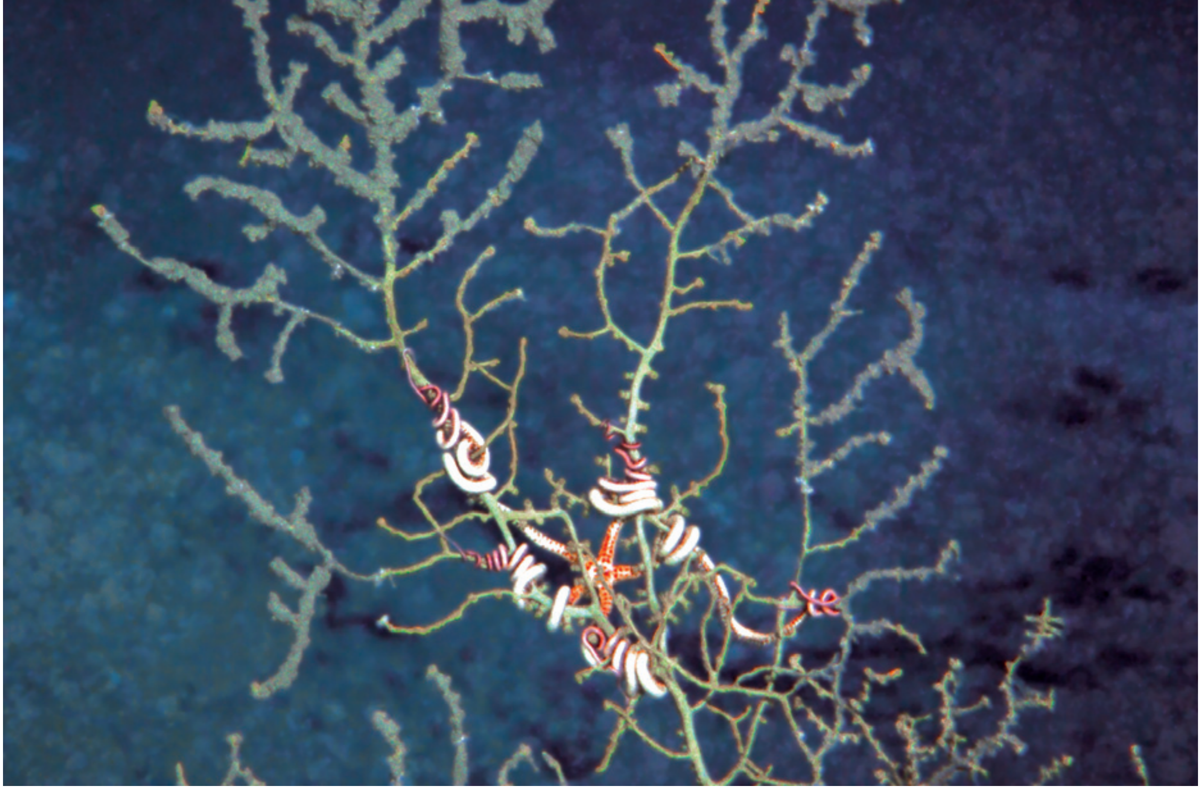


Peculiar dark material covers much of this coral from the Gulf of Mexico. A sickly brittle star clings to the coral, little of which is still alive.

# DEEP WOUNDS

The Gulf of Mexico oil spill set records for its size and depth. A year on, the biggest impacts seem to be where they are hardest to spot.

BY MARK SCHROPE

Late last year, oceanographers prowling the sea floor of the Gulf of Mexico came upon what looked like a crime scene. Cameras on a remotely operated vehicle revealed corpses of deepwater coral covered in brown goo. As the researchers watching from above saw one grim scene after another, "the whole place got silent, everything totally stopped", says Tim Shank an oceanographer from the Woods Hole Oceanographic Institution in Massachusetts, and a member of the survey team.

The field of coral was just 11 kilometres from the Deepwater Horizon well head, which earlier in the year had spewed out more than 4 million barrels of oil and a similar amount of methane — the largest ever accidental release in the ocean. The spill was unique in other ways, too. Located beyond the continental shelf and some 1,400 metres below the surface, it happened in deeper water than any other major spill in history.

Those factors make it much harder for researchers to discern what happened to the oil and how it affected wildlife. Assessing the impacts of this spill in deep water is "probably one of the most challenging things ever", says Steve Murawski, chief scientist for the Fisheries Service at the National Oceanic and Atmospheric Administration (NOAA) during the spill and now a fishery biologist at the University of South Florida in St Petersburg. And that is "not only because of the physical environment but also because of the breadth of the potential impacts", he says.

But tracking the oil and its impacts remains an essential task. It will help to determine how much needs to be paid in restoration costs by BP — the company in charge of the well — and possibly other companies deemed partially responsible. And as drilling by the United States and other countries expands into deeper waters, lessons from last year's spill could help in responding to any future ones.

At first, scientists and the public were most concerned about how the disaster would harm coastlines and near-shore waters.

Although those areas sustained some damage, they did not come to as much harm as many had feared. Instead, as the anniversary of the spill approaches, signs of significant damage are showing up farther from shore and in deeper water. It was a stroke of bad luck that the well happened to be located in the most species-rich part of the deep gulf.

Thomas Shirley, a veteran of spill research at the Harte Research Institute at Texas A&M University in Corpus Christi, says that his view of the spill is evolving. "I'm beginning to think the deep sea is where we'll see most of the effects," he says.

LOPHELIA II 2010 EXPEDITION, NOAA-OER/BOEMRE

## BEYOND THE EDGE

True to its name, the Deepwater Horizon oil rig was stationed beyond the lip of the continental shelf, where the sea floor rapidly falls away towards the lower reaches of the Gulf of Mexico. On 20 April 2010, a catastrophic blowout caused an explosion on the oil rig that claimed 11 lives and sent the rig to the sea floor. Government and independent estimates calculate that the broken well sprayed 4.1 million barrels of oil — and perhaps as much as 363,000 tonnes of natural gas — into the deep waters of the Gulf of Mexico.

Operations to collect and burn the oil took care of only about one-quarter of the liquid that came out of the well, according to a controversial government report[1]. The rest dissolved into the sea, dispersed into small drops, evaporated into the atmosphere or initially formed visible surface slicks and tar balls (see 'What happened to the oil?').

Some of it apparently went through an unusual transformation. Scientists who were out on boats in the spill zone during the early weeks after the disaster saw unusual strings of viscous material, which they dubbed 'sea snot'. The material looked like oil mixed with phytoplankton and other organic matter — and resembled a very thick batch of egg-drop soup.

Vernon Asper, a geochemist at the University of Southern Mississippi near Diamondhead, had never seen anything like it. "What is becoming of all that," he asked in mid-May while looking into water just a few kilometres from the blowout site. "Where is it going?" Asper and others found that the substance extended well below the surface in places.

"This is very strange material," says Ed Overton, a marine chemist and spill expert at Louisiana State University in Baton Rouge. But although many researchers reported seeing it, few were equipped to collect it. "We had one hell of a time getting good samples," says Overton. Although his team is still analysing samples obtained from other researchers, the group has already made some intriguing findings that could explain the bizarre appearance.

In shallow spills, oil tends to rise quickly to the surface, where it weathers, dissolves and evaporates in chemically predictable patterns. However, the largest drops of oil from the Deepwater Horizon well head took at least four hours to reach the surface, and smaller droplets rose much more slowly. During that long voyage, smaller droplets could have lost some of the lighter hydrocarbons that help to keep the various oil compounds from separating, suggests Overton.

"That changes the properties of the oil so it goes from a nice little round droplet, I think, into these strange-looking filamentous globs floating up the water column," he says. "Unfortunately we didn't get enough oil to really harden this theory."

Still, the issue of how the oil transformed is a crucial one for researchers to address. The processes involved can affect the oil's toxicity and how long it is likely to stick around.

If Overton is right, the stringy masses that researchers found were a reminder that Deepwater Horizon was a different kind of spill. Soon after the disaster, Asper and his colleagues started seeing indications that some oil never made it to the surface — instead, it formed diffuse plumes more than 1,000 metres below the surface[2]. Reports of those finds were initially greeted with scepticism, in part because BP and most government officials expected that all the oil would float. But Asper's group and other researchers eventually confirmed that an unknown fraction of the oil had drifted away from the well head in deep-water plumes[3], the effects of which are still not clear.

Since then, controversy has also erupted over how much oil settled on the ocean floor and in what form. Samantha Joye, a geochemist at the University of Georgia in Athens is part of a team that found a layer of brown lumpy material on the sea floor that she says looks like dirty cauliflower and can be seen at sites as far as 130 kilometres from the well head.

Andreas Teske, a microbiologist at the University of North Carolina, Chapel Hill, collaborates with Joye and suggests that the lumpy layer came from oil that had once been at the surface, perhaps beginning as the stringy sea snot. As microbes consumed the oil, it would have lost buoyancy and sunk, he says. Kai Ziervogel, a biogeochemist also at the University of North Carolina, tested this hypothesis in the laboratory by incubating seawater samples with surface oil from the spill. He saw masses of bacteria and oil forming, some of which sank and looked much like the lumpy layer of material in the sediments.

Teske's team analysed samples from the lumpy layer and found that they contained oil with an unsually high percentage of the heavier compounds that would have been hard for microbes to eat, which fits with the idea that bacteria had consumed the lighter compounds. The group has also dated the lumpy layer — using the radioactive decay of thorium-234 as a clock — and found that it formed during and shortly after the spill.

Joye has called the cauliflower layer a graveyard because she and her colleagues found in it countless dead worms and other common sediment dwellers, as well as the remains of jellyfish and other animals from above. And near to the well head the layer shows little microbial activity, suggesting that it will not break down quickly.

The group has not yet published these findings and has just started to describe them at scientific conferences. But a number of researchers have questioned the existence of a widespread lumpy layer containing oil. Arden Ahnell, gulf-coast restoration science manager for BP, says that researchers working with the company have confirmed low concentrations of oil in some of the areas where Joye and her colleagues collected sediment, but found no evidence of a pervasive layer of unusual material.

Joye has grown used to people challenging her work, having been part of the group that first reported the existence of a deep oil plume. In her laboratory, she points out the difference between normal grey sediments collected from deeper layers near the spill site and the lumpy brown sediments that, she says, formed after the spill. "These are not normal-looking sediments. They are the most putrified, ugly, nasty-looking things you could imagine."

Her arguments get some support from Amanda Demopoulos, a benthic ecologist with the US Geological Survey in Gainesville, Florida. Demopoulos, too, found an unusual lumpy brown deposit at one of the sites later visited by Joye and her colleagues. In Demopoulos's samples, "there were some snails still living but the remaining animals I found were not moving around, and that's strange", she says.

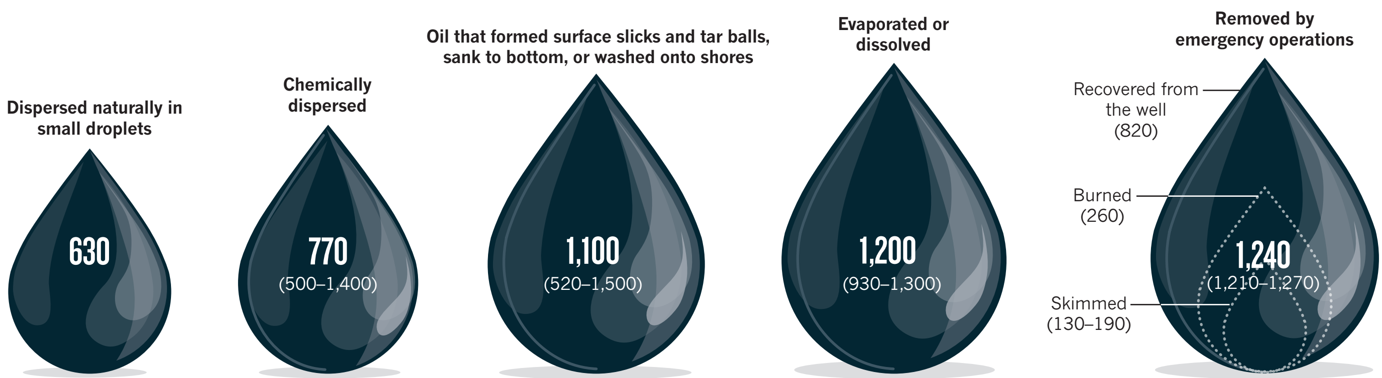
### BUILDING A CASE

Some of these data may end up in court, as part of a process called the Natural Resource Damage Assessment (NRDA). The US government will use studies conducted through the NRDA to document the effects of the spill and then determine what damages should be paid by the responsible companies. This will include reimbursing the government for the cost of the NRDA.

Because of the legal nature of the work, many of the academic

## WHAT HAPPENED TO THE OIL?

During the Deepwater Horizon crisis last year, the US government estimated where the 4.9 million barrels of oil went so it could plan response efforts. In November, it issued revised numbers, as well as ranges for some categories (shown in parentheses). All numbers are in thousands of barrels.

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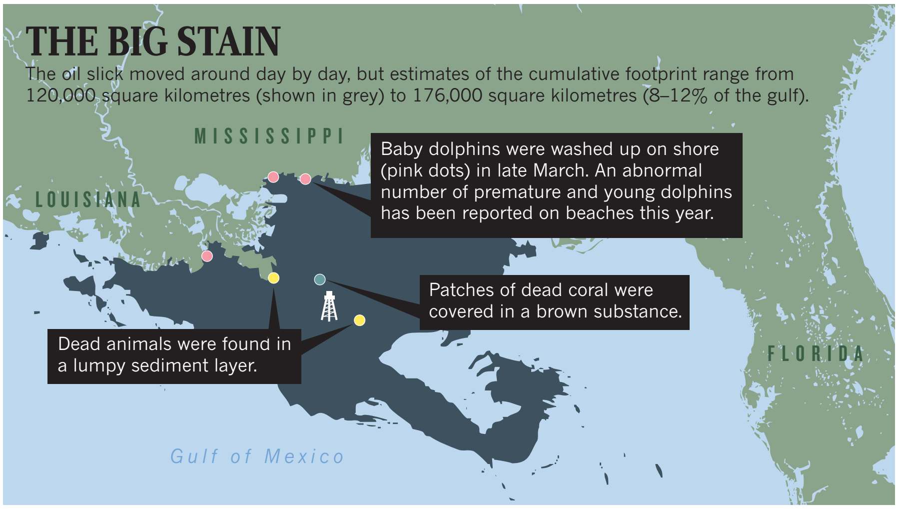


**THE BIG STAIN**

The oil slick moved around day by day, but estimates of the cumulative footprint range from 120,000 square kilometres (shown in grey) to 176,000 square kilometres (8–12% of the gulf).

SOURCE: SKYTRUTH.ORG

researchers who are participating in it find the process foreign. Some signed non-disclosure forms that prevent them from publicly discussing their results without approval. And the researchers must maintain strict procedures for handling samples.

Erik Cordes, a deep-sea ecologist from Temple University in Philadelphia, Pennsylvania, was one of the leaders of the coral study and he expressed frustration early on with the NRDA process. Cordes had wanted to conduct a well-accepted analysis of stress on the seafloor animals but was told by NRDA legal advisers that the work might not be accepted because the techniques had not been proven in court. "The idea that there was a higher standard than peer review and scientific consensus is very difficult to accept," says Cordes.

The NRDA is a major source of funding for research into the effects of the oil spill. Scientists should eventually gain access to around $400 million in research money from BP, but for now that fund has released only limited amounts because of bureaucratic and political problems[4].

A significant amount of BP's money will go towards studies of how the spill damaged gulf ecosystems. Its location 66 kilometres offshore might have helped to limit damage to the estuaries and coastal waters, but it was still located in a region of relatively rich biodiversity, says Shirley. He and his colleagues have amassed a database of 15,419 species living within the gulf. According to the database, some 1,728 species inhabit the region surrounding Deepwater Horizon at depths of between 1,000 and 3,000 metres, where the well is located. "Ironically, this is the most speciose area of the gulf for this depth range — BP could not have selected a worse area to have a spill, at least from the point of species richness," says Shirley.

Researchers are finding signs that the damage extends throughout the water column, from the sea floor to the surface (see 'The big stain'). During the expedition on which Joye and others made the sediment discoveries, other researchers were concerned by jellyfish and other creatures they pulled up in nets from lower depths as far as 150 kilometres from the well head. "The gelatinous animals are usually pinkish or translucent, but an awful lot of them were much darker brown or even black," says Joseph Montoya, chief scientist on the cruise, and a biological oceanographer at the Georgia Institute of Technology in Atlanta.

In the spill zone soon after the disaster began, Asper and his colleagues often pulled up their equipment and found it decorated with the dead bodies of invertebrates known as pyrosomes, or fire salps. Pyrosomes probably have an important role in the food web near the surface, says Shirley, because they consume small plankton.

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Read more about the oil spill at:
go.nature.com/gxp9i4

Aside from those more obvious casualties, researchers have been hard pressed to find mass deaths that are clearly linked to the spill. This year, the bodies of 151 bottlenose dolphins have washed ashore in the northern gulf, but mass dolphin strandings have happened there before. The number of animals with clear evidence of oil contamination is much smaller. Only 6 dolphins and 18 sea turtles have been found dead with visible signs of oil, according to NOAA.

Researchers caution that the oil spill probably took a much larger toll on whales, dolphins and turtles than has been observed. Blair Witherington, a sea-turtle expert with the Florida Fish and Wildlife Conservation Commission in Melbourne Beach, Florida, is particularly concerned about juvenile Kemp's ridleys (*Lepidochelys kempii*), the rarest species of sea turtle. Young turtles are the most vulnerable, he says, and are generally found well offshore. His team found hundreds that had visible signs of oil.

For dolphins and other cetaceans, the gap between known deaths and actual ones may be vast. Judging from past studies of death rates, a group of cetacean specialists concluded last month that "the true death toll could be 50 times the number of carcasses recovered"[5].

## THE MOST VULNERABLE

Researchers are especially concerned about the youngest creatures because the spill came at a time when many animals were spawning. Larvae, for example, are known to be particularly susceptible to the toxic chemicals in the oil. And the problems may have been compounded by the 3 million litres of dispersants that were released to break up the oil. The dispersants themselves can be toxic, and they make oil droplets smaller and therefore more likely to affect even the smallest creatures.

Ed Stellwag, a developmental biologist at East Carolina University in Greenville, North Carolina, is exploring what mixtures of spill oil and dispersant do to the embryos of zebrafish, the aquatic equivalent of lab rats. He found that even at the modest concentrations that many animals would have encountered during the spill, the mixture caused fatal heart and other defects in all of the embryos tested. Stellwag says that assessing how embryonic damage plays out offshore is likely to be difficult if not impossible because larger animals eat most of the larvae in surface waters. Damaged larvae, he fears, are more likely to end up as a meal than in a researcher's survey net.

**The Deepwater Horizon site is now strangely quiet.**

Larva surveys are already under way as part of the NRDA process. But given the difficulty of the work and the controls on releasing information, it could be years before researchers can offer an assessment of how the oil spill harmed larval fish and the thousands of other denizens of the gulf.

During the heat of the crisis last year, thousands of men and women flocked to the spill zone to stop the oil leak and contain its damage. A year later, the Deepwater Horizon site is strangely quiet. The last drillship pulled out in February and vanished over the horizon. On the water's surface, there are no lasting impressions of the crisis, but not so below. The wreckage of one of the world's most advanced drilling rigs lies hidden on the sea floor, as do the ecological damages that are proving so challenging to assess. ■

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