OIL SPILL SCIENCE
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OIL SPILLS AND HARMFUL ALGAL BLOOMS: DISASTERS WITH SHARED CONSEQUENCES FOR COMMUNITIES

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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.

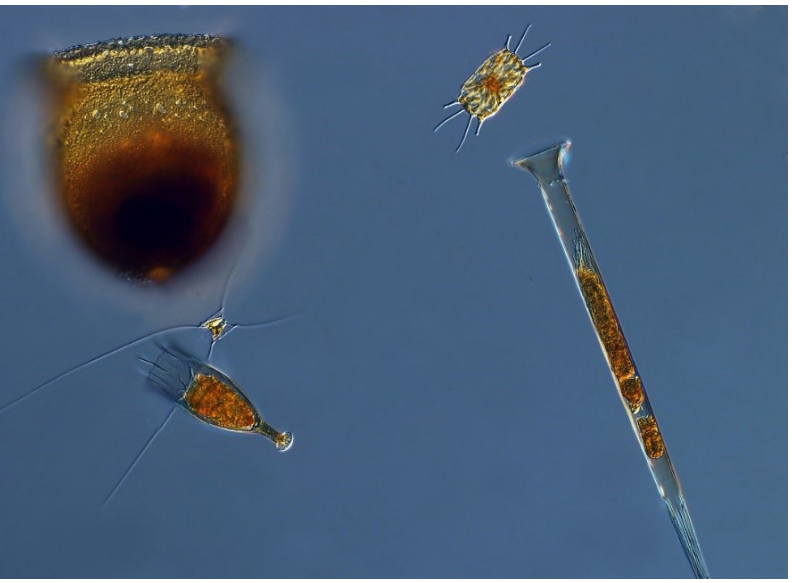
Weathered oil on the surface of water can look reddish and may be mistaken for a red tide. (GISR/ Du and Kessler)

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.[1] 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.[2] 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).



Phytoplankton, like the small, yellowish diatoms pictured here, are the base of many coastal food chains. They are eaten, or grazed on, by larger zooplankton like the bigger, brownish organisms in this photo. (NOAA)

In the Gulf of Mexico, one of the most common HABs comes from a type of algae called a **dinoflagellate**, specifically the species *Karenia brevis*, or *K. brevis* for short. These blooms, and others around the world caused by different species, are often known as 'red tide' because of the color that can be seen when algae concentrations get very high. These algae can produce a group of toxins called brevetoxins.[5] Brevetoxins can cause respiratory irritation in humans and contaminate some shellfish.[6]

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[7], though the relationship between the two events is not always clear.[8] Shortly after the 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.[9,10] Though evidence exists that Deepwater Horizon impacted algal populations[10,11], there is no proof that the spill led to HAB events in the Gulf of Mexico.[12] 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.[3] 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.[3] What is clear is that oil spills can greatly alter algal communities and so potential connections warrant continued attention.[7]

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.

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.[3] 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.[4] 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.

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)*

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.*

	ENVIRONMENTAL FACTORS	DURATION OF EVENT	PERSISTENCE IN THE ENVIRONMENT	FORECASTING	RESPONDING AGENCIES
OIL SPILLS	Weather (temperature, sunlight, wind), currents[29]	Minutes to year[40]	Oil and chemicals may remain in sand or marshes months to years if buried or submerged.[41]	Short-term movement of surface oil[29]	U.S. Coast Guard, BSEE, NOAA, EPA, state governments, FDA
HABs	Weather (water temperatures, salinity, sunlight, and wind), nutrients, currents, competition[1]	Days to years[1]	Toxins may remain in seafood or seagrass for days to weeks after bloom has ended.[42]	Pre-bloom: favorable conditions[6]; mid-bloom: daily movement and impacts[43]	State health and natural resource departments, EPA, FDA

TABLE 2. *These are a few of the potential negative effects of oil spills and harmful algal blooms on humans, along with examples of impacted habitats and animals after acute (A) or chronic (C) exposure. The letters "AC" indicate that effects can occur from both chronic and acute exposure.*

	OIL SPILLS	HABs
Digestive issues[15]		A
Respiration[1,2,3]	AC	AC
Skin irritation[15,16,44]	A	A
Death[13,15,16]	C	A
Oysters[45,46]	A	AC
Marshes[44,45]	AC	
Corals[45,47]	AC	AC
Fish kills[44,45]	A	A
Mammal stranding/ death[45,48]	AC	AC
Bird deaths[45,48]	AC	AC

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.[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.[14] Consumption of HAB toxins from contaminated seafood—primarily oysters, clams, and mussels—can cause a variety of illnesses in humans.[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.[16] In severe cases, exposure to toxins from HABs can cause death.[17]

In seafood, toxins from HABs are odorless, tasteless, and cannot be destroyed by cooking or washing.[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.[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.[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).[20]

TABLE 3. *Regulators use different standards for the closure and reopening of shellfish growing areas depending on the potential hazard to humans. Oil spill closures are based on the presence of oil while the closures for two harmful algal species found in the Gulf of Mexico are based on algal concentrations. Concentrations of algae are measured as the number of individual algal cells per liter of seawater (cells/L).*

Impact	Shellfish Closure Level (cells/L)	Shellfish Reopening Criteria
Oil spill	Oil or oil sheen present	PAHs in seafood lower than level of concern[49]
Karenia brevis	5,000 or above	Absence of toxin in shellfish samples[19]
Pseudo-nitzschia	1,000,000 or above	Absence of toxin in shellfish samples[19]

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.[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.[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.***

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.[24] 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.[25] Loss of seafood consumer confidence following both types of events can have long-lasting economic impacts for coastal fishing communities[26], especially when questions of seafood safety receive broad news coverage.[27] 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.[28]

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.[29] These same data are regularly used to predict HAB events.[30,31] 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.[12,32] 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.[12] Scientists hope to use the location of the Loop Current to predict the occurrence of major blooms in the future.

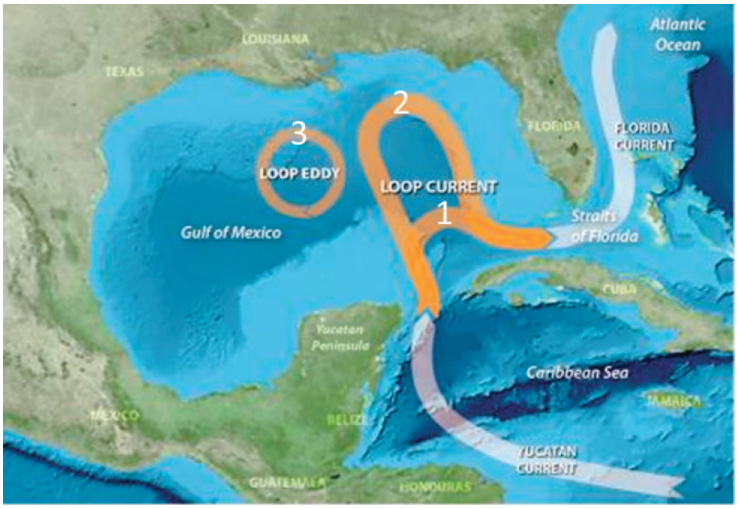


FIGURE 2. *The retraction of the Loop Current into the southern position (1) is associated with a decrease in major HABs along Florida's west coast and was also responsible for a lack of oil on those same beaches following the Deepwater Horizon oil spill.[12] When the Loop Current is in the northern position (2) it may create ideal conditions for HAB formation. Loop eddies (3) often break off from the main current when it is in the northern position. (Modified by the National Academies Press from the original by UCAR)*

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

FIGURE 3. *Scientists use satellite imagery to look for oil spills and algal blooms. Discharge from rivers, like the Mississippi in the middle of the image, can change the color of water making it difficult for scientists to see their target. (NASA)*

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.[33] 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.[33] 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.[34]

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/monitoring/database/***. 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.[35,36] Experiments are ongoing to help predict how sea level rise, increased rainfall, and warming ocean temperatures might affect algae blooms in the future.[36]

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. 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.[37,38,39] 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***.

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, chargrilled 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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