

Assessing the damage

Dr Keith Tierney provides an overview of his research into the effects of compounds of human origin present in water and the impacts on animal health



When did you develop an interest in this field?

I struggled with finding a career direction during my undergraduate studies at Simon Fraser University. Near the end of that degree, I took a course on ecotoxicology and was immediately hooked. The ability for chemicals of human origin at very low concentrations to affect life over long periods of time was both alarming and intriguing, and I became broadly interested in the impact of humans on global ecosystems.

I was fortunate enough to be hired as a research assistant in a lab that was exploring the Exxon Valdez accident, and this led to an MSc in Fish Physiology examining the effect of disease and temperature on migratory salmon. At the time, good science jobs seemed very rare and undervalued so I did something unusual and pursued an MBA at the University of British Columbia, before taking a job in specialty food marketing. I soon realised this was not the best use of my skills and decided to go back and follow my heart. I completed more graduate training in toxicology and have never looked back.

What are the overarching goals of your research?

One of my basic goals is to link compounds that are detected by sensory neurons with physiological and behavioural responses. In zebrafish (*Danio rerio*), the model organism we study, there are about 250 distinct types of receptors that detect an array of maybe millions of compounds. The story gets even more interesting when you consider that olfactory sensory neurons are able to detect novel compounds of human origin, such as pesticides.

On the applied side of my research, one goal is to determine whether animal health is affected by exposure to complex mixtures of chemicals representative of those found in the environment. In this work, we use fish and avian models. Today's reality is that animals are exposed to low levels of diverse compounds over their lifetime.

Do you employ any novel techniques to monitor fish health, in either the field or lab?

We monitor at least two unique aspects. The first is the use of sensory neurons as water quality sensors. The rationale is that the exquisitely sensitive neurons in fish noses can detect small but meaningful changes in water quality. We now have a dataset indicating that fish can detect changes in the composition of municipal and industrial effluents, and we plan to develop this model for use with a variety of chemical scenarios.

A second method is the use of behavioural phenotyping (personality profiling) to improve the ability of detection of organism responses to chemicals. Typically, when we say that fish have personalities, eyebrows are raised. Nevertheless, we have shown that newly emerged zebrafish can be separated into 24 repeatable stimulus-based phenotypes. For example, fish given an excitatory odorant may change from high activity to low activity, or do exactly the opposite.

Which gaps in knowledge do you seek to address?

Just as my research has many overlapping goals, we also hope to fill in diverse knowledge gaps. Among these, we aim to elucidate the significance of specific olfactory receptors involved in responses to food odors, pharmaceuticals and personal care products that are deposited into our lakes, rivers and streams, as well as the 'olfactory bouquets' that enable the migration of so many invaluable fish populations.

Another goal is to understand how animals cope with the changing thermal landscape brought about by global warming. We work in Nunavut with Arctic char (*Salvelinus alpinus*) to explore its ability to respond to heat stress at the molecular level.

Could you explain the process of bioaccumulation? Why might this make low-level contamination a greater problem than anticipated?

The key question is how can compounds at very low environmental concentrations become so concentrated in life? Physics teaches us that things cannot move up their concentration gradient, and this is not wrong. However, some synthetic compounds such as persistent organic pollutants (POPs) are water fearing (hydrophobic). When released, such compounds move into sediment and the fat of organisms at the bottom of the food chain. As life higher up on the food chain feeds on the lower levels, the fat content is taken up. In doing so, the hydrophobic chemicals follow the fat.

Although most POPs are not produced anymore, some still are, and we will see legacy effects of these compounds for decades. Exposure to POPs is associated with developmental toxicity, and immune and cognitive problems in wildlife and humans.

Fishy business

In order to encourage legislation that protects animal habitats and health, researchers at the **University of Alberta** seek to uncover crucial information about the effects of anthropogenic contaminants on fish and birds

THE PLANET'S BURGEONING human population is placing greater pressure on water resources due to a rising demand for food and sanitation, while at the same time, development is diminishing the health of aquatic environments through the release of industrial and agricultural pollutants, eg. pesticides, pharmaceuticals and cosmetics.

Since the Cuyahoga River first gained the public's attention in 1868 as the 'river that caught fire', measures have been taken to improve Great Lake and global water quality for the benefit of human health and recreation. But what is often overlooked is the long-term and multiplicative impact effluent has on aquatic animals. Relatively little is known about these ramifications, although there are many species that are vulnerable to such challenges. If the policy-making community is to intervene and introduce measures to reduce the amount of contaminants that enter the hydrosphere, research that demonstrates relationships between water quality and aquatic animal health is necessary.

UNDERSTANDING THE EFFECTS

Dr Keith Tierney of the University of Alberta, Canada, is an environmental toxicologist engaged in a number of basic and applied studies to explore water-vertebrate interactions, primarily focused on different types of fish and waterfowl. His research aims to address a number of different knowledge gaps related to the ways in which aquatic vertebrates interact and move through water. Specifically, he is interested in how animals use sensory information to travel, and the ways that different water conditions – and waterborne contaminants – can affect this movement.



ARCTIC CHAR IN RESPIROMETER
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While Tierney's applied research centres on the long-term health impacts for fish and birds exposed to low-level chemical compound contaminants over prolonged periods, he is also conducting basic research that aims to assess links between compounds detected by sensory neurons in zebrafish (*Danio rerio*) and their physiological and behavioural responses.

THE IMPORTANCE OF SMELL

A unique facet of Tierney's work lies in his interest in olfaction – the sense of smell – in fish. As with many other animals, olfaction is crucial to survival: without it, fish would find tasks such as mating, feeding and migration very difficult. Tierney's collaborators on Vancouver Island have come across blind salmon that have successfully managed to complete migration, and it is already known that cave fish which live in darkness and have lost their sight, exist in a world of olfaction. However, little is known about how olfaction contributes to their survival. "These examples highlight just why looking at olfactory toxicity in fish is such a meaningful pursuit," Tierney enthuses. "By protecting the neurons in fish noses from pollution, we help ensure fish survival."

CONTROLLING AN AQUATIC PIT BULL

Olfaction is particularly important in the control of alien invasive species. Since the European round goby (*Neogobius melanostomus*) invaded the Laurentian Great Lakes in around 1990, having arrived via the ballast tanks of Atlantic-bound European shipping boats, this small yet highly aggressive fish has proven itself to be a menace within its adopted habitat and can be likened to a 'pit bull'. Not only do round gobies eat the eggs of indigenous fish, but they are prolific breeders that can spawn several times in a mating season. Furthermore, as bottom-feeding fish, they are continuously moving the contaminants they consume from lake beds up the food chain through the process of bioaccumulation; the lengthy biological half-life of synthetic chemicals means they are accumulated at a greater rate than at which they are lost. Spreading toxic chemicals throughout other animals can lead to death or health issues on a large scale if not abated.



LARVAL ZEBRAFISH
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Tierney is part of a research group tasked with restricting the expansion of the round goby range and staving off their spread into other North American freshwater bodies. A potential method to protect native species spawning grounds and fishing sites is by devising an 'olfactory trap'. Based on knowledge that females are drawn to males through a combination of sensory clues, which include pheromones, this trap will contain a cocktail of compounds to entice them. Another control strategy may be to physically prevent their movement by using dams, culverts or weirs. To date, there are few attempts to prevent the movement of the round goby in this manner. "To indicate how good gobies are at moving, there are species in Hawaii that move up waterfalls," Tierney emphasises. With a 9 billion-strong goby population in the western basin of Lake Erie alone, these fish will never be eradicated, but Tierney and his colleagues should be able to manage numbers. They also hope that any significant findings could be applied to other areas around the world experiencing a similar problem. In fact, a colleague in Switzerland is already tackling a similar problem.

DIRECTLY INFLUENCING POLICY THROUGH RESEARCH

Research must not remain hidden away in journals, and researchers are increasingly trying to engage the public and regulators. Dialogue with members of North American federal bodies, as well as widespread dissemination, is essential to ensure this work goes some way towards solving real-world issues. As Tierney explains: "Over time, my lab hopes to provide regulatory information on how mixtures of organic chemicals may alter animal behaviour in the environment". Some of his colleagues, Drs David Baldwin



TIERNEY LAB © FRANK NARGANG

A unique facet of Tierney work lies in his interest in olfaction – the sense of smell – in fish

and Nathaniel Scholz of the National Oceanic and Atmospheric Administration (NOAA), used fish olfactory toxicity endpoints to successfully lobby for limits on the amount of copper in salmon spawning streams in the US. This was an important victory for the use of sensitive sublethal toxicity endpoints that Tierney and others use and represents a major breakthrough in how regulators understand the science and therefore ensure the migration of incredibly valuable salmon species.

FOSTERING FUTURE ENVIRONMENTAL TOXICOLOGISTS

A cornerstone of Tierney's research is its role in providing training opportunities for budding researchers. He is an active proponent of the University of Alberta's undergraduate research initiative, in which second year undergraduates are invited into Tierney's lab to engage with his various research projects. Participants work with graduate students, and gain experience of producing posters and small theses, which helps prepare them for a career in science. Many students then choose to continue this work in their third and fourth years, and Tierney has mentored several through to graduation – something he takes great pride in. He is also considered by many of his peers to be a leader in olfaction, and his expertise is regularly sought after for book chapters and high-profile events: in 2012, Tierney gave a keynote speech at the American Fisheries Society Symposium and was Chair of Olfaction at the International Congress on the Biology of Fish.

FUTURE PLANS

Currently, Tierney's research is moving towards establishing the multigenerational toxicity effects of compounds released during hydrocarbon exploration. It is widely understood that changes that impact maternal health can affect the life of the offspring, and he is currently developing metrics, be that behavioural or neurological, that can pinpoint these specific effects: "In my research, we aim to specialise in 'ethotoxicology', ie. behavioural toxicology, as we would like to

know if exposure to realistic chemical mixtures alters vertebrate behaviour over long time periods," he elucidates. In light of expanding oil exploration activity, it is clear that this avenue of work will prove to be particularly important in the conservation of wildlife.



KT AND ZEBRAFISH RACK © MATTHEW GILBERT

INTELLIGENCE

AN AQUATIC CENTER FOR THE EVALUATION OF THE EFFECTS OF WATER QUALITY ON VERTEBRATE HEALTH

OBJECTIVES

- To link chemosensory cues to animal physiology and behaviours
- To understand how contaminants affect chemosensory-based responses
- To determine how water quality issues affect salmon migration

KEY COLLABORATORS

Senior Environmental Quality Scientist **Mark Sekela**; Environmental Studies Scientist **Melissa Gledhill**, Environment Canada • **Professor Daniel Schlenk**, University of California, USA • **Professor Patricia Burkhardt-Holm**, University of Basel, Switzerland • **Professor Geraldo Wilson-Fernandes**, Federal University of Minas Gerais, Brazil • **Associate Professor W Ted Allison**; **Professor Mike Belosevic**; **Associate Professor Daniel Barreda**; **Professor Arturo Sanchez-Azofeifa**; **Professor Cindy Paszkowski**; **Associate Professor Andrew Keddie**; **Professor Mohamed Gamal El-Din**, University of Alberta, Canada • **Professor Barbara Zielinski**, University of Windsor, Canada • **Dr Cameron Stevens**, Golder Associates, Canada • **Professor Chris Kennedy**; **Dr Peter Ross**, Simon Fraser University, Canada • **Professor Gary Rand**, Florida International University, USA

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KEITH TIERNEY received his BSc Biology in 1996, MSc Fish Physiology in 2001 and MBA a year later. In 2007 he completed his PhD in Aquatic Neurotoxicology and went on to carry out his Postdoctoral Fellowship in Behavioural Neuroscience. Tierney is currently Assistant Professor in the Department of Biological sciences, University of Alberta, and explores environmental toxicology and physiology of fish.

