective and caused the oil to break up into small droplets.

2. Dispersants were not effective in the deep-water environment. DOSS dissolved into the water while it was rising from the wellhead, and through separation with water and natural gas, became trapped in the deep-water oil plume at roughly 3,600 feet. If DOSS dissolved, then the dispersant could not effectively disperse the oil.2

Other scientists do not agree that dispersant use below the surface was as effective. To test the effectiveness of dispersants, some scientists developed a hydrodynamic model that recreated the conditions during the DWH oil spill. The model indicated that the dispersants were not effective at depth and that applying them at the wellhead may not have changed the amount of oil rising to the surface. The model results suggested that the size of the oil particles being released at depth were already small and mostly neutrally buoyant, meaning they were not rising or were rising slowly. They were small and mostly neutrally buoyant because they were traveling through the wellhead at high speed and through a small diameter pipe.18 Model results were confirmed in an experiment that used a high-pressure visual autoclave to evaluate the effect of droplet size on the movement of oil through the water column. Results indicated that using dispersants at depth only reduced the amount of oil reaching the sea surface by 1-3%.19

Do we need to be concerned with the effectiveness and persistence of dispersants in the Gulf of Mexico? Scientists learn more every day, but there are still many questions related to using a large amount of dispersants and applying them in deep waters. Future research from programs, such as the Gulf of Mexico Research Initiative (GoMRI), will continue to study the use of dispersants to determine their persistence and effects on the marine environment.

For more information about these ongoing studies, go to GoMRI’s website:

http://gulfresearchinitiative.org

To learn more about how oil and dispersants impact aquatic life and how these organisms break down these chemicals, refer to our other publications which can be found on the Oil Spill Science Outreach Program website at: http://gulfseagrant.org/oilspilloutreach
GLOSSARY

Corexit 9527A and 9500A
Dispersants approved for use in US waters and those that were 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 can limit floating oil from impacting sensitive ecosystems such as coastal habitats.

Emulsify
Make into a fine dispersion of droplets of water and oil, with one being suspended in the other. For crude oils, it refers to the process where sea water droplets become suspended in the oil by mixing due to turbulence.

High-pressure visual autoclave
A device in which high pressure conditions can be established to measure the size of oil droplets in water.

Hydrodynamic model
Computer-based models used as a tool to describe the way a body of water moves.

Salinity
The average concentration of dissolved salts in a body of water.

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

Weathered oil
When processes such as evaporation, dissolution, bacterial decomposition, or exposure to sunlight change the chemical composition and physical appearance of oil.

Satellite image of oil slick off the Mississippi Delta on May 24, 2010. (NASA image)
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SUGGESTED CITATION


OIL SPILL SCIENCE OUTREACH TEAM

Christine Hale
Texas Sea Grant
chris.hale@tamu.edu

Larissa Graham
Mississippi-Alabama Sea Grant
larissa.graham@auburn.edu

Emily Maung-Douglass
Louisiana Sea Grant
edouglass@lsu.edu

Stephen Sempier
Mississippi-Alabama Sea Grant
stephen.sempier@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant
swanndl@auburn.edu

Monica Wilson
UF/IFAS Florida Sea Grant
monicawilson447@ufl.edu

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GOMSG-G-15-004
EMERGING SURFACTANTS, SORBENTS, AND ADDITIVES FOR USE IN OIL SPILL CLEAN-UP

Emily Maung-Douglass, Larissa Graham, Christine Hale, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson

Responders used the oil dispersants Corexit 9527A and 9500A to combat the 2010 Deepwater Horizon oil spill. What other products are currently available or in development to remove oil from water in future spills?

CURRENT APPROACHES

Deepwater Horizon (DWH) oil spill responders used sorbents and chemical dispersants to lessen the 172 million gallon spill’s impact on ecologically sensitive and valuable marine habitats in the Gulf of Mexico.

Because oil and water do not mix, oil slicks occur on the water’s surface. Booms, which often include sorbent materials to absorb oil, help keep slicks from spreading. Man-made materials like plastic, and natural materials like peat moss, straw, clay, and felted wool all work as sorbents. When responders retrieve sorbent booms, they also remove any absorbed oil.

Dispersants do not remove oil from the water. Instead, surfactants in dispersants like Corexit 9527A and 9500A help break the oil into small droplets. Microscopic sea life called microbes live throughout the marine environment. Some types of microbes ingest the easy-to-break-down portions of oil as part of their natural diet. Certain types of oil and small oil droplets are more readily consumed by microbes.
and can be more completely broken down than other types of oil.

DWH oil spill responders applied 1.84 million gallons of dispersants at the wellhead and on the slick to reduce aquatic life and shoreline oiling and to enhance the natural breakdown of oil by microbes. Tests conducted by the U.S. Environmental Protection Agency (U.S. EPA) show that Corexit 9500A has toxicity levels similar to other commercially available chemical dispersants.6 Despite these findings, lingering concerns over human and aquatic health has led community members to ask what other approaches might be available for oil spill response.7 More rigorous studies documenting human health risks are ahead in the future. These studies will better inform impacted communities.

EMERGING SOLUTIONS

Surfactants inspired by microbes

The abundance of oil-consuming microbes increases where an oil spill occurs.4,5 Laboratory tests show that some types of microbes can degrade as much as 65 percent of oil in the water in a little more than one week, depending on the type of oil.8 Multiple species of microbes produce their own surfactants to help them digest oil.9-10 These natural surfactants show promise for use in oil spill response because they are effective, disintegrate easily in the environment, and tend to have low toxicity. The surfactants produced by microbes consist of compounds including sugars, amino acids, and lipids.10-12 Because of the great need for such surfactants, scientists in the laboratory are creating surfactants modeled after microbial-based ones and searching for the genes that produce these surfactants.12,13 Surfactin is an example of a compound naturally produced by microbes that is effective at breaking up oil slicks. However, it does not mix well with water. Scientists are modifying microbes to produce a form of surfactin that effectively breaks down oil and mixes with water.11

Everyday materials – Finding treasure in unexpected places

Everyday items can be useful during oil spill response, too. Soy lecithin, a soybean by-product, is a natural surfactant commonly used to create smooth, creamy textures in processed foods. Because it attracts both water and oily, fatty substances, scientists think it might work well as a surfactant in oil spill response. Soy lecithin’s safety for human consumption makes it an attractive alternative to current chemical dispersants. But applying soy lecithin alone to an oil slick does not get lasting results — the droplets eventually reform slicks. Scientists are mixing soy lecithin with other food-grade surfactants or altering soy lecithin in the lab to keep oil slicks from reforming (Figure 1).14-16 Soy lecithin-surfactant mixtures produce smaller and more stable oil droplets than Corexit 9500A to provide microbes with a steady meal of oil.14

Sorbents also can be crafted from everyday materials. Using plastic for oil spill clean-up combines old and new technologies and offsets oil and plastic pollution. Scientists have discovered they can create a thin, oil-absorbing film by melting and mixing together different types of plastics.17 The combination creates a gooey, gel-like material that later is chemically treated and stretched out to dry. The

**FIGURE 1.** While soy lecithin disperses oil (left image on panel a), it forms large oil droplets which re-form oil slicks over time (right image on panel a). A 60 percent-40 percent mixture of soy lecithin with another food-grade surfactant creates tiny oil droplets (left image on panel b) that stay evenly distributed in water over time (right image on panel b). (Adapted with permission from Athas, J. C., Jun, K., McCafferty, C., Owoseni, O., John, V. T., & Raghavan, S. R. (2014). An effective dispersant for oil spills based on food-grade amphiphiles. Langmuir, 30(31), 9285-9294. Copyright (2016) American Chemical Society.)
finished product is a thin film with many microscopic holes that trap oil.

Natural materials like jute and bagasse make great sorbents after some laboratory modifications. Jute is a natural plant fiber commonly used to create burlap sacks and rug backings (Figure 2). The remains of sugarcane stalks after processing are tough and full of fibers called bagasse (Figure 3). Both of these biodegradable fibers can serve as sorbents. However, it is not as simple as placing these fibers directly on an oil slick. Both materials absorb water, reducing their ability to take in oil. Scientists can modify the fibers to repel water and absorb more oil, making them more effective than sorbents made of plastic fibers. Bagasse modified in this way can absorb almost twice as much oil as traditional plastic-based sorbents.18 Some sorbents and newly-developed dispersant additives, including carbon black (CB) and chitosan, work differently. CB can be produced in a number of ways, including charring natural materials like wood, tar, and bone. It not only helps microbes break down oil, it attracts and bonds with potentially toxic oil-based compounds.19 When these potentially toxic oil-based compounds adhere to the CB, they are less likely to impact aquatic animals. When chitosan is added to Corexit, it reduces the amount...
of Corexit needed. Made by chemically modifying crustacean shells in the lab, chitosan works by preventing oil droplets from gathering together to re-form slicks. It also helps create a gel-like substance that stops oil droplets from moving, making oil physically easier to remove from water.

**Nantotechnology – Tiny materials with big impact**

Engineered **nanomaterials** are made up of pieces only nanometers in size. For reference, a nanometer is equivalent to 0.00000025 inches. That is 100,000 times smaller than the diameter of a human hair. Industry uses these tiny materials in everything from computers and cellular phones to workout clothing. Their next application could be oil spill clean-up.

Some nanomaterials show great promise as sorbents because of their ability to absorb oil and repel water. **Carbon nanotube (CNT)** sponges are one example. CNT sponges look like their name suggests, resembling large household sponges up to 10 inches in length (Figure 4). However, the sponges’ fibers are actually tiny tubes made of carbon. CNT sponges repel water, and some can absorb up to 23 times their weight in oil in only 15 minutes. Traditional sorbent materials like plastic fibers and felted wool can only take in eight to nine times their weight (Figure 5).

How do responders remove these innovative nanomaterials from the water after they have soaked up unwanted oil? Magnets may be the answer. Highly-engineered, magnetic CNTs effectively isolate and remove oil-based compounds from water, but CNTs can be expensive. Scientists have created relatively inexpensive, magnetic, iron-based nanoparticles in the laboratory. They

**WHEN WILL THESE EMERGING PRODUCTS BE USED?**

The new products mentioned in this bulletin are fascinating and many answer the increasing need for low-cost response tools that will not only breakdown oil, but also breakdown in the environment afterward. However, much testing, both in the lab and the field, and regulatory steps lay ahead before these products may be utilized during an oil spill.

To learn about the legal framework, including some of the testing requirements, governing the use of dispersants, visit the Mississippi-Alabama Sea Grant Law Center site and click on the keyword ‘oil spills’. [http://masglp.olemiss.edu/publications/index.html](http://masglp.olemiss.edu/publications/index.html)

add tiny, magnetized particles to coconut oil to create a suspension called a nanofluid. Magnetic coconut oil nanofluids are 91 percent effective at removing motor oil from water in lab tests. The coconut oil attracts and attaches to oil, allowing magnets to remove the mixture of magnetic particles, oil, and coconut oil from the water (Figure 6).

Nanotechnology can be used to do more than absorb oil. It efficiently carries and applies dispersant directly to individual oil droplets too.

Scientists are investigating how additives made from nanomaterials might combine with existing surfactants to improve oil spill clean-up. Nano-sized particles of silica create stable oil-water mixtures in the lab when paired with certain surfactants. Oil droplets in these mixtures are well-distributed, creating excellent conditions for natural breakdown by microbes. Halloysite nanotubes (HNTs) are another nanomaterial scientists combine with surfactants to improve oil spill clean-up. Scientists form them by rolling microscopic sheets of a naturally occurring clay called halloysite into nanometer-sized tubes. They fill these HNTs with the surfactant used in the dispersants Corexit.
9500A and 9527A. The HNTs stabilize oil-water mixtures and act as a delivery system for the surfactant (Figure 7). The mixtures’ stability improves as more HNTs are added, meaning the oil droplets are less likely to recombine into a slick. The number of small oil droplets increases with the amount of surfactant loaded on the nanotubes. This system makes the dispersant more efficient and increases microbes’ ability to consume the oil.

The Gulf of Mexico Research Initiative (GoMRI) and others continue to explore new possibilities in the realm of oil spill clean-up. To learn more about this and the research being conducted on the Deepwater Horizon spill, visit the Gulf of Mexico Research Initiative website at [www.gulfresearchinitiative.org](http://www.gulfresearchinitiative.org). Visit the Gulf Sea Grant program website at [http://gulfseagrant.org/oilspilloutreach](http://gulfseagrant.org/oilspilloutreach) to view other publications that provide additional information on the dispersants and the impact of oil and dispersant mixtures on aquatic animals.

GLOSSARY

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.

Carbon nanotube (CNT) — A nano-scale (1-100 nanometer, which equals 1-100 billionth of a meter) cylinder of carbon molecules. CNTs have novel properties that make them potentially useful in a wide variety of applications in electronics, optics, and other fields of materials science, as well as oil spill response.

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

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

Dispersant additives — Compounds added to enhance the abilities of dispersants.

Halloysite nanotubes (HNTs) — A nano-scale (1-100 nm) cylinder constructed from a naturally occurring aluminosilicate (halloysite). They have properties that make them potentially useful in a wide variety of applications including drug delivery, technology, and oil spill response.

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

Nanomaterials — Engineered materials of which a single unit is sized between 1 and 1000 nanometers (nm), but is usually 1—100 nm.

Silica — A mineral composed of silicon and oxygen. In nature, this mineral is a component of quartz and a major component of some sands. It is used by humans in some toothpastes, electronics, and pharmaceuticals.

Sorbents — Materials used to absorb oil during oil spill clean-up operations.

Surfactants — Compounds that work to break up oil. Dispersants contain surfactants that break the oil slick into smaller droplets that can more easily mix into the water column.

Suspension — A mixture of particles that are dispersed throughout a bulk of fluid.

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**SUGGESTED CITATION**

MICROBES AND OIL: WHAT’S THE CONNECTION?

Emily Maung-Douglass, Larissa Graham, Christine Hale, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson

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. 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.
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. When ideal energy sources are plentiful, like in the upper sediment layers of a beach, oil-eating microbes efficiently break down oil. However, breakdown is slower in deeper layers of the beach where lower oxygen levels create less ideal conditions for microbes to degrade oil.

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.

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. 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. 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. 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. Adding nitrogen to heavily oiled waters can fuel microbes to break down oil more quickly. Stimulating the natural microbial community into breaking down oil is a form of bioremediation and considered another response tool. 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.

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

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)

Nutrients such as nitrogen and phosphorus also dictate oil breakdown rates. (U.S. Fish and Wildlife Service/Tom MacKenzie)
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. 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. 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. However, while dispersant use may increase production of EPS, dispersants can also disperse EPS which reduces marine snow formation.

As the marine snow sinks through the water column, it combines with oil droplets, carrying oil to the sea floor. 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. Pellets of zooplankton feces carry any oil eaten to the seafloor. Oil carried by the marine snow to the sea floor may accumulate over time. 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. 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)
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.\textsuperscript{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.\textsuperscript{12} Additionally, oil-eating microbes can also break down dioctyl sodium sulfosuccinate, or \textbf{DOSS}, a major component of the dispersants \textbf{Corexit 9527A} and \textbf{9500A}, used during the DWH oil spill.\textsuperscript{16}

Other research indicates that dispersants can have negative impacts on oil-degrading microbes.\textsuperscript{12,32} 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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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 \url{www.gulfresearchinitiative.org}. Visit the Gulf Sea Grant program website at \url{http://gulfseagrant.org/oilspilloutreach} to view our other publications, about dispersants, oil, and other topics.
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.

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)
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**SUGGESTED CITATION**


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**OIL SPILL SCIENCE OUTREACH TEAM**

**Christine Hale**
Texas Sea Grant College Program
chris.hale@tamu.edu

**Emily Maung-Douglass**
Louisiana Sea Grant College Program
edouglass@lsu.edu

**Stephen Sempier**
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

**Tara Skelton**
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

**LaDon Swann**
Mississippi-Alabama Sea Grant Consortium
swanndl@auburn.edu

**Monica Wilson**
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine, and Great Lakes resources in order to create a sustainable economy and environment. There are 34 university–based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10–year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20–member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

The main goal of oil spill response is to protect people and natural resources to the best extent possible. How do emergency responders stay coordinated when faced with an oil spill? Even before an oil spill occurs, emergency response professionals gather at local and regional levels, often multiple times per year. Attendees at these Regional Response Team and Area Committee meetings represent agencies from several sectors, including local, state,
and federal government, industry, and sometimes non-governmental organizations. Topics of discussion include response techniques, lessons learned from previous spills, and planning for future spills. Responders also discuss documents – known as Contingency Plans – used for guidance on response options. Area Committees also participate in training exercises to prepare for a multitude of oil spill scenarios.

ASSESSING AND RESPONDING TO THE SPILL

The foremost concern of emergency response workers is human safety, followed by protecting natural resources. Responders try to reduce any damage from the spill by predicting where oil may end up in the environment and determining the best strategies to protect animals and habitats. Action must be taken quickly, as spilled oil can spread rapidly with winds and currents, coat aquatic life, and impact habitats such as wetlands. There are many types of response tools, each with their own applications. They may be used alone but are often used in concert with one another (Cover image; Table 1).

For example, booms may be used to restrict the movement of oil and to deflect oil away from sensitive areas. Once the oil is corralled with a boom, emergency responders may remove the oil from the water using methods, such as skimmers, sorbents, solidifiers, or in situ burning. Each spill is unique and each tool has its own set of limitations and considerations (Table 1). Therefore, no ‘one-size-fits-all’ response technique can be used for every spill. Emergency responders take multiple factors into account when selecting response strategies. For example, the type of oil involved helps guide the selection of response tools since light and heavy oils may each be more easily cleaned using specific strategies. Further, environmental and spill conditions – such as wind, waves, ice, debris, and oil volume – create challenges during response and may make it difficult to use certain clean-up strategies. Responders must weigh the environmental trade-offs of each response option in the context of the situation – including doing nothing – to reduce harm to animals and habitats (Table 1).

FIGURE 1. The Incident Command System (ICS) has many players. Together they work toward the common goals of protecting human safety and natural resources. Depending on the nature of the incident, an intelligence/investigations section may be included as well. (adapted from NOAA, 2013)

WHO IS IN CHARGE?

To respond to an oil incident in a coordinated way, an incident command system (ICS) is used (Figure 1). Unified Command (UC) is formed within the flexible structure of the ICS. In UC there are at least three distinct groups represented which must include the federal government (U.S. Coast Guard Federal On-Scene Coordinator, FOSC), the state government (State On-Scene Coordinator, SOSC), and the responsible party (Responsible Party Incident Commander, RPIC). Depending on the nature of the incident, additional groups may be represented in the UC, such as tribes. Working together as a unit, UC makes decisions regarding how to achieve desired outcomes. Other personnel support UC in many areas, including operations, planning, logistics, finance, and in some situations, intelligence/investigations. A scientific support coordinator (SSC) also acts as the lead scientific advisor, supporting the U.S. Coast Guard FOSC and informing scientific decision making. The SSC has a suite of duties and may work with a scientific support team (SST) to achieve them. The duties include but are not limited to reporting the environmental hazards associated with the oil involved, sharing the forecasted movement of oil in the environment, gathering scientific information from various sources to aid in creating response plans, and evaluating the environmental impacts and outcomes of potential clean-up methods. In coastal and offshore spills, the National Oceanic and Atmospheric Administration (NOAA) fulfills the SSC duties, while the U.S. Environmental Protection Agency (EPA) is the SSC for inland spills.
Berms—Physical barrier constructed from sediments that prevent oil from entering shoreline habitats.39,40
• Berms require large amounts of sediment from other locations.39,40
• Construction can be costly.40
• Berms are unlikely to stay in place in the long term.40
• Stirred up sediments can decrease water quality and negatively impact aquatic life.40

Booms—Plastic, metal, or sorbent barriers that float on the water’s surface, preventing oil from spreading into surrounding waters or sensitive habitats.4
• Used sorbent booms require proper oil disposal and fire-resistant booms can be cumbersome, expensive, and break down quickly during use.2,11
• Waves can cause the oil to ‘jump’ over or under the boom.9
• Booms can come ashore in event of unexpected extreme weather and damage onshore habitats, like wetlands.41 Anchors remaining in the water can create boat hazards (NOAA, personal communication, March 2020).

Dispersants—Chemical mixtures that allow oil and water to mix, creating tiny oil droplets from oil slicks, speeding up the breakdown of oil by microbes, sunlight, and evaporation.42
• Many formulations of dispersant exist.20,42
• Dispersants may protect air quality by reducing the volatile oil-based compounds released into the air.42
• Laboratory studies indicate mixtures of oil and dispersant increase exposure of aquatic life to oil-based compounds and can cause negative effects to the organisms.20,22,23,43
• They are best used during early days of a spill, while oil is still fresh.42

Diversions—Sending a river from its natural course, allowing large discharges of freshwater to flush oil away from shore to protect sensitive habitats.40
• Diversions are not a standardly used method (NOAA, personal communication, March 2020).
• They may result in large losses of organisms sensitive to salt-levels like oysters because of extended exposure to freshwater.40,44,45

In situ burning—Setting an oil slick on fire at the site of the spill, which can remove up to 95% of oil from the water, converting it mainly into carbon dioxide and water.6,10,11,46
• Oil slicks must be at least 0.04 inches thick – about the thickness of a dime.11

Skimmers—Mechanical devices that remove oil from the water’s surface.7,9
• Multiple types exist.7 Some act like a dam, trapping oil, while others work by suction. Others have a rotating surface – such as a drum or belt – that attracts oil, which is then scraped off into a collection container.31
• Skimmers minimally impact the environment.2
• Skimmers can be slow and ineffective when dealing with thick, viscous, or weathered/emulsified oil; diesel and gasoline; or heavy wind/wave conditions.9
• Recovery of oil from the water can depend on the thickness of oil layer present.12
• Marine debris can jam the skimmer, complicating clean-up efforts.31

Solidifiers—Semi-solid, porous material that is attractive to oil and creates a solidified mass that responders can physically remove from the water.5
• Solidifiers may be stuffed into booms or sprinkled on surface of water.5
• Solidifiers will not leak the absorbed oil but may sink after mixing with oil.5

Sorbents—Products made from both natural and manmade materials that attract and soak up oil to remove it from the water.8,47
• Sorbents can hold between 3 to 70 times their weight in oil.5,47
• Sorbents may be stuffed into booms or crafted into absorbent pads to scatter onto the water’s surface.8
• Lighter, thinner oil tends to leak from during removal from water due to the added weight of the recovered oil.8
SPECIAL MONITORING OF APPLIED RESPONSE TECHNOLOGIES (SMART)

Protecting humans and minimizing damage to natural resources are the highest priorities for emergency responders. The Special Monitoring of Applied Response Technologies (SMART) is a collaborative program – made up of the U.S. Coast Guard, National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA), Centers for Disease Control and Prevention (CDC), and Bureau of Safety and Environmental Enforcement (BSEE) – to help ensure that these needs are met when certain response techniques such as dispersants and in situ burning are used. During an active spill, teams collect real-time data, such as air and water samples, from the field to monitor spill conditions.

INNOVATIONS AND NEW DIRECTIONS IN RESPONSE

The design of response tools themselves can present challenges for response and opportunities for innovation.

Booms

There are several styles of boom, such as those stuffed with sorbents meant to absorb oil and those made from plastic or metal meant to deflect oil, often away from sensitive habitats. Using a single boom is not always effective at containing a spill. By pairing together different types of booms, any oil that ‘jumps’ the initial boom may be contained or absorbed by a secondary boom (Figure 3). Towing strategies and configurations of multiple boom systems have been a focus of research to enhance collection and deflection of oil, depending upon the situation. Additionally, modifications of the four basic types of fire-resistant boom – stainless steel, ceramic, water-cooled, and thermally resistant fabric – are continually developed by industry.

Dispersants

Dispersants are a continual focus of research. The first dispersants debuted in 1967 and were industrial degreasers, chemically different from the dispersants responders and oil spill scientists in the U.S. run test scenarios at facilities, like Ohmsett, a government facility with a wave tank over 660 feet in length that holds 2.6 million gallons of seawater (Figure 2). At this facility, scientists from academia, industry, government, and other organizations test oil spill clean-up technologies under a variety of simulated spill conditions, including heavy waves and ice (Figure 2).

FIGURE 2. Researchers take oil and water samples from the wave tank at Ohmsett during oil spill response testing.

TESTING OIL SPILL RESPONSE TECHNOLOGIES

The United States does not allow intentional oil spills in the environment for any purpose, including testing new response technologies. In the U.S., BSEE is developing Technology Readiness Levels (TRLs) to make development of experimental oil spill technologies as smooth, direct, and cost-effective as possible. Emergency
in use today.\textsuperscript{18,19} Those early dispersants were highly toxic, killing much of the aquatic life on the rocky shorelines where they were applied.\textsuperscript{18} In contrast, the main dispersant used during Deepwater Horizon oil spill was Corexit 9500A, which has low toxicity.\textsuperscript{20,21} However, dispersants do increase the availability of oil-based compounds in the water, which can cause negative impacts to aquatic life.\textsuperscript{20,22,23}

Dispersant use continues to be regulated via the National Contingency Plan.\textsuperscript{1} Its application is not permitted near shorelines, vessels, or people.\textsuperscript{24} Dispersants have been used rarely in the U.S. and not since the Deepwater Horizon oil spill in 2010.

Ongoing research is examining how clay minerals like halloysite can be combined with a surfactant found in existing dispersants, such as Corexit 9500A. The clay minerals act as cargo vessels for surfactant molecules, delivering them in a targeted way to the surface of microscopic oil droplets. This technique reduces the amount of dispersant needed.\textsuperscript{25} Scientists are also developing combinations of food-grade surfactants that create smaller oil droplets than current dispersant technologies.\textsuperscript{26,27} The smaller oil droplets created are more easily broken down by oil-eating microbes than larger droplets.\textsuperscript{26}

**In situ burning**

In the past, responders ignited oil on the water’s surface from nearby vessels.\textsuperscript{17} In recent years, the development of aircraft-delivered ignition devices has enhanced in situ burning operations. These ignition devices are gels specially engineered to sustainably burn at temperatures of 1472°F for several minutes.\textsuperscript{17} This provides just enough heat to ignite even heavy oils which are often hard to clean up.

While the design of fire-resistant booms used to contain oil for an in situ burn are continually being improved, they can be cumbersome, expensive, and broken-down quickly during use.\textsuperscript{11,17} For this reason, surface collecting agents (SCAs) – an alternative to fire-resistant booms – are a hot topic in in situ burning research, though they have existed for some time (see sidebar).

**Surface Collecting Agents (SCAs) AKA ‘Chemical Herders’**

When applied at the outer edge of an oil slick, SCAs work at the molecular level to ‘herd’ oil to a smaller area (Figure 4).\textsuperscript{28} This may enable emergency responders to mechanically recover the oil with skimmers or remove it through in situ burning. The latter is possible because SCAs can create a layer of oil thick enough to sustain an in situ burn.\textsuperscript{29,30} In cold climates, SCAs could be valuable as well since ice acts as a physical barrier, making deploying booms difficult.\textsuperscript{29} As of 2019, two chemical surface collecting agents – ThickSlick 6535 and OP-40 – are listed on the National Contingency Plan Product Schedule but have never been used in active spill situations.\textsuperscript{1,30}

**Skimmers**

Scientists continue to investigate new ways to increase the efficiency of skimmer design, mechanics, and other response tool pairings.\textsuperscript{31,32} Currently, oil recovery is fast when a thick oil layer is present but relatively slow when only a thin layer exists.\textsuperscript{12} Additionally, it is difficult to remove all of the oil from the skimmer surface – it often transfers from the skimmer back into the water.\textsuperscript{31} To overcome these issues, scientists developed a skimmer with a grooved surface that improves the removal of oil from the water by as much as 33% over traditional skimmers.\textsuperscript{31} This modified design works with a wide range of oil types and nearly all the oil on the skimmer can be recovered for disposal. Another method under research increases oil removal efficiency by using a high-tech solidifier to absorb oil in the water and collect it via skimmer.\textsuperscript{32}
Sorbents and solidifiers

Sorbents may be made from a variety of materials, both natural and human-made. These often include human-engineered modifications of pre-existing materials such as mixtures of plastics or natural fibers chemically modified to retain less water and more oil.33,34 The development of aerogels – springy sorbents like those found in diapers – from recycled paper waste are another innovation.35 These sorbents have an excellent ability to soak up oil but have the added advantage of being biodegradable. In the realm of solidifiers, ‘gelators’ derived from natural materials like sugar are a focus of innovation.36-38 Gelators bond with oil to form a gel that can be removed from the water. Naturally-derived gelators are attractive because of their ability to break down in the environment and low toxicity.38

WHERE DO WE GO FROM HERE?

The Gulf of Mexico Research Initiative (GoMRI) and others continue to develop an understanding of oil spills. To learn more, 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, sorbents, oil, and other topics.

GLOSSARY

**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.

**Heavy oil** — Oil, whether crude or refined, that does not flow easily due to its chemical composition.

**Light oil** — Oil, whether crude or refined, that flows easily due to its chemical composition.

**Sediment** — Natural materials (including rocks, minerals, and remains of plants and animals) broken down by weathering and erosion, and then transported and deposited to a new location by wind, water, or ice or gravity.

**Sorbents** — Materials used to absorb oil during oil spill clean-up operations.

**Solidifiers** — Porous materials that physically bond with oil, causing the oil to solidify for removal during oil spill clean-up operations.

**Surfactants** — Compounds that work to break up oil. Dispersants contain surfactants that break the oil slick into smaller droplets that can more easily mix into the water column.
REFERENCES


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SUGGESTED CITATION

OIL SPILL SCIENCE OUTREACH TEAM

Dani Bailey  
Texas Sea Grant College Program  
danielle.bailey@tamu.edu

Emily Maung-Douglass  
Louisiana Sea Grant College Program  
edouglass@lsu.edu

Missy Partyka  
Mississippi-Alabama Sea Grant Consortium  
m.partyka@auburn.edu

Stephen Sempier  
Mississippi-Alabama Sea Grant Consortium  
stephen.sempier@usm.edu

Tara Skelton  
Mississippi-Alabama Sea Grant Consortium  
tara.skelton@usm.edu

LaDon Swann  
Mississippi-Alabama Sea Grant Consortium  
ladon.swann@usm.edu

Monica Wilson  
Florida Sea Grant, UF/IFAS Extension  
monicawilson447@ufl.edu

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HELPING OILED ANIMALS RECOVER: GULF OF MEXICO

When a marine oil spill occurs, animals like birds, dolphins, whales, and sea turtles who migrate throughout a wide range of habitats tend to be at high risk of exposure.

Migratory marine animals move through coastal marshes, shallow bays, and deep water to eat, grow, and mate. Oil and spill-related chemicals can enter all of these habitats, putting birds, dolphins, whales, and sea turtles in danger of breathing in oil, eating it, or absorbing it through the skin.

Experts in the emergency response community are trained in how to rescue oiled animals. Yet beachcombers, boaters, fishermen, beach hotel staff, and others working and playing along the coast may also encounter oiled or injured wildlife and not know how to help. Learn what to do if you come across an oiled animal, and call the experts, listed below.*

<table>
<thead>
<tr>
<th>Dolphins and Whales</th>
<th>Birds</th>
<th>Sea Turtles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TX</strong> 877-WHALEHELP or 800-962-6625</td>
<td><strong>TX</strong> 512-389-4848 or 281-842-8100</td>
<td><strong>TX</strong> 866-TURTLE5</td>
</tr>
<tr>
<td><strong>LA</strong> 877-WHALEHELP or 504-235-3005</td>
<td><strong>LA</strong> 800-256-2749 or 225-765-2800</td>
<td><strong>LA</strong> 337-962-7092</td>
</tr>
<tr>
<td><strong>MS</strong> 877-WHALEHELP or 888-767-3657</td>
<td><strong>MS</strong> 601-576-6000</td>
<td><strong>MS</strong> 228-369-4796</td>
</tr>
<tr>
<td><strong>AL</strong> 877-WHALEHELP</td>
<td><strong>AL</strong> 334-242-3469</td>
<td><strong>AL</strong> 866-SEA-TURT</td>
</tr>
<tr>
<td><strong>FL</strong> 877-WHALEHELP or 888-404-3922</td>
<td><strong>FL</strong> 888-404-3922</td>
<td><strong>FL</strong> 888-404-3922</td>
</tr>
</tbody>
</table>

There’s an app for that!
To access state stranding information or to download the Dolphin & Whale 911 application for your phone, visit http://bit.ly/19KX6Hv.

*What if it's a sizable spill?*
In the event of a large spill, check the media for a temporary hotline that can be set up to assist these agencies with the volume of calls.
From 2010 through 2014, 1,101 dolphins and whales were found stranded along the coasts of Alabama, Mississippi, and Louisiana.\textsuperscript{1,2} This was the largest known marine mammal die-off in the Gulf of Mexico. Experts determined that this unusual die-off was in part due to oil exposure from the Deepwater Horizon oil spill. Oil exposure led to reproductive failure and sickness in dolphins living within oiled waters.\textsuperscript{1,2}

Scientists estimate that the oil spill killed nearly 35,000 hatchling sea turtles, between 55,000 and 160,000 small juvenile sea turtles, and between 4,900 and 7,600 large juvenile and adult sea turtles.\textsuperscript{2,3} However, more than 28,000 eggs from 274 nests were excavated and moved from Florida and Alabama beaches to a protected hatchery on the Atlantic coast of Florida.\textsuperscript{2,3} Nearly 15,000 baby turtles emerged from these nests and made their way into the Atlantic Ocean.\textsuperscript{2,3}

**REFERENCES**


**SUGGESTED CITATION**


**ACKNOWLEDGMENT**

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TAMU-SG-18-501  GOMSG-G-18-004
Scientists are studying aquatic ecosystems in order to fully understand the 2010 Deepwater Horizon oil spill’s impact. Knowing how oil and dispersants might affect fisheries can help natural resource managers maintain healthy Gulf of Mexico ecosystems and protect the livelihoods of the people who depend on them. The following publication highlights some examples of the way species were affected by the spill.

INTRODUCTION

Oil is a mixture of many compounds. Some are known as hydrocarbons. These form from decomposed organic matter and occur in crude oil and natural gas. There are different types of hydrocarbons in oil. One type of hydrocarbon is a polycyclic aromatic hydrocarbon (PAH). Some PAHs can be harmful to living things.¹ Emergency response teams sometimes use chemicals such as dispersants to reduce the effects of oil spills. Dispersants break up spilled oil into smaller droplets. These smaller dispersed oil droplets can become more available
to the Gulf’s tiny aquatic microbes. These microbes consume oil and remove it from the ecosystem (Figure 1). Dispersants that are used on offshore oil spills can help prevent large quantities of spilled oil from drifting onto shorelines where cleaning up oil is challenging.

Individual creatures, entire populations, or communities of interacting organisms can be impacted by oil spills. For instance, if small fish die from exposure to oil, then other fish or birds that normally eat those small fish will have to find other food. This alters the food chain and could have consequences throughout an entire food web, including effects to the seafood that people eat.

When trying to understand how the oil spill affected fisheries, scientists conduct studies on three different levels:

1. The individual level, or how oil spills may impact a single living thing (like a fish).
2. The population level, or how oil spills may impact a group of living things of the same species.
3. The community-wide level, or how oil spills may impact many different kinds of living things in an area or habitat.

By dividing studies into these general levels, scientists can investigate impacts to the complex Gulf of Mexico ecosystem. Figure 2 portrays this approach, and the following sections highlight examples of impact studies that scientists have conducted since the spill.

**FIGURE 1.** A microscopic image of oil droplets being colonized and consumed by bacteria (a type of microbe) *P. aeruginosa*. As bacteria eat, the oil droplets change in size and consistency. Photo by DROPPS/Tagbo H.R. Niepa, adapted by Chris Hale

**FIGURE 2.** Diagram of scientifically documented impacts from the Deepwater Horizon oil spill, organized by level: the organism or individual level, the population level, and the community or ecosystem level. See the figure key for symbol description. Adapted by Florida Sea Grant/Anna Hinkeldey/USF with permission from CWC/Joel Fodrie.

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1. Physiological and developmental consequences
2. Potential mortality, especially for young fish
3. Habitat loss, degradation or alteration
4. Changes to base of food chain
5. Fishery closures

- Established negative effects of oil
- Effects of oil are unclear
- Indicates direct (solid) and indirect (dashed) effects of oil (+ other stressors) on fishes
INDIVIDUAL-LEVEL IMPACTS TO FISH

When an oil spill occurs, animals in ocean and coastal waters may be exposed to oil and dispersants in several ways. This exposure can impact their health. For example, fish breathe by passing oxygen-rich water across their gills. In doing so, oil-polluted water can make contact with the gills and cause damage. This makes respiration challenging.\(^4,5\) Contaminants can also enter the bloodstream through the gills and then be delivered into the fish’s other body parts, which can harm or kill them.\(^6\) Fish can also be exposed to PAHs when they eat prey tainted with oil.\(^5\) Additionally, bottom-dwelling fish and other animals could potentially be exposed to PAHs from contaminated sediments when their skin makes direct contact with the sea floor.\(^6\)

Gulf killifish are an abundant bait fish in the Gulf and tend to stay within a small area for their entire life. Killifish are regarded by scientists as a sentinel species whose presence or absence, abundance and relative well-being can indicate the general health of its environment.\(^3\)

Thus, scientists often test these fish to monitor oiled Gulf coastlines. Scientists have found that Gulf killifish experience negative effects to their genes, enzymes, gills, heart, blood vessels, and embryos when exposed to oil and dispersants.\(^4,7,8,9\)

After the oil spill in 2010, numerous fishermen reported seeing skin lesions (sores) on offshore fish species like red snapper, yellowedge grouper, tilefish, and others.\(^6\) These observations raised questions about the cause-and-effect relationship between the oil spill and fish health. Scientists verified that for a short time after the spill, fish were exposed to elevated levels of PAHs.\(^6\) During that time there was also an increase in the occurrence of fish skin lesions.\(^6\) However, scientists could not directly link DWH oil samples to the fish that had lesions. Through further testing, many other possible sources of contamination were eliminated as causing the lesions.\(^6\) The frequency of lesioned fish in the northern Gulf has declined in the years since Deepwater Horizon oil spill (DWH).\(^6\)

population impacts

The DWH spill happened when many aquatic species were spawning in the Gulf. Eggs, embryos, and larvae were at risk of exposure to oil and dispersants.\(^11\) Studies have shown negative impacts to individual fish.\(^4,6,7,8,9\) Scientists want to know if those impacts carry over to entire populations of fish or other wildlife.

Scientists think that fish eyes could become biomarkers of environmental pollution.\(^10\) A part of the eye known as the lens has been found to reveal information about an individual fish’s life, such as where it has lived.\(^10\) To figure out the connection between fish lenses and their habitats, scientists remove the eyes from captured fish. They then read certain parts of the eyes to look for chemical clues—similar to reading a tree’s rings to learn its age. Scientists want to know if a fish that lived in a polluted area will have remnants of that pollution in its eyes. This idea is still being tested, and someday it might be possible to link fish to local contaminants by analyzing their eyes (Figure 3).\(^10\)
To determine the population level impact to red snapper, scientists observed population numbers of young red snapper using reefs. Young red snapper normally move from coastal nursery areas to inshore and offshore reefs to continue growing. Therefore, scientists set up artificial reefs along coastal Alabama to count young red snapper for a year after the spill. They could not link red snapper recruitment levels on those reefs to the oil spill. However, at one study site they discovered that the presence of older and more territorial red snapper influenced how many younger red snapper lived near that particular site. Low oxygen conditions also played a role in recruitment. Factors like habitat preference, fish behavior, and environmental condition are important in assessing the impact of oil spills on fisheries and the Gulf ecosystem.

Blue crab is another vital fishery species that was spawning in the northern Gulf of Mexico when the DWH oil was spilling. Scientists had questions about the impact to blue crab larvae and how different groups of blue crabs were interacting with each other. In nature, sub-populations (or smaller groupings) of a species usually live in different locations within a region. The individuals from these sub-populations move around in order to mate or find food. Blue crabs (and other creatures) benefit from interacting with one another because these connections help them survive if a disaster like an oil spill happens. To better understand this population connectivity, scientists looked at blue crab larval dispersal and larval settlement. Field studies of the movement of large numbers of live, tiny, aquatic organisms like blue crab larvae are very challenging and costly. Instead, scientists used computer models to make predictions about dispersal and settlement. They calculated that a portion of the Gulf blue crab population was exposed to oil during spawning time. They also determined that the blue crabs that survived oil exposure had settled in a particular area (east of the Mississippi River Delta). This type of species-specific and location-specific population information can help managers make decisions about prioritizing resource protection activities during future spills.

**COMMUNITY-WIDE IMPACTS**

Scientists can examine interactions between predators and prey to learn about oil spill impacts on aquatic communities. Exposure to contaminants could alter the species composition of food webs if species within the web change or decrease in numbers. For instance, species that are sensitive to pollution can diminish in abundance over time because they die or become unable to reproduce. If the number of a species decreases dramatically, then prey or predator population sizes could be altered. This could change the food web. Decades after the 1989 Exxon Valdez oil spill in Alaska, scientists continued to find oiled habitat and wildlife. Over the years they documented changes in the structure of food webs as species numbers changed.

Food web and community-wide impacts like those seen after the Exxon Valdez spill are a focus for many Gulf of Mexico scientists. Some are studying what fish are eating to gain clues about potential shifts in diet resulting from oil exposure. For example, a study found red snapper usually consume a variety of prey ranging from small zooplankton to fish and decapods. In that study, the scientists demonstrated that red snapper diets change as the fish grow.
They found that smaller red snapper consumed more fish prey.\textsuperscript{13} Larger, more mature red snapper included smaller organisms such as zooplankton as a substantial portion of their diet.\textsuperscript{13} After the DWH event, scientists found that adult red snapper shifted their diets away from zooplankton and increased their consumption of other animals like fish, squid, shrimp, and crabs.\textsuperscript{14} Some scientists believe that the diet shift could be a result of the oil spill because plankton populations in certain parts of the Gulf of Mexico experienced a temporary die-off during the spill.\textsuperscript{14} In the absence of zooplankton, larger red snapper had opportunistically fed on other prey.\textsuperscript{14} Feeding ecology information like this is useful to scientists as well as decision makers working to protect natural resources and the livelihoods of people who depend on them.  

In addition to food web studies, the number of different species found living together in a habitat can also help determine if there were oil spill impacts on fisheries. Fisheries scientists do this by catching fish and counting them. They compare population numbers within communities over time to look for changes. Scientists compared fish abundance and the type of species present at oiled versus unoiled marshes of Louisiana.\textsuperscript{15} They did not find any negative oil effects on type, abundance, or size of fish.\textsuperscript{15} Similarly, in coastal Alabama, scientists collected animals that normally use both offshore and nearshore habitats throughout their life cycle to see if exposure to oil offshore would affect their success in recruitment to coastal waters.\textsuperscript{16} Although they did find a short-term drop in amounts of both blue crab and grass shrimp immediately after the spill, those numbers recovered to pre-spill levels by 2012.\textsuperscript{16} Overall, the research did not find evidence of negative impacts at the community level.\textsuperscript{16}

FACTORS THAT INFLUENCE IMPACTS TO FISHERIES

Many factors must be considered when making conclusions about what affects fisheries. Some factors include fisheries management decisions, fishing effort, environmental conditions, and time of year. A fishery closure is an example of a management action made during and after the DWH oil spill. Emergency managers closed large fishing areas of the Gulf and reopened them when seafood test results showed safe levels for eating.\textsuperscript{17,18} The largest closure on June 2, 2010, was an area of 88,522 square miles, which is about 37 percent of the U.S. fishable waters in the Gulf of Mexico.\textsuperscript{18} This fishing closure may have enabled some species to survive and reproduce because they were not being fished.\textsuperscript{19,20} For instance, scientists collected fish in oil-affected seagrass meadows in the northern Gulf to assess the types of fish living there. Comparing catch numbers from 2006 through 2010, they found that the DWH oil spill did not negatively impact communities of

The decrease and delay in hatching of Gulf killfish is associated with developmental defects that are characteristic of oil exposure. Photos: RECOVER/Ben Dubansky

Long-term studies that synthesize the various pieces of the puzzle will provide answers to ecosystem impact questions.
estuarine fish. Mangrove snapper, pigfish, spotted sea trout, hardhead catfish, and sheepshead are some of the species they caught in greater numbers after the oil spill compared to before. Although many of those species spawned during the spill and their larvae were potentially exposed to oil-polluted water, the catch was still high after the spill compared to the four years before the spill. This suggests that fishing closures may have enhanced spawning and allowed more young fish to survive, so any negative oil spill impacts would be difficult to determine, especially in such a short time frame. Similarly, other scientists monitoring shrimp found that brown and white shrimp abundances increased in estuaries that were oiled from the DWH spill. One possibility for the increase could be that shrimp fishery closures gave shrimp more chances to reproduce and add to the population. More time, and more sampling, is needed to make conclusions about management decisions impacting fisheries during and after the spill.

Some scientists use the three-tiered approach (they study individual, population, and community-wide impacts) to understand oil spill impacts in the Gulf of Mexico, both in the short and long term. Thus far, oil spill science has shown evidence of negative impacts to individual fish in the Gulf. There has not been conclusive evidence that those negative impacts expand to populations and communities in the Gulf, as some people would expect. Scientists continue to explore factors influencing these results. For example, most study sites have a history of oil exposure and completely unoiled locations in the Northern Gulf no longer exist, so populations of marsh fishes may be conditioned to PAH exposure and able to survive oil exposure. Some scientists suggest that young transient animals, like the fish that spend their lives moving among estuaries, are better suited to cope with big disturbances like spills. Clearly, more work is required to assess the full extent of the suite of impacts to fisheries, including oil spills.

For emerging GoMRI-funded science related to fisheries and oil spills, and to view more bulletins like this one, visit the program website at www.gulfseagrant.org/oilspilloutreach.
GLOSSARY

Aquatic ecosystems
Communities of organisms that live in the water and are dependent on each other and on their environment. The main types of aquatic ecosystems are marine, estuarine and freshwater ecosystems.

Benthos
The flora and fauna found on the bottom, or in the bottom sediments, of a sea, lake, or other body of water.

Biomarker
A measurable substance in an organism whose presence is indicative of some phenomenon such as disease, infection, or environmental exposure.

Community
A group of populations of plants and animals in a given place.

Decapod
A crustacean of the order Decapoda, such as a shrimp, crab, or lobster.

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

Embryo
An unborn or unhatched offspring in the process of development.

Enzyme
A substance produced by a living organism that acts as a catalyst to bring about a specific biochemical reaction, such as digestion of food or metabolism of a toxicant.

Fisheries
All of the activities involved in catching finfish, shellfish or seafood.

Food chain
A series of organisms each dependent upon the next as a source of food.

Food web
A system of interlocking and interdependent food chains, where numbers of predators and prey species keep each population in balance.

Gene
A sequence of DNA that encodes a protein. A gene is the basic unit of heredity that is passed from parent to offspring, outfitting the next generation with traits of the parents.

Hydrocarbon
A compound composed of carbon and hydrogen atoms. Most hydrocarbons naturally occur in crude oil and natural gas and are formed from decomposed organic matter.

Larvae
The immature form of an animal that undergoes physical changes during its life.

Larval dispersal
The spread of larvae from a spawning location to a settlement site.

Larval settlement
Settlement phase of some animals which begin life as free-swimming larvae and eventually settle to locations on or near the sea floor.

Microbes
Very tiny or microscopic organisms including bacteria, fungi, archaea, and protists. Some microbes (bacteria and archaea) are the oldest form of life on earth.

Plankton
Very small or microscopic organisms that drift or float in bodies of water. Consisting of algae, protozoans, and the eggs and larval stages of larger animals, they are an important part of food webs.

Polycyclic aromatic hydrocarbons (PAHs)
A group of hydrocarbons commonly found in oil, tar, combustion of fossil fuels, burned wood and animal fats.

Population
A group of individuals that interbreeds and inhabits a specified area.

Population connectivity
The successful exchange of individuals between separated sub-populations.

Productivity
The rate that biomass or energy is generated in an ecosystem.

Recruitment
The addition of new individuals to a population by reproduction.

Respiration
The extraction of oxygen from the environment and resulting production of carbon dioxide.

Spawning
The release or deposit of eggs and sperm.

Species composition
All of the different organisms that make up a community within an ecosystem. This is important when trying to discover how an ecosystem works and how important different organisms are to an environment.

Zooplankton
Small animals, and the immature stages of larger animals, drifting in oceans, seas, and bodies of fresh water.
REFERENCES


OIL SPILL SCIENCE OUTREACH TEAM

Christine Hale
Texas Sea Grant
chris.hale@tamu.edu

Larissa Graham
Mississippi-Alabama Sea Grant
larissa.graham@auburn.edu

Emily Maung-Douglass
Louisiana Sea Grant
edouglass@lsu.edu

Stephen Sempier
Mississippi-Alabama Sea Grant
stephen.sempier@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant
swanndl@auburn.edu

Monica Wilson
UF/IFAS Florida Sea Grant Extension
monicawilson447@ufl.edu

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THE SEA GRANT and GOMRI PARTNERSHIP

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university-based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10-year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization and remediation technologies. GoMRI is led by an independent and academic 20-member research board. The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

Commercial fishermen have been harvesting shrimp in the Gulf since the early 1800s. Three commercially important types of shrimp are landed—browns, pinks and whites. (UF/IFAS photo)

In recent years, the Gulf of Mexico fishing industry has been negatively impacted by several disasters. Record-breaking hurricanes—Katrina and Rita in 2005 and Gustav and Ike in 2008—demolished infrastructure such as fish houses, boats, and supplies. The Deepwater Horizon oil spill of 2010 continued the devastation to both humans and natural resources, and the extent of the damage is still being investigated today. These disasters and their consequences have become significant in understanding fisheries, especially from a management perspective. Thus, the Gulf of Mexico Research Initiative (GoMRI; see sidebar) has funded scientists to investigate oil spill impacts, so that managers, as well as emergency responders, policy-makers, fishermen, and others can make informed decisions.

FISHERIES LANDINGS AND DISASTERS IN THE GULF OF MEXICO

Christine Hale, Larissa Graham, Emily Maung-Douglas, Stephen Sempier, LaDon Swann, and Monica Wilson

Coastal and ocean ecosystems provide benefits to people, including clean water, protection from storms, and food. Fishery resources are an essential part of those ecosystems and are considered to be common property. Thus, fisheries, or all of the activities involved in catching fish and shellfish, are managed by government for the benefit of all citizens. To manage and conserve fisheries resources, especially in the face of oil spill disasters, science is key.
This publication summarizes historical fisheries landings data for several significant Gulf of Mexico species within the context of manmade and natural disasters, and explores why this data is important for fisheries management. Emerging GoMRI–funded fisheries science is also introduced. Further fisheries science related to oil spills will be detailed in other publications within this series.

**LANDINGS**

Landings are the quantities, in number or weight, of seafood unloaded at a dock by commercial fishermen or brought to shore by recreational fishermen, as reported to biologists, resource managers, or seafood dealers. Landings information can include quantity and value of seafood products caught and sold to seafood dealers. Landings data are essential for interpreting harvest trends and gauging changes in fish stocks over time. A fish stock is a group of fish of the same species living in the same geographic area and reproducing with each other.

Landings are a type of fishery–dependent data, that is, information collected directly from the commercial and recreational harvest. Conversely, fisheries data collected by scientists who catch the fish themselves, rather than depending on fishermen and seafood dealers, is referred to as fishery–independent data. Fishery–independent data enables scientists to study specific factors influencing fish populations. Factors such as growth rate of a species, predator and prey interactions, environmental conditions, time of year, fishing regulations, type of gear used in catching fish, market prices and fishing effort (how much time, gear size, boat size and horsepower, used to harvest fish) are all some of the important considerations made in understanding landings trends and fisheries overall.

Both fishery–independent and fishery–dependent methods contribute valuable information to population assessments, but scientists rarely have enough resources to collect vast quantities of data over large geographic areas. Thus, scientists and resource managers rely on fishery–dependent data for management planning.

Ultimately, it is important for managers to analyze all aspects of fisheries, such as economics, in order to improve the long–term environmental health of the Gulf of Mexico, and the health of the people who depend on the Gulf for their livelihood. The seafood industry is economically important to Gulf of Mexico communities and to the nation. Healthy and productive fisheries provide jobs for both fishermen and the numerous support industries such as seafood processing, marketing, and monitoring, and vessel maintenance businesses like repair shops, marinas, and supply companies.

In 2012, the overall economic impact of the Gulf of Mexico seafood industry, expressed in terms of dollars generated from landings revenue, jobs, sales, income, and value–added impacts, totaled $35 billion (Table 1).

**TABLE 1. Gulf of Mexico seafood industry economic impacts (multiply by thousands) in 2012. Commercial fishermen landed 1.7 billion pounds of finfish and shellfish, making $763 million in landings revenue.**

<table>
<thead>
<tr>
<th></th>
<th>Number of Jobs</th>
<th>Landings Revenue</th>
<th>Sales</th>
<th>Income</th>
<th>Value Added</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>9,947</td>
<td>$46,340</td>
<td>$460,514</td>
<td>$172,314</td>
<td>$229,316</td>
</tr>
<tr>
<td>Louisiana</td>
<td>33,391</td>
<td>$331,165</td>
<td>$1,927,986</td>
<td>$659,974</td>
<td>$920,873</td>
</tr>
<tr>
<td>Mississippi</td>
<td>8,532</td>
<td>$49,295</td>
<td>$377,374</td>
<td>$149,147</td>
<td>$193,349</td>
</tr>
<tr>
<td>Texas</td>
<td>25,911</td>
<td>$194,044</td>
<td>$2,499,832</td>
<td>$677,391</td>
<td>$1,036,657</td>
</tr>
<tr>
<td>Florida</td>
<td>82,141</td>
<td>$141,671</td>
<td>$16,553,480</td>
<td>$3,092,392</td>
<td>$5,532,209</td>
</tr>
<tr>
<td><strong>Gulf Total</strong></td>
<td><strong>159,922</strong></td>
<td><strong>$762,515</strong></td>
<td><strong>$21,819,186</strong></td>
<td><strong>$4,751,218</strong></td>
<td><strong>$7,912,404</strong></td>
</tr>
</tbody>
</table>

This puts the Gulf in third place in the nation for landings revenue alone, out of total national landings.
TABLE 2. 2012 total landings and total landings revenue of U.S. fisheries, by region (in thousands).1

<table>
<thead>
<tr>
<th>Region</th>
<th>Landings (Pounds)</th>
<th>Landings (Revenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Pacific</td>
<td>5,261,421</td>
<td>$1,703,726</td>
</tr>
<tr>
<td>New England</td>
<td>664,243</td>
<td>$1,191,363</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>1,652,446</td>
<td>$762,514</td>
</tr>
<tr>
<td>Pacific</td>
<td>1,068,691</td>
<td>$661,994</td>
</tr>
<tr>
<td>Mid–Atlantic</td>
<td>751,144</td>
<td>$488,316</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>107,802</td>
<td>$170,938</td>
</tr>
<tr>
<td>Western Pacific</td>
<td>29,289</td>
<td>$91,513</td>
</tr>
<tr>
<td>U.S. Total</td>
<td>9,637,821</td>
<td>$5,099,456</td>
</tr>
</tbody>
</table>

revenue of more than $5 billion (Table 2).1 In terms of pounds of landings, the top 10 commercial fishing ports in the United States, in both 2012 and 2013, included four from the Gulf: Empire–Venice, La.; Intracoastal City, La.; Cameron, La.; and Pascagoula–Moss Point, Miss.4 These and other Gulf of Mexico fishing ports are crucial to a thriving seafood industry; thus, natural resource managers utilize landings and landings revenue data to make decisions that impact fishermen and the environmental health of the Gulf of Mexico.

Fishing regulations and management actions are a factor impacting landings and landings revenue. For example, federal and state agencies set quotas, or the maximum amount of fish that can be caught in a specified time period, for a fishery.3 Annual Catch Limits, or ACLs, are a type of quota, where fishermen can catch a certain amount of fish in one year.3 In addition to harvest limits, fishing areas may be closed temporarily, as they often are after natural or manmade disasters, out of concern for the health of the fish stock or seafood safety. For example, as a precautionary measure to ensure public safety during and after the Deepwater Horizon oil spill, large areas of the Gulf were closed to fishing from May through October 2010.5 In making management decisions such as these, scientists and managers incorporate multiple types of fishery–dependent and fishery independent data into stock assessment models. These models integrate the processes of natural death, growth, and fishery catch that affect a fish stock over time.3 Thus, if in a given year landings data are low, it may not be a lack of fish in the sea, but that a management action, environmental condition, or other factor is influencing population numbers.

LANDINGS AND DISASTERS

Many people have questions about the impacts disasters have had on fishery populations, and consequently, fisheries as a livelihood. Landings data are used by natural resource managers, fishermen, and others interested in the future of fisheries, to monitor change in populations. When managers incorporate landings trends into stock assessment models—models that include other potential influential factors, such as environmental conditions or regulations—they can determine if or how disasters impact fishery populations over time. For example, Figure 1 provides a snapshot of two Gulf of Mexico commercial fisheries landings from 1991 through 2013, including blue crab and the Eastern oyster.1,6,7 The timeline also shows the occurrence of major disasters during that time, highlighting a pos-
FIGURE 1. Recent disasters show some relationship to landings of blue crab and oysters, but the picture is incomplete. Managers must depend on additional indicators when assessing the health of the fisheries.6 Images credit: Gulf FINFO6

FIGURE 2. Both commercial and recreational red snapper landings are influenced by disasters, but managers must consider other factors influencing fish population numbers, such as management actions.6,7 Image credit: Gulf FINFO6

*Amount harvested, defined by NMFS as catch brought back to the dock in a form that can be identified by trained interviewers, plus catch used for bait, released dead, or filleted.7
FIGURE 3. Landings of the three main Gulf shrimp species can be affected by disasters, but fisheries managers consider other factors known to influence shrimp stocks, like weather, when making management decisions.\textsuperscript{7} Image credit: Gulf FINFO\textsuperscript{6}

FIGURE 4. Swings in Gulf menhaden landings happen frequently. Fisheries managers consider many factors, like changing seafood market prices, when drawing conclusions about disaster impacts.\textsuperscript{7} Image credit: Gulf FINFO\textsuperscript{6}
sible relationship between landings and disasters. In Figure 1, reported blue crab landings had decreased in 2010, the year the Deepwater Horizon oil spill disaster occurred. In 2011, after the oil spill, blue crab landings were reported to increase, which suggests a potential for recovery after the spill. However, events like oil spills or hurricanes are only some factors to consider when interpreting landings data.

Figure 2, for example, provides red snapper landings data for both the commercial and recreational sectors. This figure shows changes to this important Gulf of Mexico fishery over 23 years and includes, again, potential influential factors like storms and the Deepwater Horizon spill. From the graph, it appears that commercial red snapper landings rise and fall relative to such events. Red snapper landings, however, are also heavily impacted by annual catch limits. At first glance, the decrease in red snapper landings illustrated in Figure 2 would appear to be tied to the 2008 hurricanes. Yet, this is only part of the story; in 2007, a new Individual Fishing Quota Program (“IFQ,” a type of catch-share program that dedicates a secure share of fish to fishermen) was implemented for red snapper, and the annual catch limit under this program was significantly reduced in 2008. So, the decrease in 2008 landings could be due to the annual catch limit quota, and not necessarily the hurricane.

Another example of interpreting landings data within the framework of disasters is in Figure 3, which focuses on landings trends of three commercially important shrimp species in the Gulf of Mexico: brown (*Farfantepenaeus aztecus*), white (*Litopenaeus setiferus*) and pink (*Farfantepenaeus duorarum*) shrimp. It appears that shrimp landings drop when disasters strike but recover quickly; however, there are also dramatic drops and rises in landings in years when major disasters did not occur. Understanding shrimp life cycles, as well as environmental or climatic factors, may shed some light on the landings trends. Shrimp are short-lived and produce an abundance of offspring, which are dependent on nursery areas for survival. They are also unique as a fishery in that they can be caught almost year round (some Gulf states briefly close shrimping to allow for growth and spawning). Thus, shrimp are susceptible to environmental and climatic changes year round, such as heavy rainfall in late spring, or northerns in winter (a strong, cold, north wind blowing over the Gulf) (G. Graham, personal communication, May 13, 2015). These conditions can impact shrimp productivity, and subsequently, landings can be impacted. Disaster impacts must be considered alongside factors like these when interpreting landings trends.

The fishing industry is well aware that when landings are at risk of being impacted by disaster, then revenue from landings is also at risk. One example is the menhaden fishing industry, which has experienced negative impacts over its lifetime, mostly attributed to hurricanes. This fishery is one of the oldest and most valuable fisheries in the United States, and a significant component of the overall Gulf economy. Menhaden are used primarily for fish meal and oil, and small quantities are used for bait. In 2013, Gulf menhaden landings were valued at $95.3 million. Figure 4 depicts landings and landings revenue for menhaden, and how it has changed over time, relative to some disasters. Again, several factors must be considered when interpreting disaster impacts to landings.
Scientists use a seine net to collect fish near a marsh, another instance of fishery-independent data that contributes to our understanding of fisheries in the Gulf of Mexico. (LUMCON/CWC photo)

revenue, because annual trends vary depending on the changing state of seafood markets and the overall global economic market. However, as shown in Figure 4, menhaden landings and revenue dropped significantly in 2005 during Hurricane Katrina, and fishery managers have since attributed that drop to major loss in, and damage to, infrastructure such as seafood processing plants and fishing vessels. Conclusions like these are made using many years of fishery-dependent and fishery-independent data.

EMERGING SPILL SCIENCE

While landings data are significant monitoring tools, and are baselines for evaluating changes to fishery populations, they have limitations. As shown in the previous diagrams, landings data can help identify when changes occur, and identify potential relationships between significant events and landings numbers, but landings data alone cannot identify the exact cause of change. To better control for biological, ecological, and other factors involved with population studies, scientists must conduct fishery-independent studies to make reliable conclusions about impacts to fisheries. In doing so, GoMRI scientists are conducting catch studies as one step in the long-term process of understanding oil spill impacts to fisheries. For example, scientists compared data from trawls (fishing using a custom-made net behind a boat) conducted before (2006–2009) and after (2010) the Deepwater Horizon spill. Catch rate is the total number or poundage of fish captured from an area over a set period of time. They concluded that post–spill, an immediate loss of young, seagrass–dependent fish, such as spotted sea trout, pipefish, and gray snapper, among others, did not occur. The scientists noted that the higher catch rates in 2010 for typically fished species, such as gray snapper and spotted sea trout, might have resulted from post–spill fishery closures, a management action that occurred during the spill. Because fishing was not allowed after the spill, these scientists speculated that fish populations may have flourished, making oil spill impacts difficult to identify in catch rate studies such as theirs. If in the long term any impacts from disasters like Deepwater Horizon are to be revealed, then it is essential that research and the practice of monitoring landings continue. Comprehensive ecological and biological research, bolstered by landings data, is just beginning to reveal the more complete story on oil spills and fisheries—and the challenges in understanding the complex Gulf of Mexico ecosystem as time goes on.
**GLOSSARY**

**Annual Catch Limits**
A type of quota in which fishermen are allowed to catch a certain amount of fish in one year.

**Catch rate**
The total number or poundage of fish captured from an area over a set period of time.

**Effort**
The amount of time, gear size, boat size, and horsepower used to harvest fish.

**Fish stock**
A group of fish of the same species, living in the same geographic area, and reproducing with each other.

**Fisheries**
All of the activities involved in catching finfish, shellfish or seafood.

**Fishery–dependent data**
Fisheries data collected directly from the commercial and recreational harvest.

**Fishery–independent data**
Fisheries data collected by scientists who catch the fish themselves, rather than depending on fishermen and seafood dealers.

**Individual Fishing Quota Program**
A type of catch–share program that dedicates a secure share of fish to fishermen.

**Landings**
The quantities, in number or weight, of seafood unloaded at a dock by commercial fishermen or brought to shore by recreational fishermen, as reported to biologists, resource managers, or seafood dealers.

**Landings revenue**
The income from bringing fish and shellfish to shore for sale.

**Norther**
A strong, cold, north wind blowing over the Gulf.

**Quota**
The maximum amount of fish that can be caught in a specified time period, for a fishery.

**Stock assessment models**
Models that integrate the processes of natural death, growth, and fishery catch that affect a fish stock over time.

**Trawl**
A form of fishing where a net is typically pulled behind a boat to catch multiple species of fish and sea animals.
SKIN LESIONS IN FISH: WAS THERE A CONNECTION TO THE DEEPWATER HORIZON OIL SPILL?

Christine Hale, Larissa Graham, Emily Maung-Douglass, Stephen Sempier, LaDon Swann, and Monica Wilson

In the winter following the Deepwater Horizon oil spill of 2010, numerous fishermen reported seeing skin lesions on offshore fish in the Gulf of Mexico. Skin lesions are a relatively rare occurrence in offshore fish populations. People had questions about what caused the lesions and concerns about fish health and seafood safety.

FIGURE 1. A red snapper caught in the Gulf of Mexico by scientists studying fish skin lesions. Inset: A close-up photograph shows a lesion on the skin of a red snapper caught in Gulf waters after the Deepwater Horizon oil spill. The cause of this lesion is unknown. (C-IMAGE/ Steven Murawski)

WHAT ARE FISH SKIN LESIONS?

A fish skin lesion is generally a change in color or an opening in the skin or fins of a fish (Figure 1). Lesions can occur on the surface of the skin, and they can go deeper into the muscle or organs of a fish. Other lesions originate beneath the surface of a fish’s skin and push outward, spreading through to the surface (Figure 2a).

There are many causes of lesions. Skin lesions can develop when a fish is wounded by another animal or is injured from nets or traps. Contact with harmful
algae, fungi, bacteria, parasites, or toxins can also cause lesions. Poor nutrition, drastic changes in weather, environmental pollution, and other stressors can induce lesions (Figure 2b). Many of these factors can occur simultaneously, challenging scientists and natural resource managers when they try to identify a root cause of fish skin lesions.

**WHY DO FISH SKIN LESIONS CAUSE CONCERN?**

If too many fish are unhealthy and become unable to reproduce, that population of fish may decrease in numbers. A dramatic change in population numbers of a fish species can cause an imbalance in an ecosystem. It can also negatively affect the fishing and seafood industries. Unhealthy fish can signal to people that the surrounding environment may be unsafe not only for aquatic creatures, but for humans as well. Fish lesions or sores are unattractive and worrisome to tourists and anglers, potentially resulting in negative impacts on tourism and recreational fishing industries.

**DID THE DEEPWATER HORIZON OIL SPILL CAUSE INCREASED FISH SKIN LESIONS?**

Of particular concern about oil from the Deepwater Horizon (DWH) wellhead were the polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of hydrocarbons commonly found not only in oil and tar, but also in smoke from burning wood or tobacco, in grilled meats, and emissions from vehicles and power plants. Although PAHs naturally occur, some can be harmful to living things. Certain PAHs are known to cause cancer, birth defects, mutations, or even death in animals. The public also had questions about the use of chemical dispersants that emergency responders sprayed onto the surface oil slicks and injected at the leaking wellhead during DWH. Dispersants are used in oil spills to help break up oil into smaller droplets and prevent it from reaching shorelines where clean-up is more challenging.

Fish and other aquatic creatures can be exposed to PAHs in a variety of ways, including eating contaminated prey, swimming through an oil slick, or dwelling on the ocean floor where oil has settled. While the immune systems of fish are very sensitive to PAH pollution, they are able to break down oil compounds in their bodies. Fish response to oil exposure varies depending on the composition and concentration of the PAHs, fish species and age, duration of exposure, how they were exposed to oil, and many other environmental factors.

Scientists, natural resource managers, and emergency response managers have previously documented multiple types of PAH-related injuries to fish in other oil spills. For example, scientists found that exposure...
to PAHs and other chemicals in waters along the Pacific coast increased the risk for development of liver lesions in fish living there. Following the DWH oil spill, there were mounting questions from the fishing community about a perceived increase in Gulf offshore fish with skin lesions. This public concern led teams of scientists to investigate whether there was an increase in skin lesions in offshore fish and if the DWH oil spill caused the lesions.

No baseline information about fish lesions and associated PAH levels existed before the DWH spill. Without pre-spill information, there was no way to determine if fish lesions noted afterwards were a result of the spill. Scientists attempted to determine if PAHs caused the lesions in 2011 and again in 2012 by studying thousands of deep-dwelling fish. These fish included red snapper, red grouper, Gulf smoothhound, Atlantic sharpnose shark, yellowedge grouper, king snake eel, and golden tilefish. They recorded the various types of wounds they found on the fish, differentiating between lesions and mechanical damage (bite marks or injuries from fishing gear). After analysis in the lab, scientists confirmed the fishermen’s observations that during and shortly after the DWH spill, offshore fish were experiencing skin lesions. A consistent and relatively high frequency of skin lesions took place in 2011, especially near the DWH well site. The scientists also determined it was an episodic exposure. This meant that fish were exposed to increased levels of PAHs for a period of time and then exposure decreased. The lesions occurred for a short time in the year following the spill and then frequency decreased. By 2012, there appeared to be fewer lesions. The PAH concentrations measured in the fish were all well below levels of concern for seafood consumption.

The next challenge scientists faced was to find the source of the PAHs they identified in the lesioned fish. More specifically, they wanted to know if PAHs from DWH oil caused the lesions on the fish they sampled. To determine the source of the PAHs, researchers considered oil from many sources. They studied PAHs from natural seeps, rivers flowing into the Gulf, land runoff, atmospheric fallout, and low-level inputs from oil and gas production structures in the Gulf. Scientists eliminated each potential PAH source as the cause for the lesions.
Chemical tests did show a strong similarity between the PAHs in lesioned fish and the PAH samples of the DWH oil. However, lacking pre-spill baseline data, the results do not reveal a clear cause-and-effect connection.4

Scientists considered other potential causes for the lesions. Reduced salinity and temperature changes are known causes of stress in fish, so scientists compared historical salinity and temperature levels in the northern Gulf of Mexico to levels in 2010. They found salinity and temperature to be consistent and rejected them as factors causing the lesions.4

For now, scientists recognize there is a correlation between the skin lesion event and the increased PAHs in the water following the DWH oil spill. Long term monitoring of PAHs in Gulf finfish may help determine if the lesions were caused by the DWH oil spill.4

In the skin lesion study, scientists found that golden tilefish had the highest occurrence of lesions compared to other fish sampled in 2011 and 2012.4,14 To better understand the many factors involved in oil contamination of Gulf of Mexico species like golden tilefish, scientists compared PAH levels of fish living within, on top of, and away from the ocean bottom. They wanted to determine how oil exposure impacted fish living in these areas after the oil settled on the ocean floor.14

The scientists chose three species for their study: red snapper, king snake eel, and golden tilefish. Red snapper spend most of their time in the water around reefs searching for food like squid, crabs, and other fish. Because of this, scientists considered the snapper to be at a lower risk of exposure to oiled sediments.14 King snake eel dwell on top of the sandy or muddy bottom, putting them at moderate to heavy risk of oiled sediment exposure. Golden tilefish burrow in the soft sandy

Figure 3. After the Deepwater Horizon oil spill, scientists found high levels of polycyclic aromatic hydrocarbons in golden tilefish and a high occurrence of skin lesions.14 (C-IMAGE/Susan Snyder)

A fish’s habitat and behavior may influence its health after a spill like Deepwater Horizon.
bottom, exposing them to sediments that could have relatively high contamination levels (Figure 3).\textsuperscript{14}

In this study, scientists found that golden tilefish had persistent and significantly higher levels of PAHs compared to the other two species, though the PAHs’ source was not identified.\textsuperscript{14} The golden tilefish PAH levels did not significantly decrease over the three-year sampling period, but the levels for red snapper and king snake eel returned to normal.\textsuperscript{14} Scientists think that the golden tilefish’s burrowing behavior is a key factor in its high PAH exposure levels. Using their mouths and fins, golden tilefish constantly dig up the ocean floor to keep their burrows from filling in with sediment. This behavior could also repeatedly expose golden tilefish to buried oil, entering the golden tilefish through their skin or mouths.\textsuperscript{9,14} Clues about where fish spend their time, what they eat, and how they interact with their environment help scientists determine the role the DWH event and other sources of petroleum releases in the Gulf had – and may continue to have – on fish and other aquatic wildlife.

One team of scientists studying the movement of Deepwater Horizon oil in the Gulf utilized the fish skin lesion data to corroborate their conclusions about the path oil took in 2010.\textsuperscript{15} They created computer models incorporating different types of oceanographic information such as water circulation patterns, depth, and weather patterns to track oil movement.\textsuperscript{15} They concluded that oil from the DWH oil spill floated beneath the water’s surface from the wellhead to the West Florida Shelf (Figure 4).\textsuperscript{15} The scientists noted the path of oil to the West Florida shelf corresponded with the locations of fish caught with lesions. They also found that chemical
Scientists, natural resource managers, and emergency response agencies regularly monitor aquatic ecosystems for sick or injured fish. Lesions on fish can indicate an unhealthy environment or other stress. Authorities can determine if sick fish are a result of an acute or chronic event. In other words, they try to determine if fish have been harmed from an abrupt and damaging event or if they have been exposed to injury over a longer time. For example, the Texas Parks and Wildlife Department’s Kills and Spills Team investigates incidents of fish kills to determine the cause and protect the environment. Fish kills are mass die-offs in populations and communities of fish and other aquatic creatures. Common causes of fish kills include low dissolved oxygen, chemicals and toxins, disease, and extreme weather or algal blooms (Figure 2a and 2b). Reporting sightings of unhealthy or dead fish helps managers and public health officers make these determinations and keep people and wildlife safe (see side bar on page 7).

Reporting sightings of sick fish can help scientists and natural resource managers.

Scientists process the fish they sampled during a research cruise in the Gulf of Mexico. The fish parts will be analyzed in a laboratory. (C-IMAGE)
FOUND A SICK FISH? WHAT NOW?

Bacteria that are also human pathogens can cause some fish lesions.1,6 If fish appear to be lesioned or are behaving strangely, use common sense and do not touch the fish.1 However, if contact is necessary, always take proper safety precautions, including wearing gloves and thoroughly washing your hands.1,6,7 Usually, just a few sick fish are not cause for alarm, but many sick or dead fish can be concerning.1 If you spot unhealthy or dead fish in the Gulf of Mexico, call one of these hotlines:

- Texas Parks and Wildlife Kills & Spills Team (512) 389-4848 or (281) 842-8100
- Louisiana Department of Environmental Quality (888) 763-5424
- Mississippi Department of Natural Resources (601) 961-5599
- Alabama Marine Resources Division (AMRD) (251) 861-2882 or (251) 968-7576
- Florida Fish and Wildlife Conservation Commission (800) 636-0511

A king snake eel with a skin lesion is documented during a research cruise in the Gulf of Mexico. (C-IMAGE/Susan Snyder)

GLOSSARY

- **Correlation** — The relationship or connection between things that happen or change together.
- **Dispersants** — Chemicals that are used during oil spill response efforts to break up oil slicks and can limit floating oil from impacting sensitive ecosystems such as coastal habitats.
- **Episodic exposure** — Refers to wildlife that are exposed to harmful levels of chemicals for a period of time, rather than continuously.
- **Fish kill** — A population or community of fish that dies off in a localized area.
- **Hydrocarbon** — A compound composed of carbon and hydrogen atoms. Most hydrocarbons naturally occur in crude oil and natural gas and are formed from decomposed organic matter.
- **Natural seeps** — Occur in areas where oil flows slowly up through networks of cracks in the ocean floor, forming springs of oil. As much as one half of the oil that enters the coastal environment comes from natural seeps of oil and natural gas.
- **Pathogens** — Disease- or illness-producing agents such as bacteria or viruses.
- **Polycyclic aromatic hydrocarbons (PAHs)** — A group of hydrocarbons commonly found in oil, tar, burned wood, and animal fats.
- **Salinity** — The average concentration of dissolved salts in a body of water.

Fishery scientists use the “long line” method of fishing to catch fish for their studies. (C-IMAGE)
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SUGGESTED CITATION

THE DEEPWATER HORIZON OIL SPILL’S IMPACT ON BOTTLENOSE DOLPHINS

Larissa Graham, Christine Hale, Emily Maung-Douglass, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson

After the Deepwater Horizon oil spill, the public worried that the oil spill caused health problems in bottlenose dolphins in the Gulf of Mexico. Scientists examined the health and stranding patterns of dolphins along the coasts of Louisiana, Mississippi, and Alabama and discovered oiled areas had more sick and dead dolphins than other areas.

Young bottlenose dolphins died in areas affected by the 2010 Deepwater Horizon oil spill. Unborn dolphins from the northern Gulf Coast were 18 times more likely to show signs of fetal distress than those from the other areas. (NOAA)

OIL AND ITS IMPACT ON DOLPHINS

The Deepwater Horizon oil spill occurred on April 20, 2010. The ruptured wellhead released approximately 172 million gallons of oil into Gulf of Mexico waters before responders capped it on July 19, 2010. Emergency responders used dispersants to break up oil at the sea surface and at the wellhead located almost a mile below the surface of the water.1-5

Marine mammals, like dolphins and whales, breathe air at the surface of the
water where oil slicks form during spills. The oil and its vapors can irritate and damage their airways and lungs. Marine mammals may also be exposed to oil by eating contaminated prey or ingesting oil from the water or sediments when feeding.6

Chemicals in oil can make marine mammals sick depending on the amount and type of oil animals are exposed to, how long they are exposed, and how healthy they are at the time of exposure. Their livers can break down some chemicals in oil. However, some of these chemicals can be toxic if they are present in high amounts.6,7 Chemicals in oil can also cause harm that can make animals sick over time. Exposure to chemicals can weaken their immune systems, making it harder to fight off disease or parasites.8 Oil contaminants can also affect their food supply if oil causes prey to become sick or die. There may be less food available or food may be of poorer quality.10

**TROUBLE FOR MARINE MAMMALS ALONG THE NORTHERN GULF COAST**

In 2010, scientists documented an increased number of stranded cetaceans, or dolphins and whales, along the northern Gulf of Mexico (Figure 1, Table 1). Experts declared the deaths were part of an unusual mortality event. An unusual mortality event occurs when there is an unexpected increase in stranded marine mammals. These events demand an immediate response and investigation. Understanding the cause of a die-off is important because marine mammals can serve as indicators of ocean health and provide insight into larger environmental issues. Many marine mammals are long-lived and slow to mature. Dolphins, for example, can live for 40 to 50 years. The death of even a few individuals can have a large impact on the overall population.9

Scientists began studying bottlenose dolphins and their populations along the Gulf Coast in response to the 2010 die-off.9-17 Experts determined the unusual mortality event began a month before the oil spill when especially cold temperatures caused dolphins to strand along the coasts of Louisiana and Mississippi.10 However, the largest increase in stranded cetaceans occurred in oiled areas following the Deepwater Horizon spill.13

After the oil spill, natural resource trustees assessed its impact on coastal and marine natural resources through the Natural Resource Damage Assessment (NRDA) process (Table 2). This process examined how the oil spill impacted marine mammals in the northern Gulf of Mexico.17 They determined that the oil spill was the main cause of the increase in dolphin deaths in the northern Gulf using data they collected through the NRDA process, the unusual mortality

**FIGURE 1:** Bottlenose dolphins, represented by green dots, stranded in many locations in Louisiana, Mississippi, and Alabama between 2010 and 2014. The circles with dots represent perinatal dolphins, shorter than 45 inches long. This map can be accessed at [http://www.nmfs.noaa.gov/pr/health/mmume/cetacean_gulfofmexico.htm](http://www.nmfs.noaa.gov/pr/health/mmume/cetacean_gulfofmexico.htm) and was last updated in May 2016.9 (NOAA)
event investigation, and other research. They also suggested that oil exposure led to reproductive failure, sickness, and death in dolphins living within the oil spill footprint.9,17 Experts declared the unusual mortality event closed as of July 2014 when the number of stranded cetaceans began to decrease. This event was the longest known marine mammal die-off in the Gulf of Mexico.9

**THE NORTHERN GULF OF MEXICO MARINE MAMMAL DIE-OFF**

Responders reported more than 1,000 stranded cetaceans along the coasts of Louisiana, Mississippi, and Alabama during the unusual mortality event. Some scientists believe the actual number of marine mammals that died is much higher than reported. Cetaceans that die in remote areas and deeper waters may not have been found because they did not strand.17,18 Those that die offshore are much less likely to strand than animals found in coastal waters.18

Of the 95 percent of stranded cetaceans found dead, more than 80 percent were bottlenose dolphins.9,11 Many of the dolphins were adults. However, responders also found a large number of perinatal dolphins. The number of stranded perinatal dolphins found in Mississippi and Alabama in the winter of 2011 was much higher than in previous years.12 Scientists discovered 769 bottlenose dolphins stranded along the coasts of Louisiana, Mississippi, and Alabama between January 2010 and December 2013. Of these, 22 percent were perinatal dolphins.10,12

**DEEPWATER HORIZON’S IMPACT**

Scientists believe that oil exposure during the spill caused health problems in Gulf Coast dolphins. They examined the time of year, location, and number of stranded dolphins along the coasts of Louisiana, Mississippi, and Alabama to see if areas that received more oiling had a greater number of dead dolphins. Dolphins living in areas affected by the spill were more likely to be ill. The poor health conditions of dolphins in heavily oiled areas were similar to conditions scientists have found when they expose animals to oil in the laboratory.15,17,19,20 In contrast, the coasts of Florida and Texas, where there was little or no oiling, did not have an increase in stranded bottlenose dolphins after the oil spill.11,13,16
Breathing in fumes from oil slicks and possibly ingesting oil when feeding may have weakened dolphins’ immune systems, making it harder for them to fight off diseases and infections.\(^8\) The most common cause of death during between June 2010 and December 2012 was infectious diseases, such as bacterial pneumonia. Dolphins living in oiled areas in the northern Gulf were four times more likely to die from infections than dolphins stranded elsewhere.\(^16\)

A combination of stressors, including the oil spill, may have also caused the high number of perinatal deaths in 2011. Perinatal dolphins that stranded along the coasts of Mississippi and Alabama in 2011 were eight times more likely to have pneumonia or inflamed lungs compared to perinatal dolphins from non-oiled sites in South Carolina and Florida. These dolphins were also 18 times more likely to show signs of fetal distress than those from areas outside the region. They were shorter in size, on average, compared to stranded dolphins from previous years. Scientists think this is because they died before they were born. They also think that cold and freshwater runoff prior to and following the oil spill may have affected pregnant female dolphins.\(^10,\!12\)

**DOLPHINS IN A HEAVILY OILED AREA WERE Sicker THAN DOLPHINS IN OTHER AREAS**

Heavy oiling occurred in Barataria Bay during the spill. Responders observed dolphins swimming through and feeding in visibly oiled waters. These dolphins may have encountered higher amounts of oil over a longer time period than dolphins in other areas.

Following the oil spill, scientists collected a lot of information about the dolphins in Barataria Bay. They tested the blood, skin, and blubber tissue and obtained the age, weight, and length of live dolphins. They also performed ultrasound examinations of the
lungs to check for sicknesses, such as pneumonia. Scientists did not have any data for dolphins in this area before the spill, so they conducted the same health assessment for dolphins in Sarasota Bay, Florida, because it was not oiled by the spill. They found that dolphins in Barataria Bay were more likely to be ill and had many health conditions not found in Sarasota Bay dolphins.19,20

Barataria Bay dolphins had excessive tooth loss and were in poor condition. Twenty-five percent of dolphins studied were underweight. These dolphins were also five times more likely to have lung problems, with many having moderate to severe lung disease. Dolphins in Barataria Bay had **adrenal glands** that were not working properly. Adrenal glands are important because they help dolphins respond to stress and control blood pressure.19,20 The lung and adrenal gland problems in live dolphins corresponded to abnormalities found in the dead dolphins from oiled sites.16 Also, only 20 percent of pregnant dolphins that scientists saw had live young following their due dates. In healthy dolphin populations, about 83 percent of pregnancies typically result in the birth of live calves.15

Scientists gave nearly half of the Barataria Bay dolphins a bad prognosis, indicating these animals were sick. There was a high rate of deaths in the adult dolphins in this area. In one study, scientists estimated that 17 percent of dolphins that they observed would die based on their condition. In another study, 14 percent of the dolphins died before the study was completed. This rate of death is about three times higher than typically observed in healthy populations of dolphins.15,19,20

Experts predict that the oil spill reduced the population of bottlenose dolphins in Barataria Bay by as much as half. Scientists estimate it could take this population nearly 40 years to recover.17

The numbers of dolphin deaths may seem alarming. However, scientists cannot say how alarming because they do not have baseline data about the health of Barataria Bay dolphins before the spill. Baseline data serves as a starting point to allow scientists to determine how much something has changed over time or after an event. The lack of baseline data in Barataria Bay limits the full understanding of the extent that the oil spill affected dolphin populations. It is possible dolphins in Barataria Bay were in a different or poorer condition even before the oil spill.

**TEASING OUT OTHER FACTORS THAT CAUSED DOLPHIN DEATHS**

An increase in dolphin strandings occurred primarily along the coasts of Lake Pontchartrain in Louisiana and western Mississippi in March through May 2010. So what was the cause of the deaths during this time? Scientists believe that prolonged exposure to low salinity and cold temperature in these areas resulted in dolphin deaths.11,17 They also believe that the changes to temperature and **salinity** may have affected the dolphins’ habitat and food sources.10

Scientists retrieved this dead dolphin from Grand Isle Beach, Louisiana, in January 2012. The visible ribs and depressions along the back are signs of extreme weight loss. (NOAA)
The largest, most prolonged cluster of stranded dolphins occurred one year after the spill. This die-off included a large number of perinatal dolphins found along the Mississippi and Alabama coasts. Scientists believe that oil exposure made pregnant dolphins more susceptible to infection. They also believe that exposure to contaminants in the womb may have caused perinatal dolphins to die. The cold winter and freshwater from inland snow melt may have also contributed to the timing and location of these strandings.\textsuperscript{10} Marine mammal strandings typically do increase during cold, winter months.\textsuperscript{9} However, scientists do not believe cold weather alone caused health problems found in sick and stranded dolphins in 2011. It is possible that dolphins were more susceptible to sickness or death because of their exposure to cold temperatures.\textsuperscript{14}

Scientists also wondered how bacterial and viral infections affected dolphin health. Some dolphins tested positive for the bacteria \textit{Brucella}, which can cause poor health in dolphins. \textit{Brucella} does not typically cause mass die-offs, but it can cause late-term miscarriages in dolphins. \textit{Morbillivirus} is a viral disease often linked to unusual mortality events in marine mammals but rarely found in stranded dolphins during and after the oil spill.

The amount of \textit{Brucella} and morbillivirus in dolphins in oiled waters was similar to levels found before the spill and in adult dolphins outside of the northern Gulf of Mexico. Scientists found higher levels of \textit{Brucella} in perinatal dolphins in Mississippi Sound compared to dolphins from non-oiled waters. These scientists believe the oil affected the pregnant dolphins’ immune systems, making them more susceptible to infections.\textsuperscript{12} For all of these reasons, scientists believe that \textit{Brucella} or morbillivirus may have contributed to but was not the main cause of death for young and adult dolphins that have stranded during the Gulf of Mexico unusual mortality event.\textsuperscript{11,13-16}

**SCIENTISTS TAKE THE NEXT STEP**

The unusual mortality event is closed, but it does not mean that the effects of oil on these marine mammal populations have ended. Scientists continue to study dolphin populations throughout the Gulf of Mexico and monitor the long-term health effects of the oil spill.

Scientists measure a healthy 21-year-old adult male during a dolphin health assessment in Sarasota Bay, Florida. Scientists studied dolphins in this area to provide a comparison because Sarasota Bay did not receive Deepwater Horizon oil. (NOAA)

\textbf{Bottlenose dolphins are one of many marine mammals being studied post-oil spill.} Scientists are collecting data on 21 different types of whales and other dolphins that live in the Gulf of Mexico, including the beaked whale and the endangered sperm whale. Scientists use acoustic monitoring to estimate population sizes of some marine mammals because they live in deep water and are harder to study.
causing large declines in marine mammal populations. Scientific and public concern that human activity was unknown, and immediate response is needed. These many marine mammals die, sometimes for reasons medical attention. Unable to return to its natural habitat, or in need of the water or any live marine mammal washed ashore, salts in a body of water. — The average concentration of dissolved salts in a body of water. — A stranding event where any dead marine mammal on shore or in the water or any live marine mammal washed ashore, unable to return to its natural habitat, or in need of medical attention. A stranding event where many marine mammals die, sometimes for reasons unknown, and immediate response is needed. These events are defined in the Marine Mammal Protection Act, which lawmakers created in 1972 because of scientific and public concern that human activity was causing large declines in marine mammal populations.

References


More information about some of these ongoing studies is available on Gulf of Mexico Research Initiative’s website at [http://gulfresearchinitiative.org](http://gulfresearchinitiative.org).

To learn about impacts to dolphin populations reported by the Natural Resource Damage Assessment, visit [http://www.gulfspillrestoration.noaa.gov/affected-gulf-resources/](http://www.gulfspillrestoration.noaa.gov/affected-gulf-resources/).

Additional publications focusing on dispersants, impacts to fisheries and habitats, and other topics are on the Sea Grant Oil Spill Science Outreach Program website at [www.gulfseagrant.org/oilspilloutreach](http://www.gulfseagrant.org/oilspilloutreach).


To access state stranding information or to download the Dolphin & Whale 911 application for your phone, visit [http://sero.nmfs.noaa.gov/protected_resources/outreach_and_education/mm_apps/](http://sero.nmfs.noaa.gov/protected_resources/outreach_and_education/mm_apps/).

**SUGGESTED CITATION**


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**OIL SPILL SCIENCE OUTREACH TEAM**

*Christine Hale*
Texas Sea Grant College Program  
chris.hale@tamu.edu

*Larissa Graham*
Mississippi-Alabama Sea Grant Consortium  
larissa.graham@auburn.edu

*Emily Maung-Douglass*
Louisiana Sea Grant College Program  
edouglass@lsu.edu

*Stephen Sempier*
Mississippi-Alabama Sea Grant Consortium  
stephen.sempier@usm.edu

*Tara Skelton*
Mississippi-Alabama Sea Grant Consortium  
tara.skelton@usm.edu

*LaDon Swann*
Mississippi-Alabama Sea Grant Consortium  
swanndl@auburn.edu

*Monica Wilson*
Florida Sea Grant, UF/IFAS Extension  
monicawilson447@ufl.edu

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GOMSG-G-17-002
In April 2010, the Deepwater Horizon (DWH) oil spill, the largest offshore spill in U.S. history, occurred in the Gulf of Mexico. Emergency response personnel, natural resource managers, non-profit organization staff, scientists, volunteers, and many others worked together to rescue sea turtles. Sea turtles are some of the world's most well-known endangered and threatened animals. So far, what have we learned about the impact DWH had on sea turtles in the Gulf?

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10-year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20–member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

A healthy green sea turtle swims in the Gulf of Mexico. (Texas Sea Grant/Pam Plotkin)

**THE BASICS OF THE SEA TURTLE LIFE CYCLE**

Sea turtles are long-lived, air-breathing reptiles that spend most of their lives in the sea. They are highly migratory and depend on several habitats across large geographic areas throughout their life cycle (Figure 1). As hatchlings, sea turtles emerge from eggs located in nests on sandy beaches. Hatchlings crawl from their nests to the nearest coastal waters and swim out into the open ocean. These young turtles spend the next phase of their lives in and around convergence zones, or areas where open ocean currents come together. Here they feed and grow. As juveniles, they spend much
Potential Oil Impacts on the Sea Turtle Life Cycle

1. Egg Laying
2. Hatchling dispersal
3. Open ocean feeding; small juveniles in sargassum
4. Mating
5. Internesting near beach
6. Breeding migration

Oil on the shoreline can contaminate nesting females, nests, and hatchlings.

Large turtles can inhale oil vapors, ingest oil in prey or sediment, and become coated in oil at the surface.

Juvenile turtles ingest oil, inhale vapors, and become fatally mired and overheated.

Winds and currents create ocean fronts, bringing together oil, dispersants, and Sargassum communities, causing prolonged floating oil.

Prey that turtles would otherwise eat may also be killed by becoming stuck in heavy oil or by dissolved oil components.

Sargassum fouled by oil and dispersants can sink, leaving Sargassum-dependent animals without food and cover and vulnerable to predators. Dead turtles may sink.

FIGURE 1. Sea turtles in the Gulf of Mexico require many different types of habitat throughout their long lives, putting them at risk during oil spills. (Florida Sea Grant/Anna Hinkeldey, adapted from NOAA)

of their time at or near the ocean surface. Sea turtles have a long life span and, depending on the species and environmental conditions, can survive more than 50 and even up to 100 years old. They grow slowly and mature later in life. They swim back toward the continental shelf to mate when grown to sexual maturity. Most sea turtles in the Gulf of Mexico spend the majority of their lives in the waters of the continental shelf area, though leatherbacks spend their lives in open ocean waters. During the nesting season, mature females of all species return to the same coastal area from which they emerged as hatchlings to dig their own nests and lay eggs.\(^1\)

**THREATS AND PROTECTIONS**

The federal *Endangered Species Act (ESA)* classifies all sea turtle species found in U.S. waters as *endangered* or *threatened*. Five species of sea turtles live in the Gulf of Mexico: loggerhead, leatherback, green, Kemp’s ridley, and hawksbill. Loggerheads are listed as threatened, while the other four are listed as endangered. Additionally, many international organizations require protections for sea turtles. For example, the *Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)* prohibits international trade of some endangered wildlife, including sea turtles.

Even though sea turtles are under international and domestic protection, they are vulnerable to death from both natural and human causes (Table 1). Sea turtle eggs are eaten by animals like ants, raccoons, foxes, coyotes, and crabs.\(^1\) If the hatchlings survive their race across the beach from nest to ocean, they are then at risk of being eaten by seabirds, sharks, dolphins, tarpon, snapper, and other fish.\(^1\) Scientists estimate that only 1 in 1,000 hatchlings survive to adulthood, though this rate varies depending on the species and other factors.\(^3,4\) Additionally, drastic drops in water temperature cause “cold-stunning”
Sea turtles die from both natural and man-made causes. Understanding the impacts from the many sources of mortality throughout their life cycle can help resource managers protect sea turtles. (adapted from NOAA)

<table>
<thead>
<tr>
<th>Source of mortality</th>
<th>Primarily caused by humans</th>
<th>Main life stage affected</th>
<th>Level of Impact</th>
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<tbody>
<tr>
<td>Shrimp trawling</td>
<td>Yes</td>
<td>Juveniles to adults</td>
<td>High</td>
</tr>
<tr>
<td>Natural predation</td>
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<td>Eggs, hatchlings</td>
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<td>Disease</td>
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<td>Juveniles to adults</td>
<td>High for green sea turtles</td>
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<tr>
<td>Other fisheries</td>
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<td>Juveniles to adults</td>
<td>Medium</td>
</tr>
<tr>
<td>Vessel-related injuries, including propellers</td>
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<td>Juveniles to adults</td>
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<tr>
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The Rise and Fall of the Kemp’s Ridley

Scientists are studying the role the DWH spill played in the decline in Kemp’s ridley sea turtles in 2010. The status of the Kemp’s ridley population is of particular importance because they are the most endangered sea turtle in the world. They live primarily in the Gulf of Mexico, nesting on beaches in Mexico and Texas. The Kemp’s ridley population severely declined in the 1960s, almost to the point of extinction. This was due to over-harvest of eggs from beaches in Mexico.

Shrimp Fishers Protect Turtles Using Turtle Excluder Devices (TEDs)

Fishing gear is one of many threats sea turtles face. In particular, shrimp trawl nets unintentionally capture sea turtles. Often, sea turtles can’t escape these nets and they drown. However, shrimpers and natural resource managers have worked together to come up with a solution that promotes turtle-safe, wild-caught shrimp. They created Turtle Excluder Devices (TEDs), a metal grid that attaches to one end of a shrimp trawl net; its design allows sea turtles to escape the net. When properly installed, TEDs have been shown to be 97 percent effective in excluding turtles from shrimp trawls. Federal law now requires TEDs on most shrimp trawlers in the Gulf of Mexico and South Atlantic.

Texas Sea Grant extension agent Tony Reisinger works with shrimpers in Brownsville to correctly install Turtle Excluder Devices in shrimp trawls. (Texas Sea Grant/Chris Hale)
and loss of turtles from commercial shrimp trawling in the Gulf of Mexico. The Kemp’s ridley population numbers began to rebound only after two decades of successful bi-national conservation and management efforts. Kemp’s ridleys continued to thrive so much that the National Marine Fisheries Service predicted that by 2011, Kemp’s ridleys would be down-listed on the Endangered Species list and eventually delisted by 2024. This means the ridleys would have been moved from the category of endangered to threatened, and potentially removed from the list by 2024. However, the Kemp’s ridley population drastically decreased again in 2010, the year of the DWH spill, changing the outlook for the species. The prediction for a 2011 down-listing did not come true, and the Kemp’s ridley remains on the Endangered Species list as endangered.

WHAT HAPPENED TO SEA TURTLES DURING AND AFTER THE DEEPWATER HORIZON OIL SPILL?

Risk
DWH oil spilled for 87 days throughout the northern Gulf of Mexico, spreading from the open ocean to the continental shelf, coastal wetlands, and beaches. Sea turtles use all of these habitats, so they were at high risk of oil exposure (Figure 1). Sea turtles do not always swim away from oil spills, and they must take large breaths of air above the water before they dive. This behavior can lead to inhaling or ingesting surface oil. Additionally, sea turtles feed in convergence zones where oil tends to accumulate, potentially causing them to eat oil with their food.

Rescue
Representatives from many organizations worked together to rescue oiled sea turtles during the spill. These included fishermen, marine mammal and sea turtle stranding networks, federal and state agency personnel, scientists from various institutions, and volunteers. Rescue crews headed offshore in charter fishing boats to search for oiled turtles. Teams cleaned and examined the sea turtles, obtained oil samples, and transported turtles to rehabilitation facilities in Louisiana, Mississippi, and Florida to receive veterinary care. Sea turtle experts rehabilitated more than 450 oiled sea turtles and later released them into oil-free waters.

Turtle nests were also rescued. Experts relocated nearly 275 loggerhead turtle nests from oiled beaches from the northern Gulf to the Atlantic coast of Florida. To do so, they dug up the eggs and placed them in special foam boxes for transport. They transported approximately 28,000 sea turtle eggs to an incubation facility at the Kennedy Space Center in Cape Canaveral, Fla. Authorities there monitored the eggs in a climate-controlled environment until the hatchlings emerged and could be released on unoiled Atlantic coast beaches.

Impact
In total and across all Gulf sea turtle species, the Natural Resources Damage Assessment (NRDA) estimated that the DWH oil spill and related response activities killed approximately 35,000 hatchling sea turtles, between 55,000 and 160,000 small juvenile sea turtles, and between 4,900 and 7,600 large juvenile and adult sea turtles. NRDA also estimated that the DWH spill impacted the reproductive potential of sea turtles in the Gulf, meaning that thousands of baby turtles will not be born. The magnitude of sea turtle loss due to the DWH spill will make recovery of these populations challenging.

During DWH, sea turtles came into contact with oil in every type of habitat they use throughout their life cycle. Adult females, eggs, and hatchlings encountered oil on beaches and coastal areas. They swam through oil at the surface and in convergence zones where oil tends to accumulate. Oil on beaches caused nesting activity to be delayed or predated on. Oil on coastal waters and in the open ocean caused turtles to become oil-covered, which can impair their ability to breathe and dive. Oil in the open ocean also affected turtle foraging, which can lead to malnutrition and an increased risk of predation.

FLOATING SAFE HARBORS
The National Oceanic and Atmospheric Administration (NOAA) considers Sargassum or Gulf weed to be an Essential Fish Habitat (EFH) because many species use it for spawning, feeding, and growth. Sargassum offers juvenile turtles protection from predators and is a food source. It floats and drifts with currents in the ocean, accumulating in convergence zones, as do surface oil slicks. Oil from the Deepwater Horizon spill caused the loss of nearly 25 percent of the Sargassum habitat in the northern Gulf. Losing such an important habitat created challenges for small and juvenile sea turtles.
surface of the water, including within floating *Sargassum* habitat. Responders retrieved many sea turtles from the water completely covered, or *mired*, in oil. Miring in oil decreases a sea turtle’s ability to move and dive and causes exhaustion, dehydration, overheating, and death. Responders also found turtles with DWH oil coating their eyes, nasal openings, and mouths, resulting in vision loss and causing them to inhale and ingest oil (Figure 2). Without intervention from rescuers, sea turtles mired in oil most likely died.

Despite extensive rescue efforts, many turtles died as an unfortunate consequence of the emergency response to the DWH spill. For example, on-shore activities such as moving turtle eggs from Gulf beaches to the Atlantic coast of Florida caused the loss of some sea turtle hatchlings. Oil spill response boats collided with turtles, killing them. Response activities such as oil skimming and burning led to additional turtle injury and death. The emergency response community must often weigh the benefits and risks of available tools and approaches when making oil spill response decisions.

Scientists have not yet pinpointed what caused the 2010 Kemp’s ridley population decline and slow rate of recovery, but they suggest that a combination of factors could be at play. Cold seawater temperatures around nesting grounds, reduced food sources, and oiled habitat are some of the factors being considered. Although computer models suggest that the 2010 Kemp’s ridley hatchlings did not encounter the DWH oil directly, the majority of sea turtles found dead since the spill were Kemp’s ridleys. The NRDA suggested that in 2010, young (older than hatchlings) Kemp’s ridleys could have been exposed to oil. Any turtle deaths from oil exposure would have removed them from the breeding population of turtles. This is one example of a potential indirect impact to one sea turtle species. Scientists consider many factors as they continue to evaluate the long term and indirect impacts to ridleys and other sea turtle species from the spill.

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**DECISION POINT**

The emergency response community is tasked with deciding how to respond to a spill while protecting what is at risk. While preventing spills is the priority, planning for them is necessary. Several processes are available to help guide communities in planning and preparing for oil spills. One process, Environmental Tradeoff Analysis, is an approach used by the response community alongside stakeholders during oil spill planning. Environmental Tradeoff Analysis compares the benefits and risks of potential response options to develop a response strategy that will reduce impacts of a spill on the environment.
Any turtle deaths from oil exposure would have removed them from the breeding population of turtles. This is one example of a potential indirect impact to one sea turtle species. Scientists consider many factors as they continue to evaluate the long term and indirect impacts to ridleys and other sea turtle species from the spill.8

Multi-national collaboration is necessary to understand oil spill impacts and improve the protection of sea turtles.13 Scientists used ocean circulation models to find connections between major turtle nesting beaches and the DWH oil’s path.13 These computer simulations estimated that more than 95 percent of the sea turtles likely to have been located near the spill were from non-U.S. nesting populations (Figure 3).13 These results emphasize how a relatively local disturbance such as an oil spill can have far-reaching impacts.

CONTINUED RESEARCH AND MONITORING

Scientists and natural resource managers do not fully understand oil’s impacts on sea turtles’ health and reproduction.8 They continue to monitor Gulf sea turtle populations by counting numbers of nests, hatchlings, and adult females on beaches. However, turtles are far more difficult to track once they reach the open ocean.13 Scientists have coined a specific term for this period of a sea turtle’s life – the “lost years.”14 In the past, scientists thought juvenile sea turtles drifted along with strong ocean currents during this time.14 More recently, scientists have used computer models and satellite tracking tags to study turtle migration. They found that juvenile green, loggerhead, and Kemp’s ridley turtles actively swim in the open ocean and do not behave only as passive drifters.14,15

Scientists continue to fill in knowledge gaps about sea turtles so that they can better understand how threats like

**FIGURE 3.** Scientists used computer models to find connections between major turtle nesting beaches and the Deepwater Horizon spill area. More than 95% of sea turtles estimated to be in the spill area hatched from beaches outside of the United States, emphasizing the need to work with international partners.13

**FIGURE 4.** Scientists identified the major foraging “hot spots” for 31 female Kemp’s ridley sea turtles from 1998 to 2011. They estimated how much time the turtles spent in these areas feeding as they migrated after nesting. The Deepwater Horizon oil spill impacted major foraging areas off the coasts of Louisiana, Mississippi, and Alabama.16 (adapted from D. Shaver)
A SEA TURTLE NEEDS YOUR HELP – WHO DO YOU CALL?

If you encounter a sick or injured sea turtle, contact the Sea Turtle Stranding and Salvage Network Coordinator in your area. The following are contacts for the Gulf of Mexico region, but Coordinators operate in other locations as well.

- Texas: 1-866-TURTLES (1-866-887-8535)
- Louisiana: 1-225-765-2377
- Alabama: 1-866-SEA-TURT (1-866-732-8878)
- Florida: 1-888-404-FWCC (1-888-404-3922)
- Mississippi: 1-888-806-1674

Oil spills impact populations, with the aim of ultimately improving management.13–16 For example, scientists are learning more about where turtles feed. From 1998 to 2011, they tagged and tracked female Kemp’s ridleys to identify “hot spots” or preferred foraging areas. They discovered a critical foraging corridor in the northern Gulf, including coastal Louisiana, Alabama, and Mississippi (Figure 4).16 Knowing the location of important sea turtle habitats and migration routes helps managers zero in on areas for protection.16

For more information about the Deepwater Horizon oil spill’s impact to wildlife and other oil spill science topics, visit gulfseagrant.org/oilspilloutreach.

GLOSSARY

**Continental shelf** — A shallow undersea plain of varying widths forming a border to a continent and typically ending in a comparatively steep slope to the deep ocean floor.

**Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** — An international agreement between governments to ensure that international trade in wild animals and plants does not threaten their survival.

**Endangered** — Under the U.S. Endangered Species Act, a species is listed as endangered if it is in danger of becoming extinct throughout all or a significant portion of its range.

**Endangered Species Act (ESA)** — U.S. legislation that provides a framework for conservation and protection of endangered and threatened species and their habitats.

**Essential Fish Habitat (EFH)** — Under the U.S. Magnuson-Stevens Fishery Management and Conservation Act, NOAA identifies EFH as waters and submerged lands that fish need for spawning, breeding, feeding, and growth.

**Hatchling** — A young animal that has recently emerged from an egg.

**Juvenile** — An early phase of growth associated with youth.

**Migratory** — Having to do with the periodic travel of an animal from one area to another, often over long distances.

**Mired** — To be covered in, stuck or entrapped within, or be hindered by, a sticky, heavy, or muddy substance.

**Natural Resource Damage Assessment (NRDA)** — The legal process used to determine the impacts of oil spills, hazardous waste sites, and ship groundings on natural resources and humans.

**Threatened** — Under the U.S. Endangered Species Act, a species is listed as threatened if it is likely to become endangered in the foreseeable future throughout all or a significant portion of its range.
REFERENCES


SUGGESTED CITATION


OIL SPILL SCIENCE OUTREACH TEAM

Christine Hale
Texas Sea Grant College Program
chris.hale@tamu.edu

Larissa Graham
Mississippi-Alabama Sea Grant Consortium
larissa.graham@auburn.edu

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
swanndl@auburn.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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TAMU-SG-17-501 GOMSG-G-17-001
CORALS AND OIL SPILLS

Christine Hale, Larissa Graham, Emily Maung-Douglass, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson

The largest offshore spill in American history, 2010’s Deepwater Horizon oil spill occurred deep in the ocean, spreading oil at depth and into shallow and coastal areas. Scientists have since discovered the spill injured some coral communities living in the Gulf of Mexico.

This sea fan, an octocoral, lives in the deep Gulf of Mexico. Its healthy branches are a home for other animals, including the brittle sea stars and squat lobsters seen here. (Ocean Exploration Trust and ECOGIG)

CORAL: ANIMAL, PLANT, OR ROCK?

Corals support a diverse ecosystem that is fundamental to the health of the ocean. Scientists and educators often describe coral communities as “cities under the sea” or “the rainforests of the sea.” Healthy coral communities provide food, shelter, and habitat to thousands of creatures, from tiny plankton to larger crustaceans, mollusks, fish, reptiles, mammals, and even birds. Humans also depend on healthy coral communities for sources of medicine, food, livelihoods, recreation, and as protection from storm surge.1

What most people think of as “a coral” is really a colony of coral polyps — tiny, soft-bodied animals related to jellyfish and anemones.2 Hundreds to thousands of polyps can live connected to each other, established as a coral branch or coral head. Corals begin life in the water as tiny, free-
swimming organisms, eventually settling on the seafloor or on other structures in the ocean to grow. Thousands of different types of corals exist in oceans around the world. Some coral species are mistaken for rocks because they are stony and hard; others are soft and branching like plants or blades of grass.  

Stony corals are reef-building corals and are often what people envision when thinking about coral reefs. The polyps of stony corals produce a hard, limestone skeleton that is the foundation for a mature coral reef ecosystem. Other types of corals do not form limestone skeletons. Instead, their polyps are housed in structures made from more flexible, horn-like protein material. These soft corals are called octocorals because their polyps have eight tentacles around their mouths, as compared to stony corals that have six. Octocorals, such as sea fans and sea plumes, attach to hard structures, like stony coral reefs or oil rigs, to live out their lives (Figure 1).  

Corals usually grow very slowly (from 0.1 to 4 inches a year) and can live for a long time — some are thousands of years old. Scientists have identified corals in the Gulf of Mexico that are several hundred years old.  

Corals can be exposed to pollutants in the water either by direct contact (like when oil or oil products contact coral tissue), or indirectly through their feeding behavior. Corals feed on live prey by extending the tentacles on their
polyps into the surrounding water. The polyps capture small plankton that drift or swim by in the water, pulling the plankton into their mouths. If corals eat contaminated food, they are then at risk for becoming contaminated. Corals living in shallower depths also use sunlight for energy. Tiny algae living inside their polyp tissue transforms sunlight into nutrients useful to the coral.

Corals anchor themselves to the ocean bottom, so they cannot move from threats or changes in the environment around them. One way they protect themselves from debris and other harmful substances is by producing a mucus. Scientists think this mucus plays many roles in a reef community, including helping corals to remove or “slough off” unwanted materials from their tissues. While the mucus production and sloughing can help, it takes a lot of the coral’s energy and does not always suffice against thick, heavy layers of oil or oil-soaked sediments.

WERE CORALS IN THE GULF IMPACTED BY THE DEEPWATER HORIZON OIL SPILL?

The spill impacted important habitat for deep-sea octocoral and mid-depth communities, but not shallow coral reefs.

During the Deepwater Horizon (DWH) oil spill, the risk of coral exposure to spilled oil was high because the broken wellhead was close to hard-bottom habitat where deep-sea coral communities grow. Oil spilled at a depth of about 5,000 feet, and emergency responders injected dispersants into the leaking wellhead at this depth. Although some dispersant-treated oil rose to the ocean surface, a large subsurface plume of oil formed in the water around 2,500 to 4,000 feet deep. Scientists estimated that the plume covered 400 to 700 square miles. Meanwhile, at the ocean surface, natural weathering processes, burning of surface oil, and dispersant use on oil slicks caused much of the unrecovered oil and dispersants to sink to the ocean floor.

Research conducted before and after the DWH spill has shown that oil exposure can harm corals in a variety of ways. Oil can reduce corals’ ability to reproduce and therefore may prevent growth of new colonies. Oil also negatively affects their early life stage development. Oil on the seafloor can prevent coral larvae from settling there. To understand how the DWH spill may have impacted corals in the Gulf of Mexico, scientists explored three general ocean zones where corals are known to live (Figure 2):

1. the deep-sea,
2. the mesophotic or “middle light” zone, and
3. the shallow-water zone.

![Figure 2](image_url)
Deep-sea zone

The deep-sea zone begins at about 500 feet deep and extends to more than 10,000 feet deep. Nearly 95 percent of the Gulf of Mexico deep seafloor is soft-bottom mud, and the remaining areas consist of hard bottom. Soft coral communities live in these hard-bottom habitats but are limited by the availability of hard surfaces for attachment. Experts have identified more than 23,700 distinct hard-bottomed areas along the Gulf’s seafloor. These areas are widely and patchily distributed in deep water, and not all support coral growth, making finding and sampling deep-sea coral a challenge for scientists.6,8 Despite the difficulties in locating and studying deep-sea communities, scientists estimate that 770 square miles of ocean bottom surrounding the wellhead, including coral habitats, were impacted by the DWH oil spill.7

After the spill, scientists used remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) equipped with cameras to find and observe deep-sea corals in the Gulf of Mexico. In late 2010, one group of scientists located a coral community near the spill site.10 These scientists found that more than half of the corals were covered in a flocculent (‘floc’) or clumped, brown material. The corals also showed signs of stress such as loss of the tissues that make up the coral polyps, and excess mucus production.10 Scientists sampled the floc and determined that it contained a trace of both oil and dispersants from the DWH spill.10,11

FIGURE 3. Injuries to coral following the Deepwater Horizon oil spill progressed over time. In November 2010, scientists found clumped, brown material containing oil from Deepwater Horizon on the coral branches. By March 2011, most of the brown material had disappeared but the corals started losing tissue, and the brittle sea star that lived on this coral abandoned it. By October 2011, hydroids grew on the branches, a sign of coral deterioration. By March 2012, coral branch loss was apparent.12 Scientists document other animals in a coral community, such as hydroids or sea stars, in order to gain better understanding of overall community health. (ECOGiG/Pen-Yuan Hsing)

Scientists returned to check for any changes in coral health over time, as seen in Figure 3.12 They photographed these corals from 2010 through 2012. By March of 2011, most of the floc had disappeared and the corals seemed to be recovering. However, some tissue loss did not heal, and exposed portions of coral branches became colonized by stinging organisms called hydroids.12 Eventually, scientists observed other changes to the coral community and associated animals — notably the lack of brittle sea stars — who commonly reside on healthy coral communities. By March 2012, scientists witnessed coral branch loss.13 Because of these studies, scientists now look for hydroid colonization of deep-sea corals, as it has shown to be a reliable indicator of coral deterioration.6 Scientists have yet to document recovery of deep-sea corals because of the challenges in studying them. Due to the slow rate of growth in the deep sea, it could take decades to hundreds of years to see recovery of corals there. Scientists will continue to study this deep sea coral community and others in the area for long-term changes and to establish better baseline data.7,8

Mesophotic zone

The mesophotic (‘meso’ means middle and ‘photic’ means light) zone, around 100 to 500 feet below the ocean’s surface, is a lower-light environment. Both reef-building stony corals and soft octocorals live in this zone. Some corals here feed on plankton and some use sunlight for energy. The mesophotic zone is considered by some
scientists to be a transition zone between the shallow and deep-sea zones. Recent research has shown that the area might be an important refuge for some corals living in the shallower zone.\textsuperscript{13} Corals in the shallows are often threatened by impacts from warming sea temperatures, pollution, and coastal development. Scientists think mesophotic zone corals might help re-populate damaged coral reefs in shallower waters.\textsuperscript{13,14}

DWH oil and dispersants likely affected corals in the mesophotic zone.\textsuperscript{5,7} To determine the spill’s impact, scientists compared the health of octocorals living below the surface oil slick to corals living further away from the spill area. Scientists evaluated these corals’ health in 2010, 2011, and 2014 and compared their pre-spill condition using photographic data from as early as 1997. Scientists saw a severe decline in the condition of octocorals closer to the oil after the spill. Before the spill, records showed natural or non-spill related damage (such as coral predation and fishing activity) to around 10 percent of colonies, but by 2011, the spill had injured more than 50 percent of colonies. They described the injuries as eroded polyps, overgrowth of hydroids, residue on branches, discoloration, bare branches, and missing or broken branches.\textsuperscript{5} Nearly all injured colonies declined in health over the next few years, so scientists suggest this means recovery of the damaged corals is unlikely.\textsuperscript{5}

\textbf{Shallow-water zone}

The shallow-water zone is generally considered to be from the surface to about 200 feet deep.\textsuperscript{1,7} The mesophotic zone extends into or overlaps with the deeper end of the shallow-water zone. Corals in shallower areas tend to be the stony reef-building type, and they depend on warm, clear, clean water to receive sunlight for energy.\textsuperscript{1} Octocorals also live in these shallow waters. As part of the spill assessment activities, scientists observed areas of rocky, shallow-water reefs in the northern and eastern Gulf of Mexico, offshore of Alabama and Florida. Scientists did not locate any shallow-water coral reefs impacted by oil and dispersants from the DWH oil spill, unlike the coral colonies in the deep-sea and mesophotic environments.\textsuperscript{7}

\textbf{TO DISPERSE OR NOT TO DISPERSE?}

Emergency responders use a variety of approaches, including dispersants, to combat oil in areas containing corals, as seen in Table 1.\textsuperscript{2,15} In 1989, the National Research Council published recommendations for dispersant use near shallow coral reefs.\textsuperscript{2,16} These guidelines work in conjunction with local area contingency plans to help emergency personnel make spill response decisions. Dispersant use in areas where corals live is generally not recommended, though some situations may make it appropriate.\textsuperscript{9} The DWH spill was the first time responders

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|}
\hline
\multicolumn{2}{|c|}{\textbf{Cleanup methods for shallow coral reefs}} & \multicolumn{3}{c|}{\textbf{OIL TYPE}} \\
\hline
 & \textbf{Gasoline products} & \textbf{Diesel-like products \& light crudes} & \textbf{Medium crudes \& intermediate products} & \textbf{Heavy crudes \& residual products} & \textbf{Non-floating oil products} \\
\hline
\textbf{Booming} & n/a & B & B & B & n/a \\
\textbf{Skimming} & n/a & B & B & B & n/a \\
\textbf{Manual oil removal/cleaning} & n/a & n/a & B & B & B \\
\textbf{Mechanical oil removal} & n/a & n/a & n/a & D & D \\
\textbf{Sorbents} & n/a & A & A & A & B \\
\textbf{Vacuum} & n/a & n/a & B & B & B \\
\textbf{Low-pressure, ambient water} & B & B & B & C & C \\
\textbf{Dispersants} & n/a & C & C & C & n/a \\
\textbf{In-situ burning} & n/a & B & C & C & n/a \\
\hline
\end{tabular}
\caption{Below is a quick guide for trained personnel who respond to spills in shallow coral reef areas. Emergency responders must consider the environmental impact of each response method based on the type of oil that has spilled near coral communities.}
\end{table}

\textbf{KEY:} A = least harmful impact; B = some harmful impact; C = significant harmful impact; D = most harmful impact; n/a = not applicable.\textsuperscript{15} (Adapted from NOAA Office of Response and Restoration)
applied dispersants below the ocean’s surface at such great depths and in such large amounts.

In order to study oil and dispersant effects in a more controlled setting, scientists have recently brought common deep-sea, cold-water corals into the laboratory. They tested how corals would react to different doses of DWH oil and dispersants. Though they did not exactly reproduce the conditions of the DWH oil spill, their goal was to understand the sensitivity of deep-sea corals to a range of oil and dispersant concentrations. They reported that in the laboratory setting, corals showed more severe health declines in response to dispersant exposure than to oil alone. Mixtures of oil and dispersant caused more severe effects than oil exposure by itself. Additionally, they found that higher concentrations of dispersant, and of the oil and dispersant mixtures, resulted in more severe health impacts.

However, laboratory results can be very different from what happens in real-life dispersed oil situations, especially considering the various environmental conditions and the many types of oil that can be spilled. In other words, concentration levels of oil and dispersant, the length of exposure time, depth in the ocean, temperature of the ocean, and ocean and wind currents are just some of the factors influencing how oil and dispersants impact corals. Previous studies about oil and dispersant effects have been inconsistent, and questions remain about how toxic oil and dispersants are to different coral species. Therefore, scientists are conducting new experiments to establish a standardized baseline of toxicity levels for corals. Updated toxicity information could help emergency responders and managers make more informed decisions about dispersing oil spilled near valuable coral communities.

CORAL RESTORATION

The Natural Resource Damage Assessment (NRDA) for the DWH spill includes recommendations to restore impacted natural resources. Scientists have established techniques for restoring shallow coral reefs, such as coral transplantation, but very few restoration methods exist for deeper habitats. Some experts suggest that continued monitoring will improve understanding of mesophotic and deep-sea coral communities to inform better management. Cooperative management can help protect against multiple threats and provide a framework for monitoring, education, and outreach.

For more oil spill science and information, visit gulfseagrant.org/oilspilloutreach.

BRITTLE SEA STARS

Certain species of brittle sea star live entwined on the branches of deep-sea octocorals, using the coral as an anchor so they can extend their arms into the water to gather passing food. Brittle sea stars may have protected some corals from oil and dispersant impacts during the Deepwater Horizon oil spill. Corals with attached brittle sea stars were more likely to recover in the years following the spill. Scientists think the sea stars may have prevented oil and dispersant materials from settling on the corals where they were living. The sea stars may have also prohibited hydroids from growing on the corals. This coral and sea star relationship is an example of resilience to stressors. (adapted from ECOGIG/Fanny Girard)
**Coral Struggles**

Corals all over the world face many threats. For example, excess carbon dioxide in the atmosphere is dangerous to corals. The oceans absorb excess carbon dioxide from the air, causing the water to become more acidic over time. Changes in ocean acidity make it more difficult for many corals to form skeletons, the foundation of reefs. Additionally, stress from changing ocean temperatures can cause coral bleaching. Coral bleaching happens when corals evict the algae living in their tissues, causing the coral to turn white. If conditions do not improve quickly enough, corals can die from bleaching, especially if they are already weak from disease or injury. Other threats, such as damage from fishing gear, energy exploration, and cable deployment can destroy coral communities. Some corals can live hundreds to thousands of years, but because they grow so slowly, it can take them hundreds of years to recover from damage. Faced with so many threats, many species of coral are under both domestic and international government protection.1,2,7,19,21

**Glossary**

**Autonomous Underwater Vehicles (AUVs)** — Programmable robotic vehicles that can drift, drive, or glide through the ocean without being controlled by humans.

**Contingency plans** — Plans developed to enable responders to address incidents by helping to identify and coordinate the activities of the different government agencies and private organizations involved in a response.

**Crustaceans** — A large group of mostly aquatic animals (such as crabs, lobsters, and shrimps) with a body made of segments, a tough outer shell, two pairs of antennae, and limbs that are jointed.

**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.

**Hydroid** — Colonies of hundreds of tiny, stinging organisms related to jellyfish and coral. They form into what looks like a feather or seaweed. They tend to attach to and colonize other creatures and structures.

**Mollusks** — Invertebrates with a soft and unsegmented body often enclosed in a shell, such as a snail, mussel, or squid.

**Natural Resource Damage Assessment** — The legal process used to determine the impacts of oil spills, hazardous waste sites, and ship groundings on natural resources and humans.

**Plankton** — Very small and microscopic organisms that drift or float in bodies of water. Consisting of algae, protozoans, diatoms, crustaceans, and the eggs and larval stages of animals, etc., they are an important part of food webs.

**Remotely operated vehicle (ROV)** — An underwater mobile device that is tethered to a ship. They are often used in deep-sea exploration where human access is not possible.

**References**


SUGGESTED CITATION

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OIL SPILL SCIENCE OUTREACH TEAM
Christine Hale
Texas Sea Grant College Program
chris.hale@tamu.edu

Larissa Graham
Mississippi-Alabama Sea Grant Consortium
larissa.graham@auburn.edu

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium			tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
swanndl@auburn.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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THE SEA GRANT and GOMRI PARTNERSHIP

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university-based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10-year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20–member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

OYSTERS AND OIL SPILLS

Christine Hale, Larissa Graham, Emily Maung-Douglass, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson

Oysters regularly cope with challenges like pollution, changing water temperatures, fluctuations in fresh and salt water, harvesting, and coastal development. Science shows that oysters can be resilient, but extreme natural and manmade events can degrade oyster reefs.

In order for oyster reefs to thrive, young oyster larvae prefer adult oyster shells to attach to, settle, and grow. To help oysters do this, many communities organize oyster restoration projects such as this one in Hernando County, Florida. (UF/IFAS/Camila Guillen)

OYSTERS 101

Oysters grow in clusters, forming reefs in nearshore areas, such as along salt marsh shorelines and on intertidal mudflats. Oysters also grow farther out from shorelines in shallow water known as the subtidal zone. When the conditions are right, oysters can spawn several times throughout the year, usually during the warmer months. Adult male and female oysters release sperm and eggs into the water simultaneously for successful reproduction. Adult oysters in nearshore areas exchange sperm, eggs, and larvae with oysters in subtidal waters. This exchange between areas is important for
sustaining oyster populations (Figure 1).

Young oyster larvae float in the water until they settle on and attach to shells of older, well-established oysters. If oyster shells are unavailable, larvae will settle on other nearby things like rocks, boat docks, or marine debris. At this stage, the tiny oysters are known as spat and will stay attached to the mature oyster shells or other structures as they, too, grow into adults. Generations of oyster growth such as this creates oyster reefs. Similar to corals, oysters are commonly regarded as the ‘engineers’ of their ecosystem because of their reef-building abilities.1,2

These thick, strong mounds of shells are not only essential for the growth of oysters themselves; they are also a home or a source of food for other living marine resources. As a key species in their food web, oysters play a critical role in a healthy coastal wetland. Oyster reefs trap sediment and provide hard structure to help stabilize shorelines from the natural process of erosion and land loss. Additionally, oyster reefs protect against storm surge by buffering and spreading wave energy back out to sea.1,2 Thus, oysters provide protection from strong storms to communities of people that live along the coast.

**Brackish** water is very important for oyster survival. Too much or too little salt can reduce their ability to live, grow, and reproduce. Oysters do well in an environment where the salinity ranges between 14 and 28 parts per thousand.1 Oysters are famous for their ability to ‘clean’ the water they live in. They pull in water past their gills to capture and eat tiny food items and then expel that filtered water back out. In doing so, they also sift out natural and foreign materials, thereby maintaining higher water quality and clarity and cycling important nutrients in the ecosystem. By filtering water around them, oysters provide a valuable service to the animals and plants living in their area, promoting the growth of other important habitats such as seagrass beds (Figure 2).1

---

**FIGURE 1.** Oysters need each other to survive. After fertilization occurs, their larvae float in the water until settling on and attaching to the shells of mature oysters, becoming spat. Here the spat will grow and become part of either the nearshore or subtidal oyster community. When they are old enough to reproduce, nearshore oyster beds exchange their sperm, eggs, and larvae with the subtidal oyster reefs, and the cycle continues. Healthy oyster reefs support a variety of wildlife in wetland ecosystems. (Anna Hinkeldey, adapted from www.hook.life)
IF OYSTERS FILTER THE WATER, CAN THEY BECOME CONTAMINATED BY OIL SPILLS AND BE UNSAFE TO EAT?

Multiple studies revealed no evidence of oil-related chemical accumulation in shellfish after the Deepwater Horizon oil spill.

When a spill happens, slicks and mats of oil can drift over and settle onto oyster reefs. As oysters filter water through their bodies they can then encounter contaminants dissolved in the water. Oil compounds like polycyclic aromatic hydrocarbons (PAHs) and spill-related chemicals like dispersants cause concern because they can be harmful to humans and wildlife.3

Some contaminants, such as dispersant and PAHs, can build up, or bioaccumulate, once they enter an organism’s body. Oysters cannot move away from oil and dispersants because they are cemented to their reefs. So if they are living and feeding in an area where a spill has occurred, they are more likely to bioaccumulate pollutants. Oysters are also less efficient at removing chemicals from their bodily tissues compared to other animals like fish or crabs.4 These qualities may put oysters at risk, but those same qualities make them useful for monitoring changes in the environment and how oil and other chemical pollution might move through a food web.5,6

For example, scientists examined what oysters, mussels, and barnacles were eating in oiled and unoiled locations before, during, and after the Deepwater Horizon oil spill (DWH) of 2010. They sampled surrounding waters as well as shellfish tissues and shells and found no evidence of oil-related chemical accumulation in the shellfish.6,7,8

However, those results do not mean that oysters did not encounter oil. It could mean that the methods in these studies, the timing, and locations they studied were not capturing the full story. Perhaps the oysters did not eat oiled materials or they did not eat enough oiled materials to be able to detect it.6 Oysters can slow or stop feeding when under stress, so they could have stopped feeding when exposed to oiled materials, which would make levels of oil in their bodies undetectable.6

Though studies are limited, some scientists think that oysters and other bivalves living in areas where natural seeps regularly release oil might be more tolerant of oil compared to bivalves living in non-seep locations.9,10

The different types of bacteria living in and around oyster reefs may have evolved over time to help oysters rid themselves of oil and oil-related chemicals. These bacteria biodegrade oil, or break down and eat oil, and could be the reason why some scientists have seen little to no negative impact to oysters living in spill areas. Scientists need more baseline information about relationships between bacteria and oysters to be sure.9,10

Read the publication Microbes and Oil: What’s the Connection? for more information on this topic.

Even though oysters appeared to not have bioaccumulated spill-related chemicals, experts conducted a thorough Gulf-wide seafood testing program – including oysters – to ensure that seafood in the Gulf was safe to eat after the DWH oil spill. They concluded that Gulf seafood was safe to eat.11,12 To learn more about seafood safety, read the publication The Deepwater Horizon Oil Spill’s Impact on Gulf Seafood.
HOW DO OIL SPILLS IMPACT YOUNG OYSTERS AND FUTURE OYSTER POPULATIONS?

**Oyster larvae in the lab**

If a spill happens during spawning season, oyster sperm, eggs, and larvae can be at risk of exposure to oil and dispersants. Emergency responders do not apply dispersants within 3.45 miles of shorelines or water less than 33 feet deep, where oysters usually live. However, lab studies evaluating dispersed oil impacts to wildlife can reveal important information for future decision-making.

Scientists have conducted laboratory-based toxicity experiments to understand how water contaminated with various doses of oil and dispersants might affect growth and survival rates of oyster larvae. Conducting toxicity studies like these usually involves exposing test subjects to a wide range of doses. Concentrations of chemicals used in experiments could be higher than what is usually measured in the environment and higher than what is usually in the water after a spill. This can sometimes yield results that may not reflect what happens in a real-life, constantly changing environment such as a wetland ecosystem. Additionally, changes in salinity, sunlight, and other factors can influence what happens in the field and cannot always be replicated in a lab.

Some scientists studying DWH impacts to oysters found that exposure to oil and dispersants at an early age can negatively impact fertilization, normal development, and behavior of free-swimming oyster larvae, and the survival rate of larval oysters. Similar experiments conducted by other scientists concluded that the DWH oil spill likely did not negatively affect growth and settlement of oyster larvae. To fully understand oil and dispersant impacts on oyster populations, they stressed the importance of observing not only oyster larval growth, but also oyster spat settlement, when conducting toxicity studies in the lab.

**Keeping an eye on oyster populations**

Fisheries **landings** data are used by natural resource managers, fishermen, and others to monitor changes in populations of fish and shellfish harvested by fishermen. During and after disasters like oil spills, people look to landings information to see if there are major fluctuations in landings that could signal a problem for both the fishing industry and the environment. For example, the National Marine Fisheries Service tracks the pounds of oysters commercially harvested throughout time, and their data show years with high

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**FIGURE 3.** Fisheries landings data can be used to gauge changes in populations over time, but cannot reveal the direct cause of those changes. Many factors must be considered when interpreting landings information, such as major weather events and manmade disasters.
and low levels of harvest. Sometimes landings decrease in the years following events like hurricanes and oil spills, but that is not always the case (Figure 3).

It is important to note that landings data are limited in some ways when it comes to evaluating direct impacts from disasters. Disasters can alter animal populations, but many other factors – such as environmental conditions, interactions with other species, management decisions, fishing effort, and pollution – can influence populations, too. For example, a decision by the government to close an area to commercial fishing for a period of time can have a positive effect on marine populations that is difficult to quantify. For this reason, scientists study as many factors as they can to better understand the dynamics of oil spills and oysters, and other animals. To learn more about landings and disasters, read the publication *Fisheries landings and disasters in the Gulf of Mexico*.

**WHAT DOES RIVER WATER HAVE TO DO WITH OYSTERS AND OIL SPILLS?**

Emergency responders work hard to employ the best available techniques to protect wildlife from spilled oil; however, there are trade-offs when making decisions. Some habitats can benefit from protection while others may not. For example, during the DWH incident, oil was quickly approaching shorelines. In an attempt to protect coastal areas that would be hard to clean, officials decided to release a large amount of fresh water from man-made reservoirs located along the Mississippi River. Under normal circumstances, natural resource managers routinely schedule fresh water releases from these reservoirs at specific times of the year in order to improve wetland health. Carefully controlled and brief releases of fresh water help maintain levels of salinity in wetlands where oysters, fish, and other organisms live and tolerate a range of salt levels in the water. However, if salinity drops too low for too long, oysters can have problems with growth and reproduction, and death can occur. Fresh water releases made in the past have been associated with lower oyster landings.¹₈

During the DWH incident, fresh water releases occurred at very high flow rates for several weeks in hopes that it would push the spilled oil away from the coast. The release continued much longer and at much higher flow rates than in previous years, which created very low salinity levels in wetlands, particularly in Barataria Bay and Breton Sound, Louisiana (Figure 4).²¹₉

Scientists and resource managers working on behalf of the Natural Resource Damage Assessment (NRDA) estimated that between 4 and 8.3 billion subtidal oysters

![Legend](image)

**FIGURE 4.** In an attempt to push approaching Deepwater Horizon oil away from coastal marshes, officials released fresh water from reservoirs. Salinity levels (noted in the Legend as ppt, or parts per thousand) were very low for a long time, causing harm to oysters. The area outlined in purple is where scientists measured high levels of fresh water for more than a month, much longer than what is normally experienced in a year’s time.² (Jacob Oehrig and Shahokh Rouhani)
were lost due to fresh water river releases, particularly in the Barataria Bay and Black Bay/Breton Sound areas. They found that numbers of oysters in oiled subtidal areas were very low in 2010 and, in many of these same areas, dropped to zero in 2011.2 Scientists continued to monitor oysters through 2014 and determined that fresh water releases led to reduced oyster populations as well as smaller oyster size.2,19 In addition to the river releases related to DWH emergency response, other fresh water events such as Louisiana’s Bonnet Carre Spillway release in 2011 added to the loss of oysters, causing economic hardship to the oyster harvesters and broader seafood industry.20

Combined with the effects of direct oiling of oysters, some cleanup methods—such as raking—to physically remove oil from marsh plants and neighboring oysters increased the erosion of marsh shorelines between 2010 and 2013. These actions reduced oyster habitat within about 155 miles of shoreline, resulting in the loss of an estimated 8.3 million adult-equivalent oysters.2 Additionally, experts predict that fewer mature adults means fewer potential offspring, so future generations of oysters could decline.21 They calculated that 5.7 million future adult oysters per year will be unable to grow because the mature oyster shells they would need to adhere to for growth during their larval stage will not be available.2 The emergency response community works with natural resource managers and scientists to use the best available information for decision-making and continue to improve cleanup methods to avoid damaging habitats when responding to spills.

OYSTER RESTORATION IN THE GULF

In the past, oysters have recovered from natural disturbances like floods, droughts, and hurricanes.1 Oysters can replenish and sustain themselves even when conditions are not optimal. Environmental factors such as temperature, salinity, and food availability affect the success of oyster growth and reproduction. However, the DWH oil spill was a record-breaking manmade disaster with large-scale impacts that are still unclear. The combined impacts of reduced oysters and spawning stock, decreased larval production and settlement on new reefs, and loss of suitable settlement habitat has threatened the long-term sustainability of oysters in the northern central Gulf of Mexico.2

To help oysters and oyster communities recover, experts are conducting region-wide restoration projects. Natural resource managers will focus on improving oyster abundance and spawning stock to produce more larvae. Some states are integrating oyster aquaculture into their natural resource programs to enhance oyster larvae stock. Other projects will include building habitats with surfaces that are ideal for oyster larvae to settle on and grow. Some habitats, such as marsh edges and intertidal mud flats, will be managed so that the oyster reef ecosystem can continue to thrive and function for all of its inhabitants, including fish, crabs, birds, and other wildlife.21 For more information about the impacts of oil spills on wildlife and other spill-related topics, visit gulfseagrant.org.
GLOSSARY

Bioaccumulate — The accumulation or build-up of chemicals in the tissues of an organism. In the aquatic world, the bioaccumulated chemical can enter an organism via several methods, including their food, gills, and other tissue membranes.

Bivalve — An invertebrate with two shells hinged together, a soft body, and flattened gills. These animals are part of the class Bivalva, which includes oyster, clam, and scallop.

Brackish — The mixture of river water and seawater, which results in slightly salty water.

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

Intertidal — An area of shoreline, such as sandy beach or rocky coast, that is covered by water at high tide and exposed to air and sun at low tide.

Landings — The quantities, in number or weight, of seafood unloaded at a dock by commercial fishermen or brought to shore by recreational fishermen, as reported to biologists, resource managers, or seafood dealers.

Natural Resource Damage Assessment (NRDA) — The legal process used to determine the impacts of oil spills, hazardous waste sites, and ship groundings on natural resources and humans.

Natural seeps — Occur in areas where oil flows slowly up through networks of cracks in the ocean floor, forming springs of oil. As much as one half of the oil that enters the coastal environment comes from natural seeps of oil and natural gas.

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

Salinity — The average concentration of dissolved salts in a body of water.

Spat — An early life stage in the oyster life cycle, when oyster larvae attach to the shells of an established oyster reef or other hard surface to grow.

Subtidal — The area below the low tide water line that is submerged under water most of the time.

REFERENCES


A Shoreline Cleanup Assessment Team (SCAT) discovered oil debris attached to an oyster shell on the shoreline of Raccoon Island, a protected bird breeding sanctuary in Louisiana. SCAT teams, including the U.S. Coast Guard, BP, and other agencies, worked together to prevent the spread of oil following the Deepwater Horizon oil spill. (U.S. Navy/Petty Officer 2nd Class Jonathen E. Davis)
REFERENCES


SUGGESTED CITATION


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OIL SPILL SCIENCE OUTREACH TEAM

Christine Hale
Texas Sea Grant College Program
chris.hale@tamu.edu

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Missy Partyk
Mississippi-Alabama Sea Grant Consortium
m.partyk@auburn.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
ladon.swann@usm.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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THE SEA GRANT and GOMRI PARTNERSHIP

The mission of Sea Grant is to enhance the practical use and conservation of coastal, marine, and Great Lakes resources in order to create a sustainable economy and environment. There are 33 university-based Sea Grant programs throughout the coastal U.S. These programs are primarily supported by the National Oceanic and Atmospheric Administration and the states in which the programs are located.

In the immediate aftermath of the Deepwater Horizon spill, BP committed $500 million over a 10-year period to create the Gulf of Mexico Research Initiative, or GoMRI. It is an independent research program that studies the effect of hydrocarbon releases on the environment and public health, as well as develops improved spill mitigation, oil detection, characterization, and remediation technologies. GoMRI is led by an independent and academic 20-member research board.

The Sea Grant oil spill science outreach team identifies the best available science from projects funded by GoMRI and others, and only shares peer-reviewed research results.

BIRDS OF A FEATHER — COPING WITH OIL

Emily Maung-Douglass, Larissa Graham, Christine Hale, Stephen Sempier, Tara Skelton, LaDon Swann, and Monica Wilson

Although birds can travel great distances, they cannot necessarily escape oil exposure from natural oil seeps or oil spills caused by humans. Scientists and natural resource managers are still trying to understand the many ways oil exposure can affect birds.

Though an entirely land-based species of bird, seaside sparrows showed signs of oil in their diet after Deepwater Horizon oil spill. (Andrea Bonisoli Alquati)

Oil can have a variety of short- and long-term effects on birds, including damage to plumage, poor health, delayed migration, and death. An oiled bird may experience a cascade of effects from exposure. Negative impacts to birds can include breathing problems, damage to internal organs and blood cells, as well as inability to fly and regulate their temperature. Oil exposure can cause individual birds to die, but it can also lower overall population numbers by reducing breeding, hatching, nesting habitats, and newborn survival rates, and by altering migration habits. Scientists continue to study how birds combat oil pollution, both in the timeframe immediately following a spill and in the long term.
**IMPACTS**

**Plumage**

Plumage, or the feathery covering on a bird, is critical to the health of birds. Plumage serves many roles, such as aiding in flight, attracting mates, supporting buoyancy, and insulating from cold and wet conditions. Oiling reduces the insulation provided by plumage, making it difficult for an oiled bird to maintain a stable body temperature.\(^3\) The result is often death due to hypothermia.\(^3\) Additionally, oiled birds might devote more time than unoiled birds to preening their feathers with their beaks in attempts to clean and straighten their plumage. Increased time spent on this behavior disrupts time spent on other behaviors like foraging, resting, and reproduction, which can negatively affect the overall health of the bird.\(^3\) Birds may also accidentally eat oil while preening, leading to greater negative health consequences.\(^4\)

**Toxic effects and accumulation**

Birds and many other animals can break down and excrete oil compounds from their bodies. While eating contaminated food may not cause oil-based compounds to build up or accumulate in birds’ muscle tissue these compounds still move through the birds’ bodies as the compounds are processed and may be passed to others in the food chain.\(^1\) For example, Tundra Peregrine falcons sampled from coastal Gulf of Mexico had increased levels of oil-based compounds circulating in their blood after the Deepwater Horizon (DWH) oil spill.\(^5\) The levels varied based on the age of the birds, likely due to age-

**THE COST OF BREAKDOWN**

The liver breaks down oil through a series of complex processes using enzymes. Oxygen reacts with some of the chemicals formed during these processes and the results can lead to damage in the body. The bird’s liver produces *antioxidants* to reduce this damage.\(^4\) The liver can increase the production of antioxidants in response to these damaging chemicals. Unfortunately, the damaging chemicals can also inhibit the protective actions of antioxidants, leading to damage and disease in the liver, blood, and other tissues.\(^7\) One resulting condition is hemolytic anemia. Red blood cells carry oxygen throughout the body. The damage to red blood cells by oil causes a lack of oxygen in the tissues and damages the tissues as well.\(^4,7,8\)

<table>
<thead>
<tr>
<th>Group</th>
<th>Estimated mortality (number of individuals)</th>
<th>Percent of total bird mortality</th>
<th>Example of this group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulls</td>
<td>23,050 - 37,266</td>
<td>39%</td>
<td>Laughing Gull</td>
</tr>
<tr>
<td>Pelicans</td>
<td>15,323 - 34,200</td>
<td>30%</td>
<td>Brown Pelican</td>
</tr>
<tr>
<td>Terns</td>
<td>7,885 - 13,162</td>
<td>13%</td>
<td>Sandwich Tern</td>
</tr>
<tr>
<td>Seabirds</td>
<td>3,914 - 6,020</td>
<td>6%</td>
<td>Northern Gannet</td>
</tr>
<tr>
<td>Waders</td>
<td>2,719 - 5,553</td>
<td>5%</td>
<td>Roseate Spoonbill</td>
</tr>
<tr>
<td>Rails</td>
<td>858 - 1,875</td>
<td>2%</td>
<td>Clapper Rail</td>
</tr>
<tr>
<td>Shorebirds</td>
<td>705 - 1,322</td>
<td>1%</td>
<td>American Oystercatcher</td>
</tr>
<tr>
<td>Loons and Grebes</td>
<td>781 - 1,249</td>
<td>1%</td>
<td>Common Loon</td>
</tr>
<tr>
<td>Waterfowl</td>
<td>410 - 639</td>
<td>1%</td>
<td>Mallard</td>
</tr>
<tr>
<td>Cormorants</td>
<td>476 - 1,077</td>
<td>1%</td>
<td>Double-crested Cormorant</td>
</tr>
<tr>
<td>Raptors</td>
<td>80 - 122</td>
<td>0.1%</td>
<td>Osprey</td>
</tr>
<tr>
<td>Landbirds</td>
<td>20 - 36</td>
<td>0.04%</td>
<td>Seaside Sparrow</td>
</tr>
</tbody>
</table>

**NATURAL RESOURCE DAMAGE ASSESSMENT AND THE DEEPWATER HORIZON OIL SPILL**

The federal government initiated the *Natural Resource Damage Assessment (NRDA)* process during Deepwater Horizon oil spill to determine how the spill harmed natural resources, including birds.\(^2,9\) Scientists from multiple organizations came together to study how the oil spill impacted bird reproduction, health, and long-term survival.\(^2,9\) Impacts on the breeding populations are difficult to accurately assess, but NRDA estimates indicated between 51,600 and 84,500 birds died in the months immediately following the spill.\(^2\) Many of the studies done as part of the assessment are cited in this publication.

Table 1. Scientists and natural resource managers estimated the number of birds impacted by the Deepwater Horizon oil spill in several ways during the Natural Resource Damage Assessment (NRDA). The numbers in the table represent the range and percentage of birds from each group estimated that died or were never born due to the oil spill—approximately 56,100 to 102,400 birds in total.\(^2\) (Laughing gull figure: A. Wilson)
FIGURE 1. These double-crested cormorants fishing for a meal are left vulnerable to the effects of oil when exposed to it through their skin or food. (Brocken Inaglory)

Specific differences in hunting strategies and food between adults versus younger birds. For example, young falcons tend to favor preying upon other birds that are ‘stragglers’ in a flock. These lone birds are sometimes unable to keep up with their flock due to oiling. Scientists believe that by preying upon these oiled birds, young falcons increase oil uptake through their diets compared to adults that may not selectively prey on ‘stragglers’ in a flock.5

The skin is another route for oil to enter the body via direct exposure. Scientists found that exposing birds to oil through their skin can have health effects. Exposing the skin of double-crested cormorants to a few teaspoons of oil every few days for about two weeks is enough to cause severely labored breathing, disrupt heart function, and enlarge and soften the heart muscle (Figure 1, 2).6

Migration and other far-reaching effects
An oil spill has the potential to affect birds in places far outside of an oiled area (Figure 3). Migratory birds travel long distances on a predictable course at predictable times to nest, overwinter, and mate. Successful breeding often hinges on being in the right place at the right time for many migratory bird species. Oiled birds may have difficulties flying, causing them to be out of sync with regular migration patterns and also leading to exhaustion and further difficulty when they do arrive at the location used for mating, nesting, or feeding.10

Scientists studied homing pigeons to better understand the impacts of oiling on migratory bird species.10 Homing pigeons are a good study species because they navigate long distances — like migratory birds — and can be trained to return to their human handlers. Scientists found that lightly oiled homing pigeons took longer to return home compared with unoiled birds. While many of the unoiled homing pigeons tested could complete flights without stopping, the oiled birds spent up to 50 percent of their trips not flying due to more

FIGURE 2. Birds are exposed to oil via multiple routes, including through their skin, feathers, diet, and mouth. Impacts to birds are numerous and can include damage to internal organs and blood cells. (Anna Hinkeldey)
frequent breaks or resting periods. Based on previous work done with oiled sandpipers, scientists think that the oiled pigeons needed to take long breaks during their flights because of their bodies’ high energy demand to maintain flight. Feathers matted and clumped with oil are less aerodynamic and cause difficulties with flying. In fact, scientists found lightly oiled sandpipers have significantly less powerful wingbeats than unoiled birds. Light oiling results in slower take-offs for oiled birds and leaves them more vulnerable to attack by predators compared to unoiled birds.

Migratory birds that are able to take flight can become part of food webs in multiple locations and ecosystems. This is because they may hunt and eat other animals or be eaten themselves anywhere they travel. When oiled migratory birds are eaten by other animals, it can introduce oil into food webs otherwise unaffected by an oil spill. Similarly, unoiled migratory birds may return until the plumage is dry. A similar phenomenon occurs in other oiled and detergent-cleaned animals. Allowing even one week for drying and the return of naturally protective and insulating oils of the skin brought survival rates back to normal levels in sea otters when compared with the high mortality associated with otters immediately released after cleaning.

**CLEANING OILED BIRDS – LESSONS LEARNED**

Many people have seen the practice of cleaning oiled birds with detergent after major oil spills. Survival of these rehabilitated and released birds can vary. Scientists think that survival after oiling and rehabilitation depends on several factors, including the species affected, conditions of the spill, stress due to oiling, and cleaning techniques. Scientists found that murres rehabilitated from various spills that occurred between 1969 to 1994 (including Exxon Valdez) had a post-cleanup life expectancy of just over one week. More recent studies of birds oiled in other spills (penguins, gulls, gannets, pelicans) show post-rehabilitation survival rates similar or no different than unoiled birds.

One aspect of cleaning techniques that affects post-rehabilitation survival is time allowed for plumage to dry. The naturally protective and insulating oils of a bird’s skin and feathers do not return until the plumage is dry. A similar phenomenon occurs in other oiled and detergent-cleaned animals. Allowing even one week for drying and the return of naturally protective and insulating oils of the skin brought survival rates back to normal levels in sea otters when compared with the high mortality associated with otters immediately released after cleaning.
be exposed to oil when visiting oiled habitats either by ingesting contaminated prey and/or becoming oiled themselves (Figure 2).1,14 This can have serious consequences in systems like Louisiana saltmarshes. Recent research indicates that birds there (gulls, terns, wading birds) hold uniquely important connections to many other types of marsh animals and plants.13 Scientists identified these birds — some of which are migratory — as ‘critically sensitive’ to oil spills. This means that they are vulnerable to the effects of oil and are so connected to other organisms in that habitat that negative impacts to them could have a ripple effect on other plants and animals in that system.

**Longer-term impacts and chronic oiling**

The long-term success of a species depends in large part upon reproduction and survival of the young. Seaside sparrows live in coastal wetlands in the Gulf of Mexico and demonstrate this concept (see cover photo).18 In the three years immediately after DWH oil spill, these birds were less successful reproducing than in previous years.18 A possible cause could be loss of nesting habitat. Many of the plant species used by these birds as nesting habitat died due to the presence of oil in the marsh. However, this may not be the only reason these birds were less successful at reproducing. Scientists also found that seaside sparrows living in oiled areas ate oil-contaminated prey.19 This behavior may have led to those birds producing a lower number of chicks that survived long enough to leave their nests.18,19 In studies done on mallard ducks, chicks developing in eggs painted with *weathered oil* experienced toxic effects due to exposure. The eggs painted with oil were less likely to hatch.20

What can we learn from historic oil spills about the longer-term impacts on birds? More than 30,000 oiled birds died within the first five months after the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska.21 Total long-term losses to the bird population from the spill were estimated at 250,000, but it is difficult to determine exact numbers of bird losses from the Exxon Valdez spill (or any oil spill) because it was not possible to locate all carcasses.22

Approximately three-quarters of the birds lost to oiling during those first months after the Exxon Valdez spill were murres (Figure 4).23 This bird is vulnerable to events like oil spills because it is slow to reproduce and spends...
SO MANY CHOICES — WHAT’S THE DIFFERENCE?

Determining which technology to use can depend on the environment being studied, the amount of time a scientist has, the advantages and disadvantages of the technology, and the cost to operate the equipment.

Some research suggests that the murre population in Prince William Sound increased in the years following the spill. The increase in numbers is likely due to individuals from other areas coming in and joining the locally impacted breeding population. Baseline monitoring data are needed to accurately differentiate what impacts are due to oil spills versus shifts in other environmental factors.

Meanwhile, the 2002 Prestige oil spill along the coast of Spain continues to negatively affect bird reproduction after the wrecked tanker released nearly 17 million gallons of oil. The number of fully-grown European shag chicks declined by nearly half in oiled bird colonies compared to unoiled colonies 10 years later. Further, oil exposure is not restricted to the time of the spill event itself. Recent research indicates that oil can linger in the environment after a spill event and be unburied following hurricanes, tropical storms, and flooding events, re-exposing seaside sparrows and other animals to the oil.

While the immediate impacts from major oil spills gain much attention, studying the impacts from chronic oil exposure is also important. Scientists spent five years studying the levels of oil-based compounds in the blood of common loons in Barataria Bay, Louisiana. While there were no immediate increases of these compounds in the blood due to DWH oil spill, the results revealed that the birds in the area are chronically exposed to oil, scientists think possibly via natural oil seepages in the water.

Exposure to oil via natural seeps is not uncommon. In California, for example, there are approximately 254 reports of visibly oiled birds each year. The oil is likely from natural seeps and stirred up by large storms. Constant exposure to low levels of oil can cause birds to have reduced body mass relative compared to those birds that are less exposed. Such impacts lead some scientists to think that continual exposure to oil over long periods of time could lead to long-term population-level effects.

WHERE DO WE GO FROM HERE?

The Gulf of Mexico Research Initiative (GoMRI) and others continue to develop an understanding of how oil impacts birds and other wildlife. 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.

The 2002 Prestige oil spill continued to negatively impact the development of European shag chicks 10 years later. (Bo Eide)
Scientists think that common loons living in Barataria Bay are chronically exposed to oil, possibly via natural oil seepages in the water. (Cephas)

**GLOSSARY**

**Antioxidants** — Enzymes, like vitamins C and E, that protect the body from potentially harmful compounds generated during the breakdown of foreign chemicals (such as oil).

**Ecosystem** — A large community of living organisms — such as plants, animals, and microbes — in a particular area linked together through nutrient cycles and energy flows.

**Food web** — A system of linked food chains — a series of organisms, beginning with plants and ending with carnivores, each dependent upon the next as a source of food — within an ecological community.

**Natural Resource Damage Assessment (NRDA)** — The legal process used to determine the impacts of oil spills, hazardous waste sites, and ship groundings on natural resources and humans.

**Overwinter** — Spend the winter.

**Oxidative stress** — Occurs when oxygen reacts with compounds formed from the body’s breakdown of foreign compounds and overwhelms the body’s antioxidant protection. This can lead to damage to the body. The body produces antioxidants to protect itself from this damage.

**Weathered oil** — When processes such as evaporation, dissolution, bacterial decomposition, or exposure to sunlight change the chemical composition and physical appearance of oil.

**REFERENCES**


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SUGGESTED CITATION:

OIL SPILL SCIENCE OUTREACH TEAM

Christine Hale
Texas Sea Grant College Program
chris.hale@tamu.edu

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Missy Partyka
Mississippi-Alabama Sea Grant Consortium
m.partyka@auburn.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
ladon.swann@usm.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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.

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IMPACTS OF OIL ON MANGROVES

Monica Wilson, Emily Maung-Douglass, Christine Hale, Melissa Partyka, Stephen Sempier, Tara Skelton, and LaDon Swann

Extremely productive and beneficial ecosystems, mangrove forests stabilize coastlines by protecting shorelines from storm surges, currents, waves, and tides. They improve coastal water quality and provide shelter to species of fish, crab, shrimp, and mollusks. However, if mangrove forests are compromised by oil spills, they can no longer shield coastlines, provide habitat, or feed organisms living among their roots and branches.

Mangroves are productive coastal ecosystems that dominate the intertidal shores of tropical and subtropical areas. (UF/IFAS/Tyler Jones)

BACKGROUND

Mangroves are a group of mostly woody plants that dominate the intertidal shores in tropical and subtropical areas. In the U.S., mangrove communities are widely distributed throughout the Gulf of Mexico and the Caribbean Sea. They are well-developed mainly in the southern part of Florida and in Puerto Rico, but their range, specifically the black mangrove, has expanded to southern Texas and Louisiana (Figure 1).

These coastal plant communities consist of four dominant types: red mangrove, black mangrove, white mangrove, and buttonwood. Mangroves tend to grow in a specific order from the sea edge. Typically, the red mangrove lives closest to the water and has aerial roots known as prop roots. Black mangroves are...
further inland close to the red mangroves. They have pneumatophores that poke out of the sediment. Prop roots and pneumatophores have small openings called lenticels that provide oxygen for mangroves to breathe (Figure 2). The white mangrove lives farther inland on more stable higher intertidal soils, with the buttonwood farthest away at the landward edge. Mangroves’ tangled, dense root systems provide habitat and food for many species of fish, crabs, and other living creatures. These roots also help mitigate storm surge and maintain water quality by restricting water flow, trapping sediments, and absorbing excess nutrients from the water. The calm waters provide an ideal environment for breeding and nursery grounds for young fish and shrimp. They also help to stabilize other plants in the surf. Mangroves can adapt to changing environmental conditions, such as fluctuations in salinity from flooding or long periods of drought. They use the following mechanisms to tolerate high salinities:

- Salt exclusion — mangrove roots have filters that exclude salt while extracting water from the soils.
- Salt accumulation — some mangroves have glands that cause salt to accumulate in older leaves so when they shed their leaves, they also shed salt.
- Salt secretion — special organs or glands remove salts from plant tissues by forming salt crystals on leaf surfaces that can be removed by wind or rain.

**OIL IMPACTS**

Mangroves are highly sensitive to oil exposure. The extent of damage to and recovery of mangroves depends upon the type of oil spilled and the amount reaching the mangroves and remaining after cleanup efforts. The oil’s exposure to waves and currents, the time of year of the spill, and the oil sensitivity of the different mangrove species also factor into impacts.
Spills at sea are the main cause of oil in mangroves due to their coastal locations. Mangrove forests near ports, refineries, or busy shipping channels are at highest risk. Waves and currents transport oil into the mangrove ecosystems. Once there, oil often collects, coats the vegetation, and penetrates the soil. Water moves slowly through the mangrove forest making natural removal very slow. Observations of past spills show that differences in the physical environment, such as wave exposure and land features like berms, influence where the oil will go and how long it will persist (Table 1).

Past oil spill events around the world demonstrate that mangroves can suffer lethal and sublethal effects when exposed to oil. They may show signs of oiling within the first two weeks of a spill event, though evidence of oiling may not appear until weeks, months, or even a year later. When oiling occurs, mangrove leaves can stunt or deform and branches can defoliate or die back. Mangrove seedlings can also deform or die. Plants and animals living in the mangrove forest may change in number, location, or die altogether after oiling. Oil exposure can lead to defoliation. The loss of leaves allows more light to penetrate the forest floor, which then causes temperatures and salinities to rise. These conditions can cause leaf deformities and seedling deaths or progress to tree death. Defoliation and death occurred after a spill in Panama in April 1986. Winds pushed oil towards the coast where it penetrated the soils around the mangrove roots. By September of 1986, mangroves in a heavily oiled intertidal zone experienced complete defoliation. Trees rooted in the subtidal zone suffered less defoliation.

Oil will impact mangroves regardless of the distance from shore if oil reaches their roots and pneumatophores. Mangrove roots are partially submerged, grow in anaerobic sediments, and receive their oxygen from the air through the lenticels on the exposed roots. If the root is damaged or coated with oil, respiratory capabilities of the plant will suffer, which could cause them to suffocate or die. The chemicals in the oil can be highly toxic and penetrate the root surfaces, poisoning the plant. Shorter, less mature trees may die within days of oiling. Taller, more mature trees may show no signs of damage for six or more months and then die.

In a recent laboratory study, scientists exposed sections of red mangrove roots to salt water; salt water and crude oil; and salt water, crude oil, and dispersants to examine the impacts of oil and oil plus dispersants on water movement through mangrove roots. Results showed the roots exposed to oil or oil and dispersants dried out, suggesting that water was not carried through the roots.

<table>
<thead>
<tr>
<th>IMPACT</th>
<th>WHAT HAPPENS?</th>
<th>WHAT IS AFFECTED?</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTER FRINGE</td>
<td>Oil is trapped on and in front of a high berm at the outer edge of the forest.</td>
<td>Most of the oil collects in and impacts a small area, resulting in defoliation or death of shoreline mangroves and leading to shoreline erosion.</td>
</tr>
<tr>
<td>INNER FRINGE</td>
<td>Oil is pushed into the mangrove forest and deposited on the inner berm.</td>
<td>The vegetation in the area of highest oiling is stressed or dies.</td>
</tr>
<tr>
<td>INNER BASIN</td>
<td>Oil is carried over the coastal berm or through tidal flats into a sheltered mangrove basin.</td>
<td>Oil can be spread over a wide area and damage can be more scattered.</td>
</tr>
<tr>
<td>RIVERINE</td>
<td>Oil accumulates on gently sloping sand bars, with the potential for penetration into the porous soils.</td>
<td>With both oiling of the roots and in the soils, damage can be severe.</td>
</tr>
</tbody>
</table>

| Table 1. Mangroves can experience four types of impacts when polluted with oil. (Adapted from Getter et al., 1981) |
The lack of water movement caused separation between the root layers, weakening the structure of the root (Figure 3). When a June 1991 spill sent one thousand gallons of oil into a restored mangrove area near Port Everglades, Florida, scientists tested three species of oiled mangroves to determine impacts and growth abnormalities over time. The study’s results showed that white and black mangrove seedlings were less tolerant to oiling than red mangrove seedlings. Red mangrove seedlings had fewer deaths and increased growth rates after the spill. In an earlier laboratory study, red and black mangrove seedlings exposed to oil and dispersant showed changes in growth, respiration, transpiration, and uptake of oil-based chemicals.

Plant roots are further stressed when oil coats the surrounding soil, resulting in compromised soil conditions. Mangroves growing in more porous soils are vulnerable to impacts due to oil penetrating deeper into the ground, as opposed to mangroves growing in fine clay mud. Even muddy mangrove soils can become porous when animals that live there dig burrows for their homes, a process known as bioturbation. The digging increases the mixing and turnover of the soil. This process can lead to persistent oiling because of slow rates of oil weathering in the absence of oxygen in anaerobic soils. Animals like crabs or worms living in the mangroves can be harmed by oil when it enters their burrows or if they ingest it (Figure 4). Burrowing activities help aerate the mangrove soils as tidal waters flow through the network of burrows. This aeration ceases when the animals die, causing stress to the surrounding mangroves.

Under severe conditions, oil spill impacts may continue for years to decades and can result in permanent habitat loss. When mangroves are severely oiled, plants can rot and die as a result. This loss of live plant roots, which stabilize the soil, and can increase the rate of land loss.

**Signs of oiling on the trees:**
- Leaves turn yellow.
- Defoliation takes place.
- Death can occur.

**Oil coats seedling/propagules:**
- Seedlings can absorb harmful chemicals.
- Changes in growth can take place.
- The tree’s ability to breathe can be impacted.

**Oil coats the root:**
- Oxygen cannot reach the roots.
- Lack of oxygen can cause plant death.

**Oil coats or penetrates into sediment:**
- Oil enters holes and penetrates deeper into the sediments.
- Animals living in burrows can be exposed to oil.
PROTECTION, RECOVERY, AND RESTORATION

Protection

The natural regenerative processes of mangrove forests are complex and slow, putting the recovery of oil-damaged habitat at risk. Once oil enters a mangrove forest, the intricate root systems of mangroves can make oil cleanup difficult, so keeping oil off mangrove shorelines is a high priority for oil spill responders. Determining the appropriate response action depends on multiple factors, including oil type, weather, and availability of response equipment. The ideal response would be to keep oil from reaching the shoreline. To do this, responders could mechanically recover the oil offshore, use oil dispersants or in situ burning offshore, or protect the mangrove shoreline with boom. Keeping oil off as much of the shoreline as possible is essential for the natural repopulation of mangroves. The surviving areas provide uncontaminated seedlings to transplant elsewhere and unoiled soil provides an ideal area for seedlings to grow, making these high priority zones to protect.

If oil happens to enter a mangrove area, considerations need to be made before any cleanup efforts are applied. The benefits of any response efforts should outweigh any damage caused by the cleanup. With such considerations in mind, cleanup options include the following:

- Sediment berms and dams can close off small inlets to protect mangrove habitats.
- Booming and skimming the oil on the water’s surface in mangrove creeks can keep it from reaching sensitive areas.
- Responders can remove bulk oil manually or vacuum it from the sediment surface and channels.
- Water can flush free oil from the surface of the sediment and mangroves into collection areas.
- Absorbent materials can collect oil from mangrove surfaces.

Some oil response methods can be highly destructive to mangroves. These actions include cutting or burning live trees, high-pressure or hot water flushing, digging trenches, and sediment reworking or removal. Any response techniques that lead to trees being destroyed could have long-term impacts to the mangrove forests, such as increased erosion that could leave the shore unprotected from storm surge.

There are occasions when it may be appropriate to do nothing. Cleanup operations can cause significant damage to roots and seedlings, doing more harm than good. Responders’ foot traffic can mix oil into the fine-grained sediments, reducing the oil’s breakdown rate. With no physical cleanup, the exposed oil will slowly degrade and be removed by natural or storm-generated flushing.

Recovery

Generally, mangroves have the capacity to recover from major natural disturbances such as hurricanes or floods. After a manmade disturbance such as an oil spill, recovery and rehabilitation of the forest can be slowed by the persistence of oil in the soils. When the impacts of oil are damaging but not deadly, mangrove forests can recuperate rapidly, usually in one to five years. However, sometimes mangroves can be permanently lost due to gradual degradation and weakening. When the trees die, recovery of the area can take 5 to 25 years or longer by natural recruitment. To recover, new seedlings need to come from other healthy mangrove forests, and then replacement plants grow to full maturity. When oil spills cause lethal impacts to mangrove forests, it affects the surrounding environment. The changes to sediments, erosion, water circulation, temperature, and salinity make recovery more difficult.

In April 1986, 50,000 barrels of crude oil spilled off Panama’s Caribbean coast. Scientists revisited the spill site five years later to conduct a long-term study. Impacts of oiling were still visible. Sediment testing confirmed the oil persisted in the deep muds and continued to leach into the waters. The team also noted a decrease of mangroves in the area. This change reduced the area of living substrate on the prop roots on which animals attach and grow.

To understand the long-term impacts of untreated oil and dispersant-treated oil on tropical ecosystems, in December 1984 scientists began a multi-year monitoring project in Panama. Areas were dosed with high concentrations of chemically-dispersed oil to create a ‘worst-case’ scenario. Over a two-year period, untreated oil had severe effects on the survival rate of mangroves and animals. Dispersant-treated oil had minor or no effects on seagrasses and mangroves. As for animal life, an initial severe decline in the number of mangrove tree snails took place only three days after treatment. However, all treatment sites recovered to pre-spill numbers after one year.
Ten years later, scientists revisited the original project sites. Evidence of the continued presence of oil existed with degraded hydrocarbons still present in surface and sediment samples in both the chemically-dispersed site and oil-only site. Oil made its way into the sediments by seeping through holes and dead mangrove propagules. In the oil-only area, they found many of the original trees had died, as well as healthy seedlings and saplings regenerating in the same area. This regrowth occurred in the same place where oil accumulated during the initial experiment. In contrast, the chemically-dispersed oil site had no measurable effects on adult mangroves and no deaths occurred.\textsuperscript{11} To understand chronic long-term oil impacts on mangroves, monitoring forests for years after a spill is essential.

**Restoration**

Restoration is a technique that can speed up the spill recovery process. Depending on the forest’s state after an oil spill, restoration methods may include replanting, removing pollutants from soils, improving the impacted site so that natural regeneration can occur, or restoring an alternate site to provide a similar replacement habitat.\textsuperscript{6} Removing stressors and ensuring suitable environmental conditions can help mangroves recover.\textsuperscript{23}

When planting seedlings, conditions such as soil type, location, and existing toxic elements in the water must be carefully considered. Residual oil in sediment degrades very slowly. To help stop or even reverse damage from oil, remediation may help oil break down faster by adding nutrients or aerating the soil to allow nutrients, air, and water to penetrate more deeply.\textsuperscript{5,6} However, both types of remediation have shown only modest effectiveness in field experiments and not after real spills.

Replanting areas where oil killed mangroves has two benefits: 1) speeding the natural revegetation process and 2) releasing oxygen into the soils via new root systems, which increases oil degradation through a process called phytoremediation. After the 1986 Panama spill, scientists used planted red mangrove propagules and nursery-grown seedlings in holes filled with oil-free soils. Scientists found seedlings planted 9 to 12 months post-spill grew at a faster rate than those planted at six months. Apparently, weathered oil was less toxic over time.\textsuperscript{24}

Another long-term study in the mangrove forests of Bahía Las Minas, Panama, showed that replanting may not always be the correct solution to restoring mangrove forests. Oil from the 1986 spill remained in the sediment for more than twenty-four years, making recovery slow.\textsuperscript{25} Assessments showed natural recruitment following the spill was plentiful in most areas, and the growth and survival of established plants were not affected by oil in the sediment. Natural recruits began to grow and shade the planted seedlings, causing them to die. Planted sites had lower densities, shorter trees, and smaller biomass. Planting may have also altered or damaged some sites, negatively affecting forest recovery. This included responders trampling sediment, which compacted the soil and released residual oil. Holes dug to plant increased erosion and interfered with natural recruitment by damaging existing seedlings and disrupting their establishment.\textsuperscript{26}

Scientists continue to study oil spills’ impacts on mangroves, some with funding from the Gulf of Mexico Research Initiative (GoMRI). To access other oil spill-related publications, go to GoMRI’s website at gulfresearchinitiative.org or the Sea Grant Oil Spill Science Outreach Program website, www.gulfseagrant.org/oilspilloutreach.

**GLOSSARY**

Anaerobic — Deprived of or without oxygen.

Berm — An artificial ridge or embankment used as a border or separation barrier.

Biomass — The total weight of organisms in a given area.

Bioturbation — The mixing and turning over of soil by living organisms, which can happen when organisms move, burrow, or ingest and defecate soil grains.

Boom — A temporary floating barrier used to contain an oil spill.

Defoliate — The loss or removal of leaves from a tree, plant, or area of land.

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.

Hydrocarbon — A compound composed of carbon and hydrogen atoms. Most hydrocarbons naturally occur in crude oil and natural gas and are formed from decomposed organic matter.

In situ burning — A response method used to remove oil from the water’s surface through burning.
Intertidal — The area that is above water at low tide and underwater at high tide.

Lenticels — Raised pores in the stem of a woody plant that allow gas exchange between the atmosphere and the plant’s internal tissues.

Phytoremediation — A process that uses various type of plants to remove, transfer, stabilize, or destroy pollutants in the soil.

Pneumatophores — Specialized aerial roots that grow out from the sediment’s surface to transport oxygen from the atmosphere to the roots.

Propagules — Part of a plant, such as a spore, seed, or cutting, used to reproduce itself.

Recruitment — A process where new plants populate an area through seed germination, seedling survivorship, and seedling growth.

Remediation — The process of reversing or stopping environmental damage.

Revegetation — The process of replanting and rebuilding the soil of land that has been impacted by natural or human-caused disturbances.

Salinity — The average concentration of dissolved salts in water.

Sediment — Naturally occurring material that is broken down by weathering and/or erosion and transported by wind, water, or ice. It can consist of rocks, boulders, sand, and/or the remains of plants and animals.

Soil — Sediments in which plants grow.

Sublethal — Not strong enough to kill but to cause effects that can lead to reduced health or survival.

Substrate — The surface or material where an organism lives, grows, or obtains its nourishment.

Subtidal zone — The area that sits behind the tidal zone below the low tide water line.

Subtropical — Geographic and climate zones located between the tropics and temperate zones.

Tropical — Geographic zone near the equator.

Transpiration — The loss of water through leaves.

Weather (-ing, -s, -ed) — A collection of physical, chemical, and microbial processes that alter and break down oil. It includes processes such as oil spreading, evaporation, dispersing, biodegradation, and photooxidation. These processes are influenced by many factors (e.g., type of oil being weathered, temperature, bacteria present).

REFERENCES


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SUGGESTED CITATION


OIL SPILL SCIENCE OUTREACH TEAM

Emily Maung-Douglass
Louisiana Sea Grant College Program
edouglass@lsu.edu

Missy Partyka
Mississippi-Alabama Sea Grant Consortium
m.partyka@auburn.edu

Stephen Sempier
Mississippi-Alabama Sea Grant Consortium
stephen.sempier@usm.edu

Tara Skelton
Mississippi-Alabama Sea Grant Consortium
tara.skelton@usm.edu

LaDon Swann
Mississippi-Alabama Sea Grant Consortium
ladon.swann@usm.edu

Monica Wilson
Florida Sea Grant, UF/IFAS Extension
monicawilson447@ufl.edu

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