Natural healing

How does Nature repair itself after an oil spill?

Melissa Suran

In late April 2010, the BP-owned semi-submersible oilrig known as Deepwater Horizon exploded just off the coast of Louisiana. Over the following 84 days, the well from which it had been pumping spewed 4.4 million barrels of crude oil into the Gulf of Mexico, according to the latest independent report (Crone & Tolstoy, 2010). In August, the US Government released an even grimmer estimate: according to the federal Flow Rate Technical Group, up to 4.9 million barrels were excreted during the course of the disaster. Whatever the actual figure, images from NASA show that around 184.8 million gallons of oil have darkened the waters just 80 km from the Louisiana coast, where the Mississippi Delta harbours marshlands and an abundance of biodiversity (NASA Jet Propulsion Laboratory, 2010; Fig 1).

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The resulting environmental and economic situation in the Gulf is undoubtedly dreadful—the shrimp-fishing industry has been badly hit, for example. Yet the Deepwater incident is not the first time that a massive oil spill has devastated marine and terrestrial ecosystems, nor is it likely to be the last. In fact, the US National Oceanic and Atmospheric Association (NOAA) deals with approximately 300 oil spills per year and the Deepwater catastrophe—despite its extent and the enormous amount of oil released—might not be as terrible for the environment as was originally feared. Jacqueline Michel, a geochemist who has worked on almost every major oil spill since the 1970s and

who is a member of NOAA's scientific support team for the Gulf spill, commented that "the marshes and grass are showing some of the highest progresses of [oil] degradation because of the wetness." This rapid degradation is partly due to an increased number of oil-consuming microbes in the water, whose population growth in response to the spill is cleaning things up at a relatively fast pace (Hazen *et al*, 2010).

It therefore seems that, however bad the damage, Nature's capacity to repair itself might prevent the unmitigated disaster that many feared on first sight of the Deepwater spill. As the late social satirist George Carlin (1937–2008) once put it: "The planet will shake us off like a bad case of fleas, a surface nuisance[.] The planet will be here for a long, long—LONG—time after we're gone, and it will heal itself, it will cleanse itself, because that's what it does, it's a self-correcting system."

Michel believes that there are times when it is best to leave nature alone. In such cases the oil will degrade naturally by processes as simple as exposure to sunlight—which can break it down—or exposure to the air—which evaporates many of its components. "There have been spills where there was no response because we knew we were going to cause more harm," Michel said. "Although we're going to remove heavier layers of surface oil [in this case], the decision has been made to leave oil on the beach because we believe it will degrade in a timescale of months [...] through natural processing."

To predict the rate of general environmental recovery, Michel said one should examine the area's fauna, the progress of which can be very variable. Species have different recovery rates and although it takes only weeks or months for tiny organisms

such as plankton to bounce back to their normal population density, it can take years for larger species such as the endangered sea turtle to recover.

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Kimberly Gray, professor of environmental chemistry and toxicology at Northwestern University (Evanston, IL, USA), is most concerned about the oil damaging the bottom of the food chain. "Small hits at the bottom are amplified as you move up," she explained. "The most chronic effects will be at the base of the food chain [...] we may see lingering effects with the shrimp population, which in time may crash. With Deepwater, it's sort of like the straw that broke the shrimp's back."

Wetlands in particular are a crucial component of the natural recovery of ecosystems, as they provide flora that are crucial to the diets of many organisms. They also provide nesting grounds and protective areas where fish and other animals find refuge from predation. "Wetlands and marsh systems are Nature's kidneys and they've been damaged," Gray said. The problem is exacerbated because the Louisiana wetlands are already stressed in the aftermath of Hurricane Katrina, which devastated the Gulf coast in August 2005, and because of constant human activity and environmental damage. As Gray commented, "Nature has a very powerful capacity to repair itself, but what's happening in the modern day is assault after assault."

Ron Thom, a marine ecologist at Pacific Northwest National Laboratory—a US

Fig 1 | Images of the Deepwater Horizon oil slick in the Gulf of Mexico. These images were recorded by NASA's Terra spacecraft in May 2010. The image dimensions are 346×258 kilometres and North is toward the top. In the upper panel, the oil appears bright turquoise owing to the combination of images that were used from the Multi-angle Imaging SpectroRadiometer (MISR) aboard the craft. The Mississippi Delta, which harbors marshlands and an abundance of biodiversity, is visible in the top left of the image. The white arrow points to a plume of smoke and the red cross-hairs indicate the former location of the drilling rig. The lower two panels are enlargements of the smoke plume, which is probably the result of controlled burning of collected oil on the surface.

government-funded research facility (Richland, WA, USA)—has done important research on coastal ecosystems. He believes that such habitats are able to decontaminate themselves to a limited degree because of evolution. “[Coastal-related ecosystems are] pretty resilient because they’ve been around a long time and know how to survive,” he said.

As a result, wetlands can decontaminate themselves of pollutants such as oil, nitrate and phosphate. However, encountering large amounts of pollutants in a short period of time can overwhelm the healing

process, or even stop it altogether. “We did some experiments here in the early 90s looking at the ability for salt marshes to break down oil,” Thom said. “When we put too much oil on the surface of the marsh it killed everything.” He explained that the oil also destroyed the sediment–soil column, where plant roots are located. Eventually, the roots disintegrated and the entire soil core fell apart. According to Thom, the Louisiana marshes were weakened by sediment and nutrient starvation, which suggests that the Deepwater spill destroyed below-ground material in some locations. “You can alter a

place through a disturbance so drastic that it never recovers to what it used to be because things have changed so much,” he said.

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Michael Blum, a coastal marsh ecologist at Tulane University in New Orleans, said that it is hard to determine the long-term effects of the oil because little is known about the relevant ecotoxicology—the effect of toxic agents on ecosystems. He has conducted extensive research on how coastal marsh plants respond to stress: some marshes might be highly susceptible to oil whereas others could have evolved to deal with natural oil seepage to metabolize hydrocarbons. In the former, marshes might perish after drastic exposure to oil leading to major shifts in plant communities. In the latter case, the process of coping with oil could involve the uptake of pollutants in the oil—known as polycyclic aromatic hydrocarbons (PAHs)—and their reintroduction into the environment. “If plants are growing in the polluted sediments and tapping into those contaminated sources, they can pull that material out of the soil and put it back into the water column or back into the leaf tissue that is a food source for other organisms,” Blum explained.

In addition to understanding the responses of various flora, scientists also need to know how the presence of oil in an ecosystem affects the fauna. One model that is used to predict the effects of oil on vertebrates is the killifish; a group of minnows that thrive in the waters of Virginia’s Elizabeth River, where they are continuously exposed to PAHs deposited in the water by a creosote factory (Meyer & Di Giulio, 2003). “The killifish have evolved tolerance to the exposure of PAHs over chronic, long-term conditions,” Blum said. “This suggests that something similar may occur elsewhere, including in Gulf Coast marshes exposed to oil.”

Although Michel is optimistic about the potential for environmental recovery, she pointed out that no two spills are the same. “There are lot of things we don’t know, we never had a spill that had surface release for so long at this water depth,” she said. Nevertheless, to better predict the long-term effects, scientists have turned to data from similar incidents.

In 1989, the petroleum tanker Exxon Valdez struck Bligh Reef off the coast of Prince William Sound in Alaska and poured a minimum of 11 million gallons of oil into the water—enough to fill 125 Olympic-sized swimming pools. Senior scientist at NOAA, Stanley Rice of Juno, Alaska, studies the long-term effects of the spill and the resulting oil-related issues in Prince William Sound. Rice has worked with the spill since day 3 and, 20 years later, he is seeing major progress. “I never want to give the impression that we had this devastating oil spill in 1989 and it’s still devastating,” he said. “We have pockets of a few species where lingering oil hurts their survival, but in terms of looking at the Sound in its entirety [...] it’s done a lot of recovery in 20 years.”

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Despite the progress, Rice is still concerned about one group of otters. The cold temperature of the water in the Sound—rarely above 5°C—slows the disintegration of the oil and, every so often, the otters come in contact with a lingering pocket. When they are searching for food, for example, the otters often dig into pits containing oil and become contaminated, which damages their ability to maintain body temperature. As a result, they cannot catch as much food and starve because they need to consume the equivalent of 25% of their body weight every day (Rice, 2009).

“Common colds or worse, pneumonia, are extremely debilitating to an animal that has to work literally 365 days a year, almost 8 to 12 hours a day,” Rice explained. “If they don’t eat enough to sustain themselves, they die of hyperthermia.” Nevertheless, in just the last two years, Rice has finally seen the otter population rebound.

Unlike the otters, one pod of orca whales has not been so lucky. Since it no longer has any reproductive females, the pod will eventually become extinct. However, as it dies out, orca prey such as seals and otters will have a better chance of reproducing. “There are always some winners and losers in these types of events,” Rice said. “Nature is never static.”

The only ‘loser’ that Rice is concerned about at the moment is the herring, as many of their populations have remained

damaged for the past 20 years. “Herring are critical to the ecosystem,” he said. “[They are] a base diet for many species [...] Prince William Sound isn’t fully recovered until the herring recover.”

North America is not alone in dealing with oil-spill disasters—Europe has had plenty of experience too. One of the worst spills occurred when the oil tanker Prestige leaked around 20 million gallons of oil into the waters of the Galician coast in Northern Spain in 2002. This also affected the coastline of France and is considered Spain’s worst ecological disaster.

“The impacts of the Prestige were indeed severe in comparison with other spills around the world,” said attorney Xabier Ezeizabarrena, who represented the Fishermen Guilds of Gipuzkoa in a lawsuit relating to the spill. “Some incidents aren’t even reported, but in the European Union the ratio is at least one oil spill every six months.”

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In Ezeizabarrena’s estimation, Spanish officials did not respond appropriately to the leak. The government was denounced for towing the shipwreck further out into the Atlantic Ocean—where it eventually sank—rather than to a port. “There was a huge lack of measures and tools from the Spanish government in particular,” Ezeizabarrena said. “[However], there was a huge response from civil society [...] to work together [on restoration efforts].”

Ionan Marigómez, professor of cellular biology at the University of the Basque Country, Spain, was the principal investigator on a federal coastal-surveillance programme named Orbankosta. He recorded the effects of the oil on the Basque coast and was a member of the Basque government’s technical advisory commission for the response to the Prestige spill. He was also chair of the government’s scientific committee. “Unfortunately, most of us scientists were not prepared to answer questions related to the biological impact of restoration strategies,” Marigómez said. “We lacked data to support our advice since continued monitoring is not conducted in the area [...] and most of us had developed our scientific activity with

too much focus on each one’s particular area when the problem needed a holistic view.”

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For disasters involving oil, oceanographic data to monitor and predict the movement of the spill is essential. Clean-up efforts were initially encouraged in Spain, but data provided by coastal-inspection programmes such as Orbankosta informed the decision to not clean up the Basque shoreline, allowing the remaining oil debris to disintegrate naturally. In fact, the cleaning activity that took place in Galicia only extended the oil pollution to the supralittoral zone—the area of the beach splashed by the high tide, rather than submerged by it—as well as to local soil deposits. On the Basque coast, restoration efforts were limited to regions where people were at risk, such as rocky areas near beaches and marinas.

Eight years later, Galicia still suffers from the after-effects of the Prestige disaster. Thick subsurface layers of grey sand are found on beaches, sometimes under sand that seems to be uncontaminated. In Corme-Laxe Bay and Cies Island in Galicia, PAH levels have decreased. Studies have confirmed, however, that organisms exposed to the area’s sediments had accumulated PAHs in their bodies. Marigómez, for example, studied the long-term effects of the spill on mussels. Depending on their location, PAH levels decreased in the sampled mussel tissue between one and two years after the spill. However, later research showed that certain sites suffered later increases in the level of PAHs, due to the remobilization of oil residues (Cajaraville *et al*, 2006). Indeed, many populations of macroinvertebrate species—which are the keystones of coastal ecosystems—became extinct at the most-affected locations, although neighbouring populations recolonized these areas. The evidence suggests that only time will tell what will happen to the Galicia ecosystem. The same goes for oil-polluted environments around the world.

The concern whether nature can recover from oil spills might seem extreme, considering that oil is a natural product derived from the earth.

But too much of anything can be harmful and oil would remain locked underground without human efforts to extract it. "As from Paracelsus' aphorism, the dose makes the poison," Marigómez said.

According to the US Energy Information Administration, the world consumes approximately 31 billion barrels of oil per year; more than 700 times the amount that leaked during the Deepwater spill. Humanity continues, in the words of some US politicians, to "drill, baby, drill!" On 12 October 2010, less than a year after the Gulf Coast disaster, US President Barack Obama declared that he was lifting the ban on deepwater drilling. It appears that George Carlin got it right again when he satirized a famous American anthem: "America, America, man sheds his waste on thee, and hides the pines with billboard signs from sea to oily sea!"

REFERENCES

- Cajarville MP, Garmendia L, Orbea A, Werding R, Gómez-Mendikute A, Izaguirre U, Soto M, Marigómez I (2006) Signs of recovery of mussels health two years after the Prestige oil spill. *Mar Environ Res* **62**: 337–341
- Crone TJ, Tolstoy M (2010) Magnitude of the 2010 Gulf of Mexico oil leak. *Science* **330**: 634
- Hazen T *et al* (2010) Deep-sea oil plume enriches indigenous oil-degrading bacteria. *Science* **330**: 204–208
- NASA Jet Propulsion Laboratory (2010) NASA satellite views massive Gulf oil spill. www.jpl.nasa.gov/news/news.cfm?release=2010-147
- Meyer JN, Di Giulio RT (2003) Heritable adaptation and associated fitness costs in killifish (*Fundulus heteroclitus*) inhabiting a contaminated estuary. *Ecol Appl* **13**: 490–503
- Rice SD (2009) Persistence, toxicity, and long-term environmental impact of the Exxon Valdez oil spill. *Univ St Thomas Law J* **7**: 55–67

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In the womb's shadow

The theory of prenatal programming as the fetal origin of various adult diseases is increasingly supported by a wealth of evidence

Silvia Fabiole Nicoletto & Andrea Rinaldi

About two decades ago, David Barker, Professor of Clinical Epidemiology at the University of Southampton, UK, proposed a hypothesis that malnutrition during pregnancy and resultant low birth weight increase the risk of developing cardiovascular disease in adulthood. "The womb may be more important than the home," remarked Barker in a note about his theory (Barker, 1990). "The old model of adult degenerative disease was based on the interaction between genes and an adverse environment in adult life. The new model that is developing will include programming by the environment in fetal and infant life."

The 'Barker theory' has been increasingly accepted and been expanded to other diseases, prominently diabetes and obesity, but also osteoporosis and allergies. "In the last few years, the evidence [of an extended] range of potential disease phenotypes with a prenatal developmental component to risk [...] has become much stronger," said Peter

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Gluckman at the University of Auckland, New Zealand. "We also need to give greater attention to the growing evidence of prenatal and early postnatal effects on cognitive and non-cognitive functional development and to variation in life history patterns." Similarly, Michael Symonds and colleagues from the University Hospital at Nottingham, UK, wrote: "These critical periods occur at times when fetal development is plastic; in other words, when the fetus is experiencing rapid cell proliferation making it sensitive to environmental challenges" (Symonds *et al*, 2009).

This new idea about the influence of the environment during prenatal development

on adult disease risk comes with a better understanding of epigenetic processes—the biological mechanisms that explain how *in utero* experiences could translate into phenotypic variation and disease susceptibility within, or over several, generations (Gluckman *et al*, 2009; Fig 1). "I think it has been the combination of good empirical data (experimental and clinical), the appearance of epigenetic data to provide molecular mechanisms and a sound theoretical framework (based on evolutionary biology) that has allowed this field to mature," said Gluckman. "Having said that, I think it is only as more human molecular data (epigenetic) emerges that this will happen."

Epidemiological data in support of the Barker theory have come from investigations of the effects of the 'Dutch famine'. Between November 1944 and May 1945, the western part of The Netherlands suffered a severe food shortage, owing to the ravages of the Second World War. In large cities such as Utrecht, Amsterdam, Rotterdam and The Hague, the average individual daily rations were as low as 400–800 kcal. In 1994, a large study involving hundreds of people born between November 1943 and February 1947 in a major hospital in Amsterdam was initiated to assess whether and to what extent the famine had prenatally affected the health of the subjects in later life. The Dutch Famine Birth Cohort Study (www.hongerwinter.nl) found a strong link between malnutrition and under-nutrition *in utero* and cardiovascular disease and diabetes in later life, as well as increased susceptibility to pulmonary diseases, altered coagulation, higher incidence of breast cancer and other diseases, although some of these links were only found in a few cases.

More recently, a group led by Bastiaan Heijmans at the Leiden University Medical Centre in The Netherlands and Columbia University (New York, USA) conducted epigenetic studies of individuals who had been exposed to the Dutch famine during gestation. They analysed the level of DNA methylation at several candidate loci in the cohort and found decreased methylation of the imprinted insulin-like growth factor 2 (*IGF2*) gene—a key factor in human growth and development—compared with the unexposed, same-sex siblings of the cohort (Heijmans *et al*, 2008). Further studies have identified another six genes implicated