REFLECTING ON ECOSYSTEM IMPACTS FROM THE DEEPWATER HORIZON SPILL

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The 2010 Deepwater Horizon oil spill and the dispersants used in response to it affected Gulf of Mexico ecosystems from the deep sea to shorelines. The effects were complex as habitats and organisms within these systems interacted with and influenced one another. Recently, scientists synthesized studies about the oil spill's effects on these diverse Gulf ecosystems and their recovery—or lack thereof—over the past decade. They also identified issues that still exist for some affected areas and marine life.

SYNTHESIS SERIES

The purpose of this publication is to exclusively reflect findings from synthesis activities supported by the Gulf of Mexico Research Initiative (GoMRI). GoMRI synthesis documents are the primary references for this publication. The summary may also include peer-reviewed publications and other reports cited in the GoMRI synthesis activities that help to provide foundation for the topic.

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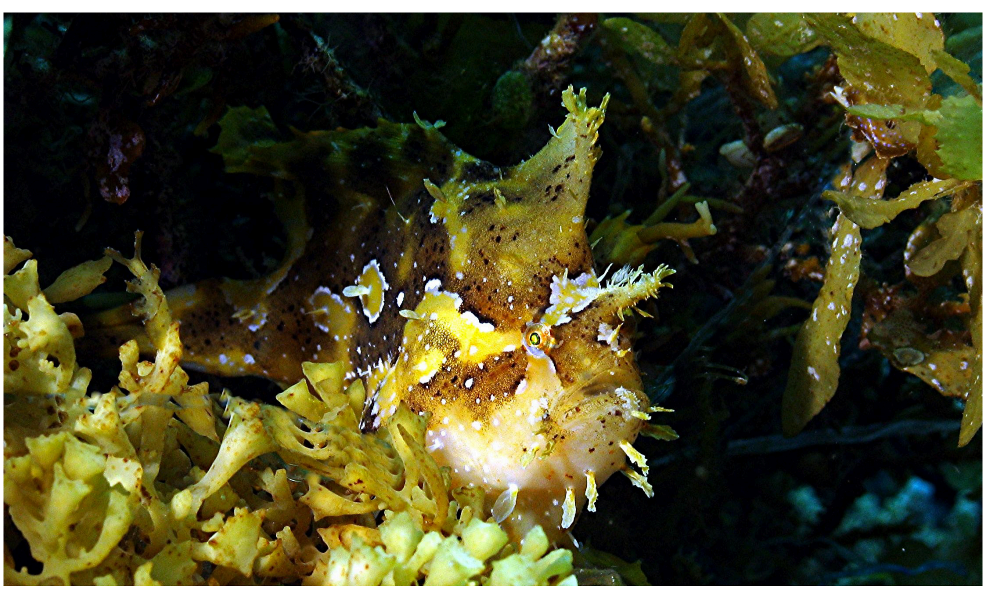
ECOSYSTEMS AFFECTED BY THE OIL SPILL

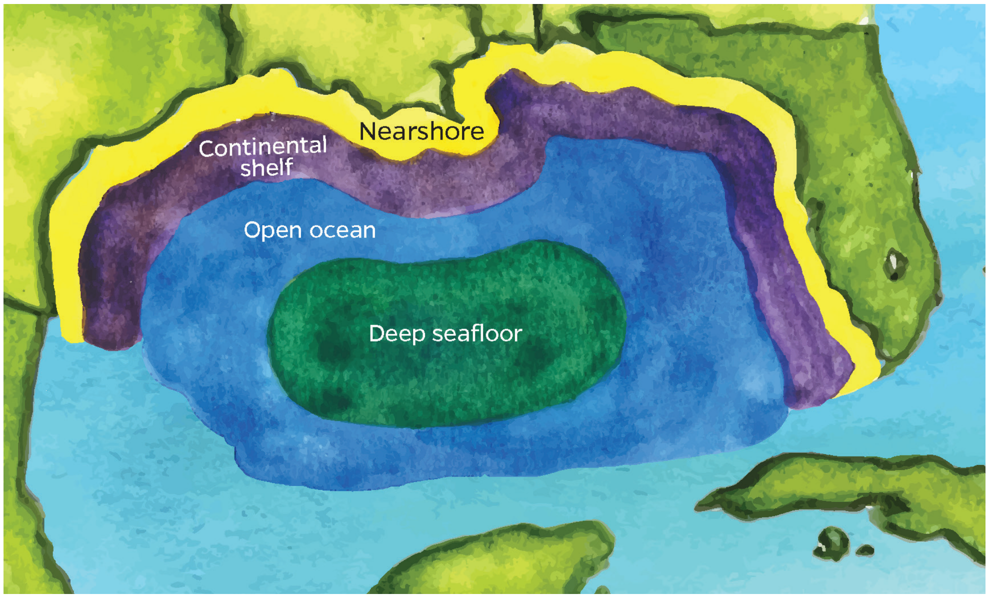
Ecosystems consist of **assemblages** or groups of plants and animals that live in and interact with their environment. Marine and estuarine environments account for over 96% of the earth's water, and the Gulf of Mexico is the world's ninth largest water body.[1] The Gulf's ecosystems consist of four distinct but interacting **ecotypes**: the deep seafloor, open ocean, **continental shelf**, and nearshore (**Figure 1**). Although the ecotypes are distinct, boundaries between habitats and communities are less so as marine life moves across and between ecotypes.[a]

The Deepwater Horizon (DWH) oil spill impacted all Gulf ecotypes, as oil and **dispersants** moved from the deep ocean to shorelines.[b] Dispersants are one of the tools responders used to lessen the spill's impacts by breaking oil slicks into small droplets that are more easily consumed by marine bacteria. During and after the DWH oil spill, responders made decisions about which response measures to use based on the location and amount of oil, how long it was present, and what natural resources were at risk. They also considered how quickly oil and dispersants would be diluted, decreased, or removed in the various ecotypes.[a] Impacts to marine and estuarine species and habitats resulted from both direct exposure to fresh and weathered



An anglerfish uses *Sargassum*, an abundant floating seaweed in the open ocean, for food and protection. (Daniel Dietrich)

FIGURE 1. The Deepwater Horizon oil spill affected four ecotype systems in the Gulf of Mexico—the nearshore, continental shelf, open ocean, and deep seafloor. (Anna Hinkeldey, adapted from J. Kilborn)



oil and indirect effects from various spill response measures, including controlled burning, mechanical pick-up, construction of sand berms, use of dispersants, and freshwater releases.[b] Scientists assessed the spill's effects by observing how plants and animals responded to and recovered from the disturbance.[c]

It is difficult to attribute specific impacts to a plant or animal population or individual to a single cause as many factors can act at the same time to influence their health and survival. Ongoing stressors such as changes in temperature, oxygen, salinity, storms, and invasive species taking over habitats can decrease the resiliency of marine life. Each organism has limited energy and must balance how much it can use for different functions such as maintaining temperature, responding to toxic substances, and reproducing. If faced with multiple stressors at the same time, an organism's natural defenses may be overwhelmed, hampering or diminishing its recovery or even survival. When that happens, it is difficult for scientists to determine which effect or combined effects caused the impacts or mortality.[a]

The deep seafloor

The deep seafloor (depths greater than 660 feet) is habitat to **benthic** organisms such as corals, crabs, worms, clams, and brittle stars.[d] Relatively little is known about the **benthos** of deep Gulf waters compared to the other environments because it is difficult and expensive to reach. However, research after the DWH oil spill provided us with more knowledge than ever before about this area and its inhabitants.

The DWH oil spill occurred at a depth of about 5,000 feet, impacting the environments surrounding it. For example, octocorals, a type of soft-bodied coral that is abundant near the spill site, were heavily damaged and have yet to recover.[d] Their recovery is slow due to their exceptionally slow rate of growth, their inability to move and avoid oil, and the slow rate of oil degradation that extends exposure time.[d] However, researchers found that corals with brittle stars living on them were healthier than corals without them. Brittle stars apparently removed the deposited oil spill material that covered the corals, helping them to recover (**Figure 2**). Deep-sea corals farther away from the spill site are returning to stable health status. However, it will take time to regrow the coral assemblages, which are likely different now than prior to the spill.[d]

Deep-sea **sediments** near the spill site were also heavily impacted as large volumes of oiled **marine snow** sank to the seafloor, which was followed by about a 90% decrease in the numbers of small organisms living in those sediments.[a] Oiled marine snow occurs when oil droplets get caught in sticky biological matter, which can include dead microscopic organisms and fecal material, that then descend through the water onto the seafloor. Oiled sediments impacted meiofauna, small organisms that live on or near the seafloor that recycle material on the seafloor and play an important role in the food web. Scientists estimate that it may take 50 to 100 years for these areas to fully recover as a result of additional sediment accumulation essentially settling on top of and burying oil contaminants at depths too deep for **bioturbation** to resuspend them.[a,d]

Open ocean

The open ocean refers to offshore waters from the sea surface to over 5,000 feet deep, depending on location.[e] It is the largest ocean habitat by volume and home to vastly diverse marine life including

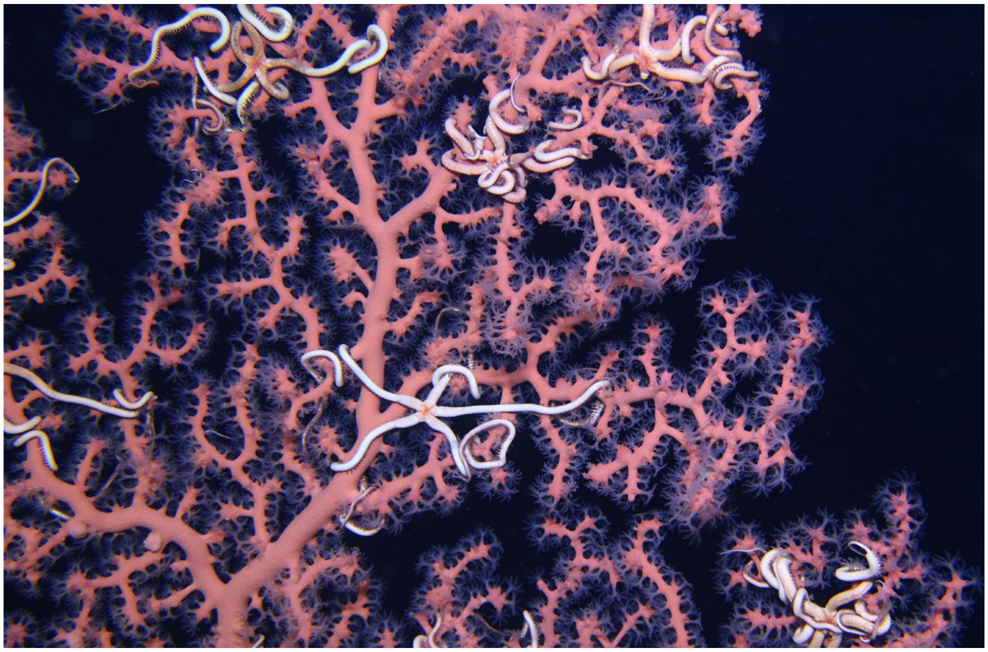


FIGURE 2. Deep-sea corals and other invertebrates are attached to hard bottoms on the seafloor and cannot move to avoid environmental disturbances such as an oil spill. However, some of the corals impacted by the Deepwater Horizon oil spill had a beneficial relationship with brittle stars (as pictured here) that helped to dislodge clumps of oil spill material that coated the corals and thus aided their recovery.[a] (ECOGIG)

plankton, whales, dolphins, fishes, seabirds, crabs, squids, and sea turtles, among others (**Figure 3**).[e,f]

This diverse community is interconnected with the other ecotypes through multiple pathways: daily species migration up and down through the water, predator and prey interactions, and use as a nursery habitat for coastal species, particularly fishes. Many commercially important fishes live and grow within Sargassum mats, floating golden-brown algae that drift at the ocean's surface. Sargassum is a critical habitat in the open ocean, providing an expansive (often miles wide) home for multiple species.

Due to the large area involved, the open ocean is a challenge for scientists to study, and limited data was available prior to the DWH spill. Therefore, researchers had to collect and compare data in this habitat over the decade following the spill to estimate its impacts. Their observations included a decrease in the number of animals—dolphins, sea turtles, and some fish species—that could result in long-term population changes.[e,f]

Continental shelf

Adjacent to the coastal and nearshore environments lies the continental shelf. In the Gulf of Mexico, this region ranges from approximately 32 to 660 feet in depth. The shelf hosts a variety of highly mobile animals such as tunas, mackerels, reef fishes, bottlenose dolphins, sea turtles, and shrimps that move horizontally across ecotypes to find food and shelter or to reproduce.[a,e,3]

The DWH spill took place at the base of the continental slope with surface slicks and underwater oil plumes contaminating the area as they moved across the region.[3] Additionally, large quantities of sinking oiled marine snow impacted the seafloor in this area. The spike in oil concentrations and **hydrocarbon** levels, a key indicator of oil presence, in continental shelf waters declined within five years after the spill.[4]

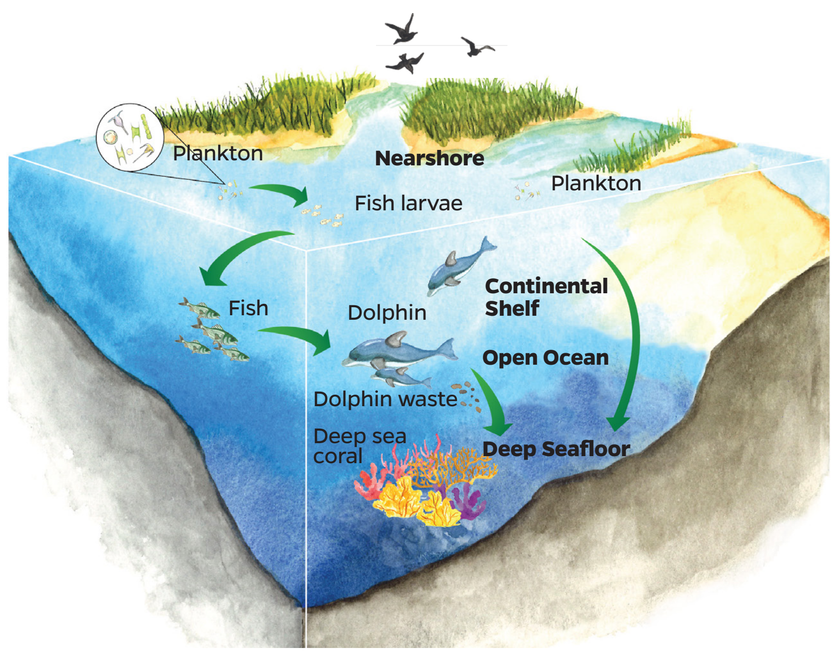


FIGURE 3. The Gulf of Mexico ecosystem has four ecotypes—the nearshore, continental shelf, open ocean, and deep seafloor. Each ecotype has unique characteristics and share multiple pathways and processes that link them together. When an environmental disturbance such as an oil spill occurs in one area, cascading effects can influence the other ecotypes through their complex interconnections. (Anna Hinkeldey, adapted from NOAA)

Researchers observed population reductions and mutations of certain plankton species and early life stages of fishes for a short duration after the oil spill, but those organisms returned to pre-spill conditions one year later.[g,3] Due to the patchiness of how oil spread and sank to the seafloor, marine life living along the shelf likely encountered different amounts of oil depending on characteristics specific to their species. For example, the golden tilefish regularly burrows into sandy clay and may have repeatedly encountered oil that settled in sediment.[h] Marine populations in this ecotype varied in their recovery after the spill. For example, red snapper and blue crabs fared better than some communities occupying offshore natural reefs that were more impacted by the spill as well as by invasive lionfish.[c]

TABLE 1. Scientists categorized general levels of oil spill susceptibility and recovery (high, medium, low) relative to observations they made of coastal and nearshore marine life after the Deepwater Horizon oil spill.[e]

Coastal and nearshore animals and plants	Susceptibility to injury from oil spills	Ease of ability to recover from oil spills
Eastern oyster*	Medium	Medium
Blue crab	High	Medium
Penaeid shrimp	Medium	High
Gulf menhaden	Low	High
Fishes (drum and croaker)	Medium	Medium
Plankton	High	High
Fish eggs and larvae	High	High
Worms, small crustaceans, snails (variable with species, conditions, and habitat)	High	Medium to high
Bottlenose dolphin	Medium to high	Medium to low

*Following the Deepwater Horizon oil spill, the influx of freshwater used to mitigate the spill lowered salinity levels, which affected the eastern oyster's survival.

Coastal and nearshore

Coastal and nearshore waters stretch from the land's edge to about 30 feet deep and include environmentally sensitive and economically important habitats such as beaches and wetland areas. Wetlands support a diversity of animals and plants and are nursery grounds for species such as shrimp, oysters, and crabs.[e] Increased hurricane frequency, larger oxygen-depleted zones, and longer drought periods have altered the sensitive and vulnerable wetland ecosystem, for example, by limiting the growth size of many fish species and contributing to shoreline erosion.[e] The DWH oil spill was an additional stressor with which this ecosystem had to cope.

TABLE 2. Select organism groups serving as indicators of ecosystem recovery showed different impacts and estimated recovery times following the Deepwater Horizon oil spill.[d]

Marine organism group	Observed impacts from Deepwater Horizon oiling	Estimated recovery period
Microbes	Lower overall diversity of community	More than 2 years
Small single-celled algae	Increase in overall number but fewer unique species	More than 3 years
Small animals living in sand or sediment (up to 2mm)	Fewer number of species, but certain species increased in population	More than 4 years
Small- to medium-sized animals	Lower number of individuals and species	More than 4 years
Large animals (approximately 1 ton)	Lower number of individuals and species	More than 7 years
Coral	Slower overall growth, patchy tissue death, and death near the wellhead (up to 50% surveyed off the Alabama coast)	10 to 30 years

Following the DWH spill, ocean currents and wind pushed oil into coastal and nearshore areas, with Louisiana wetlands experiencing the majority—more than 99%—of the heavy oiling.[5] As a result, marsh plants and animals declined throughout the eastern Louisiana coastline. However, wetlands in other Gulf locations remained fairly stable.[e] Impacts on wetland vegetation varied depending on the amount of oiling and how far inland it went, with species in heavily oiled areas experiencing combined effects of **toxicity** and smothering.[a] Researchers reviewed and synthesized studies that focused on coastal and nearshore species such as plankton, blue crabs, fish larvae, and bottlenose dolphins to assess their

TABLE 3. Scientists observed a wide range of effects from oil exposure on marine vertebrates following the Deepwater Horizon spill.[j] (Watercolors Anna Hinkeldey)

Marine vertebrate group		Observed impacts from the Deepwater Horizon oil spill
	Marine mammals (dolphins and whales)	Lung disease and damage, susceptibility to illness and infection, and reproductive failure
	Sea turtles	Hatching success variability
	Birds	Damage to lungs, sensory impairment in older individuals, hormonal disruptions, lower reproductive success, feather damage
	Fish	Gill damage, limited vision and smell, heart and development deformities
	All vertebrates	Damage to lowered metabolic functions, respiratory damage

sensitivity and recovery, including changes to the overall community (**Table 1**).[e] They found damaging health effects related to lowered survival and reproductive ability in bottlenose dolphins.[i]

EFFECTS OF OIL ON MARINE ORGANISMS

Since it is not possible to investigate every plant or animal, scientists use **indicator species** to assess environmental changes over time by observing the health of selected species. Tracking changes in these species' size, maturity, and general health can point to factors that may affect populations over time. These observations can reflect the effects on and resilience of impacted ecotypes, giving insight to decision makers for response, recovery, and conservation efforts (**Figure 2**).[c]

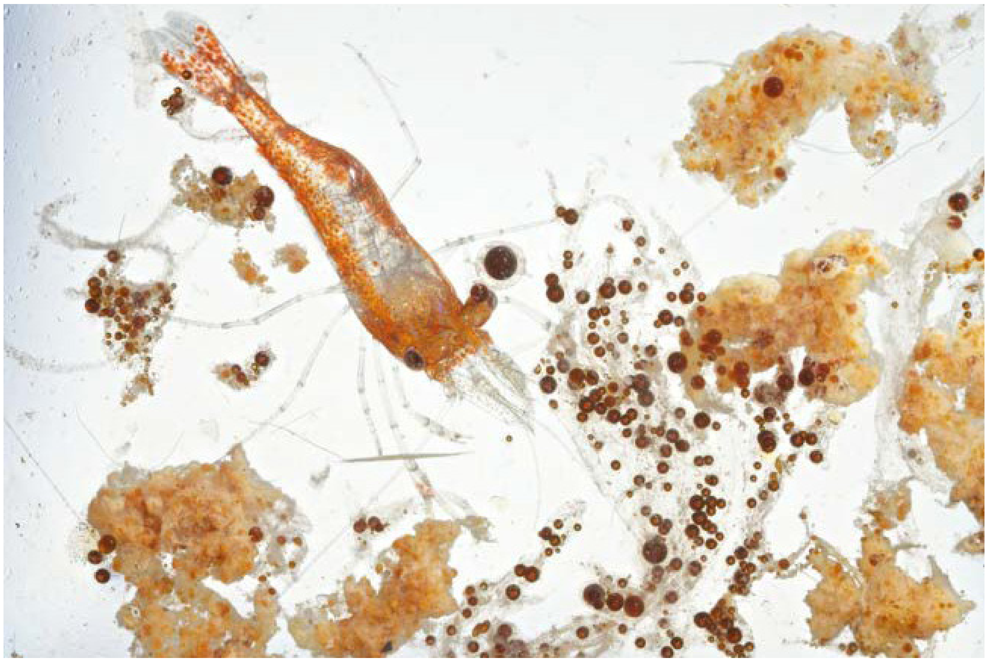
Some **phytoplankton**, a common indicator species, tolerate exposure to oil and dispersants with little discernable change while others become either stimulated or inhibited when exposed to oil and dispersants.[g,6] Variations in temperature, seasonality, and river flow into the Gulf (which raises nutrient and sediment levels and lowers the salt level) may have greater influences on phytoplankton assemblages than oiling.[6] One outcome of the science synthesis following the DWH spill is a blueprint that incorporates a variety of tools and approaches to evaluate the effects of disturbances such as oil spills and climate trends on phytoplankton.[6]

Researchers monitored the recovery of and changes to select species such as shrimp, bottlenose dolphins, and red drum in areas affected by the DWH oil spill as a means to estimate recovery of the overall ecosystem (**Table 2**).[c,d] They also conducted toxicity experiments in laboratories and **mesocosms** to understand how indicator species responded to and recovered from exposure to oil and dispersants.[b] Observations included adverse impacts to respiratory, hormonal, cardiovascular, reproductive, and other systems that can affect species' growth, development, and survival.[b] The severity of observed impacts varied by species, location, and time.

Marine vertebrates

The observed impacts on marine vertebrates like birds, whales, dolphins, fishes, and sea turtles included lowered sensory system function such as loss of smell or sight, lowered reproductive ability, damage to respiratory organs such as gills or lungs, and metabolism changes (**Table 3**).[j]

Organisms higher up in the food web, such as marine mammals, tended to show prolonged impacts and slower recovery rates due in part to toxins stored in fatty tissue, smaller population sizes, and longer life spans compared to organisms lower in the food web. Bottlenose dolphins that inhabited the heavily oiled Louisiana nearshore areas were the most susceptible to and the least able to recover from the oil spill in that area.[c] Dolphins in these areas, as well as marine mammals living near the DWH site, experienced lowered reproductive rates, which may result in smaller population sizes later. Additionally, affected dolphins continue to suffer from lung disease, abnormal stress response, and immune dysfunction.[i] Protected assemblages of sea turtles also suffered after the oil spill. Dolphins and sea turtles are long-lived and their young mature slowly. Therefore, their populations will



Dispersed oil droplets surround plankton and decaying material. (CONCORDE/David Liittschwager)

take longer to recover than species with shorter life spans and higher reproductive rates.[i]

Some fishes and bird populations recovered faster than whales, dolphins, and sea turtles because they reproduce more quickly, improving their overall populations' ability to recover in a relatively short time.[j] Laboratory experiments indicated that oil-exposed fishes, such as early life stage mahi-mahi (dolphin fish), may have experienced damage to heart muscle and function.[j] Marine birds also recovered relatively quickly if their nesting sites were unoiled; however, some experienced hormonal imbalances and lowered reproduction rates, which could impact population recovery.[j]

Marine invertebrates

The oil spill also affected marine invertebrates, which are animals without an internal skeleton such as shrimp, crabs, worms, clams, jellyfish, plankton, corals, and squids.[c,e,k,l] These animals range broadly in size, from microscopic to 35 feet tall as is the case with some deep-sea corals. Invertebrates are primary food sources for many vertebrate species and provide crucial ecosystem services such as bioturbation, which helps to recirculate nutrients that fall to the sea bottom.

Scientists observed that oil coated or clogged internal cavities of invertebrates, which prevented eating, breathing, and/or the ability to gain energy.[c] Some invertebrates lacked the capability to filter and eliminate toxins from the body, which means that they were likely the first animals to be affected by the spill. The fluctuations within invertebrate assemblages and their corresponding food web resulted in different assemblages after the spill (**Table 2**).[b-d]

The oil spill indirectly affected eastern oysters, which are a commercially important food source and an environmentally important contributor to clean water. Several factors contributed to impacts on oysters, including the freshwater river diversions responders used to push oil slicks away from shore that lowered salinity levels.[e]

BETTER PREPARED FOR THE FUTURE

Studies after the DWH spill on the Gulf ecotypes and their inhabitants have helped us understand more about vulnerable environments and species. Improved knowledge about spill impacts from the organism to the population level helps resource managers track the recovery of these species moving forward.[i]

A broad array of advanced tools, technologies, and approaches originally developed for use in other fields helped the scientific community document and evaluate the spill's impacts on animals and plants.[b] For example, scientists used tools designed to study genes to learn about how marine bacterial communities changed and used human health assessment tools to monitor dolphins' reproductive and immune systems.[b]

Scientists involved with synthesizing ecosystem research following the DWH oil spill offered recommendations to better understand and mitigate the effects of future oil spills and other environmental disturbances.[a,b] Those recommendations include establishing long-term monitoring programs, improving our understanding of how ecotypes are connected, and conducting routine toxicity screenings for marine animals and their habitats, especially those regions where oil and gas production and exploration are frequent.

GLOSSARY

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

Benthic/Benthos — Anything associated with the bottom, or bottom sediments, of an ocean, lake, or other body of water. Benthos are the organisms found in the benthic ecological region.

Bioturbation — The mixing and turning over of soil by living organisms that happens when organisms move, burrow, or ingest and defecate soil grains.

Continental shelf — A shallow undersea plain of varying width forming a border to a continent and typically ending at a "break" around 650 feet down, at which point there is a comparatively steep continental slope extending to the deep ocean floor.

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.

Ecosystems — A large community of living organisms—such as plants, animals, and microbes—in a particular area linked together through nutrient cycles and energy flows.

Ecotypes — Different habitat types or systems within a larger geographic environment, each with characteristic flora and fauna.

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.

Indicator species — A representative organism whose presence, absence, and change in population numbers or health status can help gauge the status or health of the whole system.

Marine snow — A shower of material (a sticky mix of sediment, fecal matter, mucus released from microbes, phytoplankton, and bits of decaying plants and animals) falling from the surface waters. When oil droplets are present, they can become attached to marine snow, becoming oiled marine snow, and carried to the bottom of the ocean.

Mesocosms — A experimental set up or system that mimics the natural environment for scientists to conduct tests in controlled conditions. Mesocosms offer an approach that bridges traditional laboratory tests and field observations.

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

Plankton — Organisms that drift or float in bodies of water, consisting of algae, protozoans, eggs and larval stages of larger animals, and all gelatinous organisms. They are an important part of marine food webs.

Sediment(s) — 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.

Toxicity — The degree to which a chemical or combination of chemicals causes damage to living organisms.

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