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ENVIRONMENT

Toxic effects

Environmental concerns and more stringent laws are providing opportunities for environmental toxicologists.

BY AMANDA MASCARELLI

When oil began gushing into the Gulf of Mexico after BP's Deepwater Horizon drilling rig exploded in April 2010, politicians and the public were braced for the worst. Oil lapped up on hundreds of kilometres of beach and coastal sands stretching from Florida to Texas, and threatened Louisiana's ecologically sensitive wetlands. Although the wetlands and shorelines faced substantial damage, these regions were spared the brunt of the disaster, the largest marine spill in US history. Instead, much of the oil and gas — and between 2 and 3 million litres of dispersant that BP used to help break up the oil — drifted through the sea in deep underwater plumes, exposing marine organisms, many of which were in the vulnerable reproductive stages of their life cycles, to pollutants for several months.

Many scientists were alarmed by the unprecedented use of dispersants in the deep ocean. Little was known about how the dispersants and oil would interact, how toxic they were to many marine organisms, how long they would persist in the deep-water environment at potentially damaging concentrations and what affect this would have on the growth and reproduction of the Gulf of Mexico's myriad organisms.

Toxicologists working for government agencies, local universities and private consultants — along with fisheries biologists, oceanographers and ecologists — set to work to find the answer. "It's like CSI meets [Jacques] Cousteau," says Susan Shaw, a marine toxicologist and director of the Marine Environmental Research Institute, a non-profit institution based in Blue Hill, Maine.

During the gulf spill, which took nearly three months to contain, Shaw helped to analyse the effects of the oil and dispersants on marine animals. Later she took part in a scientific working group, assembled by the US Department of the Interior, that was tasked with assessing the effects of the spill on fisheries, wildlife and human health, and with making policy recommendations. This real-world application of her work is what drew Shaw to environmental toxicology 30 years ago. She still finds it deeply gratifying.

Environmental toxicologists aim to understand the effects of chemicals and physical agents — such as dust, mould, cigarette smoke, vehicle exhaust, pesticides, radiation and heavy metals — on both human health and ecosystems. Some work in risk assessment, relying heavily on statistical computations and mathematical modelling to determine whether an agent is likely to be hazardous at a certain level of exposure. Others are mainly chemists or biologists who tackle issues such as how pollutants travel and disperse in air and water, and how these agents affect humans, animals and ecosystems. "It takes the team of those people to put the whole picture together," says Jennifer Field, an environmental chemist at Oregon State University in Corvallis, who traces pharmaceutical products and illicit drugs in wastewater systems as an alternative indicator of drug-use trends.

In the 1970s and 1980s, the field of environmental toxicology expanded rapidly, especially in the United States, triggered mainly by the 1962 publication of Rachel Carson's *Silent Spring* — an exposé of the path that pollutants, particularly pesticides, take through the environment — and by the establishment of the US Clean Water Act and an array of air-quality laws. Although the field has not been immune to the economic depression of the past few years, toxicologists are in demand in government, academia, private industry and consultancies across the United States and internationally. In the United States, toxicologists held around 117,000 jobs in 2010, up 3.5% from 2008, according to an analysis of US Bureau of Labor Statistics by members of the Society of Toxicology in Reston, Virginia, an organization representing scientists from academia, business and government, and presented as a poster at the their 2011 Annual Meeting. The analysis predicts that the number of US toxicologists will grow to some 153,000 by 2018.

New legislation could fuel a greater ▶

Beijing's Forbidden City surrounded by smog at midday.

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demand. In the European Union, for example, the Registration, Evaluation, Authorisation and Restriction of Chemical Substances (REACH) law took effect in June 2007. Phased in over 11 years, REACH aims to create a standardized, rigorous approach to testing and evaluating chemicals before they reach the market. The law will create jobs for toxicologists across all sectors, including academia, government, business and consulting firms that will require a blend of technical and managerial skills, says Mark Crane, an environmental toxicologist and founder of WCA Environment, an environmental consultancy based in Faringdon, UK. They will be needed to help to find efficient and effective ways to meet the often complex requirements of REACH, says Crane. Knowledge of how the chemical industry and its supply chains work will be a big advantage. "You need to be able to speak knowledgeably to a client, to give them strategic as well as tactical advice," he says. For instance, to help a client meet REACH mandates, it is important to be able to understand the company's specific needs, such as whether the regulations require animal testing — which can be a lengthy and costly process — or if there is a more efficient method to satisfy the regulations.

"Toxicologists are in demand in government, academia, private industry and consulting"

In fact, there may not be enough well-trained toxicologists to fulfil the demands of REACH in the public and private sector in Europe in the coming years, says Alan Boobis, a toxicologist at Imperial College London. Others have suggested the same, including in a 2007 European Commission report (see go.nature.com/zbtkdi), which noted the lack of toxicology training programmes. The problem, says Boobis, is that toxicologists with the integrated training required for risk assessment are close to retirement. Furthermore, many universities in Europe offer programmes that do not provide the broader scope of training needed for the applied science of toxicology. "With greater specialization, we are losing this expertise in Europe, and without an adequate career track there is little incentive to pursue such a career."

There are, however, some notable exceptions, including Britain's Cranfield University, which provides tailored postgraduate programmes that allow students to combine policy and applied work, says Crane. He also points to the University of Insubria in Varese, Italy, which offers a doctoral programme in environmental chemistry and ecotoxicology. The Netherlands has a handful of universities that offer good toxicology programmes, including Wageningen University and Utrecht University.

Toxicologists generally acquire expertise in one or two areas, focusing on, for instance, mathematical modelling and biostatistics, epidemiology, molecular biology, environmental chemistry or pharmacology. Most toxicology jobs require PhD training, although there are opportunities for master's students in government and elsewhere. Some of the most important skills that graduates entering the field can bring are social: understanding their clients' needs and collaborating with other experts. "The people who are going to be successful are people who have that deep expertise in their own field yet have the professional capabilities to collaborate, and to open their mind and to really listen," says Dave Stone, director of the US National Pesticide Information Center, a cooperative between the Oregon State University and the US Environmental Protection Agency in Washington DC.

The United States has at least 125 toxicology programmes, some of which concentrate on a specific subfield such as ecotoxicology, inhalation toxicology, metals toxicology or policy. Indiana University in Indianapolis, for example, is a centre of ecotoxicology and chemical carcinogenesis; Michigan State University in East Lansing focuses on food toxicology; and The University of Rochester in New York specializes in the effects of toxic chemicals on bones. George Gray, a risk analyst at George Washington University in Washington DC, says that the university's programme emphasizes policy, producing competitive graduates. "It makes them attractive to organizations when they understand not just the science but how it ends up being used," says Gray. A great toxicology programme will "allow students to work with professors in a laboratory setting, have the opportunity to contribute to publications as co-authors, and take a wide range of courses in toxicology, pharmacology, chemistry and ecotoxicology," says Margaret Whittaker, managing director and chief toxicologist at ToxServices, a consulting firm based in Washington DC that assesses health risks from chemicals.

REAL-WORLD PROBLEMS

In Europe, REACH puts the burden of proof-of-safety for chemicals on the chemical industry itself; this is not the case in the United States, where advocates have been fighting for an overhaul of existing US legislation for years. The US Toxic Substances Control Act of 1976 is widely viewed as outdated and fractured, even by members of the chemical industry.

"The US law currently takes the view that chemicals are innocent until proven guilty and REACH takes the opposite view — that chemicals are suspect unless the companies making them and using them can prove that they're safe," says Monica Becker, a sustainability consultant based in Rochester, New York. If the burden of proof were to shift, says Becker, more chemical testing and expert interpretation of toxicity data would be required, which would create a demand for toxicologists. But California is already preparing to implement regulations that will require consumer product manufacturers to investigate whether their products contain 'chemicals of concern', and suggest substitutes. Whittaker expects these regulations to create many private-sector jobs for toxicologists.

Legislation adopted in China in 2010, known as China REACH, is similar to that in Europe

Erica Holloman is hoping to make a difference.

MICHAEL NEWMAN

and will drive the country's demand for toxicologists, says Kenneth Leung, an aquatic toxicologist at the University of Hong Kong. He says that the number of industry and academic postgraduate and postdoctoral jobs in the field is growing and this is likely to continue as China attempts to meet demands for efficiency, cleaner air and water, and action on addressing climate change.

"North America confronted decades ago the problems now emerging in Asia, so individuals trained in environmental toxicology can make a substantial contribution in Asia," says Michael Newman, an ecotoxicologist at the Virginia Institute of Marine Science in Gloucester Point. China has a number of well-known training programmes, including a programme at the Guangzhou Institute of Geochemistry of the Chinese Academy of Sciences, known for its monitoring of environmental pollution, and the Research Center for Eco-Environmental Sciences, also part of the Chinese Academy of Sciences in Beijing, which is working to develop an early-warning system for environmental contamination.

Globally, the field is moving away from a focus on individual chemicals and towards understanding the cocktail of chemicals that pervade the environment, says Linda Birnbaum, head of both the National Institute of Environmental Health Sciences in Research Triangle Park, North Carolina and the US National Toxicology Program, a federal interagency programme. "People are finally beginning to realize that nobody is exposed to one chemical at a time," says Birnbaum. "We live in a soup. We've got to go beyond looking at one chemical or one exposure at a time and start looking in a more integrated fashion." In the future, toxicologists will need to consider cumulative effects of many exposures and work as part of multidisciplinary research teams.

Most environmental toxicologists say they are highly satisfied with their work, partly because they can apply their expertise to pressing, real-world problems. Erica Holloman, who recently completed her PhD in toxicology at the Virginia Institute of Marine Science, is building on her doctoral work, assessing the effects of mercury in seafood and other pollutants in a low-income community in Newport, Virginia, through a community grant from the US Environmental Protection Agency. "I wanted to see my work make a difference in everyday life," says Holloman. "I found this was a way that my passion for science and the research could lead to something that was dear to my heart, and that I could really have an impact in." ■

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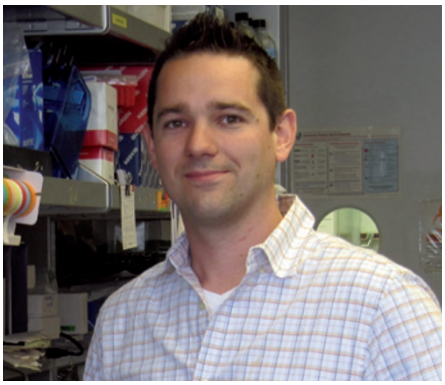
TURNING POINT
Sean Bendall

Sean Bendall, a postdoctoral fellow in stem-cell and cancer biology at Stanford University in Palo Alto, California, won the Dale F. Frey Award for Breakthrough Scientists from the Damon Runyon Cancer Research Foundation in New York on 9 January 2012.



How did you decide where to do your PhD?
After earning my bachelor's degree in biochemistry and microbiology at the University of Victoria in Canada, I decided to work for a year at a proteomics facility while I applied to graduate programmes. I was accepted to some very prestigious places, including the University of Oxford, UK and the Institute for Systems Biology in Seattle, Washington. The decision was tough because the research project that excited me the most was not happening at Oxford or in Seattle. I wanted to work on the mechanism that makes an embryonic stem cell continue to be a stem cell and stops it from differentiating into another type of cell, and I was able to do this at the University of Western Ontario in London, Canada.

Was it a good decision?
I definitely do not regret deciding to follow my passion. My stem-cell work ended up making a big splash in *Nature* (S.C. Bendall *et al. Nature* **448,** 1015–1021; 2007), even though it took a while to get the paper out. I think if you could tell any PhD student that their project would culminate in a high-profile paper in a top journal, they would consider that the best-case scenario. As it was, I left little bits of my soul behind on a long journey to get to that end point.

What did you learn while writing that paper?
How to tell the story better. Like many academics, I was blind when it came to my own research. I had to find a way to write that laid out how my observations could help to guide science in a new direction, rather than simply saying the research so far had been wrong.

How many iterations did the paper undergo?
Several. The first version was two stories — the method development and the actual stem-cell analyses — that were poorly tied together. We sent it to one journal, not *Nature*, and the reviews were not good. But the reviewers did suggest experiments that could strengthen the paper, which helped us to describe, in a new version, how some of the pathways that we had thought were most important in stem-cell cultures were not even acting on the stem cells, but on the support cells. Once I combined my work with a colleague's, a bigger story emerged of how growth factors help to control how human embryonic stem cells differentiate into, say, bone marrow or skin.

Are there downsides to training at the cutting edge of science?
There can be. In 2008, next-generation flow cytometers were so new that I was almost a year into my postdoc before we got the instrument in the laboratory. Until then, I had to send my samples to the manufacturer in Toronto. Still, once we got everything running well, we were able to quickly publish a paper that illustrated the technology's capabilities and potential. Every project in our lab is now using this technology. It is an exciting time.

Has your ongoing success delayed your efforts to seek a permanent position?
Yes. I haven't applied for any jobs yet because everything is going so well, and I want to focus on the research. But I realize that I need to put myself on the job market and that now is probably best because my work is going so well. Receiving the US$100,000 Dale F. Frey award is a nice nest egg for when I get my own lab.

What is your secret for success?
Research topics in the top journals are probably not the best PhD or postdoc topics. They already have enough people working on them. I like finding the empty space in research in which no one else is poking around. And my publication record is good partly because I work in multidisciplinary groups. Some researchers think that they should do everything on their own, but that can take so much longer, and a collaborative project might also result in a better interpretation of the data because the case has to be proved to many disciplines. ■

INTERVIEW BY VIRGINIA GEWIN