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About Zygote Quarterly

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Collection autumn 2010 | Photo: Marta Miguel, 2007 | Flickr cc

Face mites? Really? Just when you thought it was safe to be an independent human, you are told that you are not alone... ever. As a matter of fact, there is a whole host of other organisms that share our space (and our bodies) with us. In this issue ant expert Clint Penick details some of his favorite examples of uncommon life found in the most pedestrian environments.

Some of these household creatures survive conditions as extreme as that of the Antarctic icefish, the topic of our lead-off article. Icefish survive sub-zero temperatures by producing anti-freeze proteins, one of many strategies nature has for living in the extreme cold.

Entrepreneur Ryan Church, consultant Rachel Hahs, and co-editor Norbert Hoeller bring us the first chapter of four biomimetic innovation case studies across a range of disciplines from wind power to flame retardants to green infrastructure.

Our featured artist, Jennifer Wanner, makes portraits of Canadian regional plants at risk by combining them into a single (and singularly beautiful) organism.

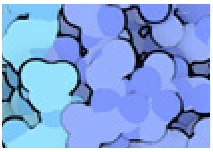
Liv Scott reviews Tamsin Wooley-Barkley's business advice book *Teeming: how superorganisms work to build infinite wealth in a finite world (and your company can too)*.

Finally, in our world interview feature, the Great Lakes Biomimicry group of northeast Ohio, USA, tells us about how they collaborate with industry, launch student research at the University of Akron, and fund their non-profit mission.

Happy reading! ×

Tom Norbert Marjan

Tom McKeag, Norbert Hoeller and Marjan Eggermont



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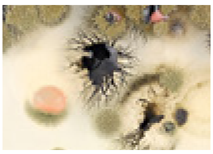

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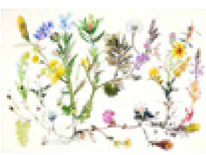

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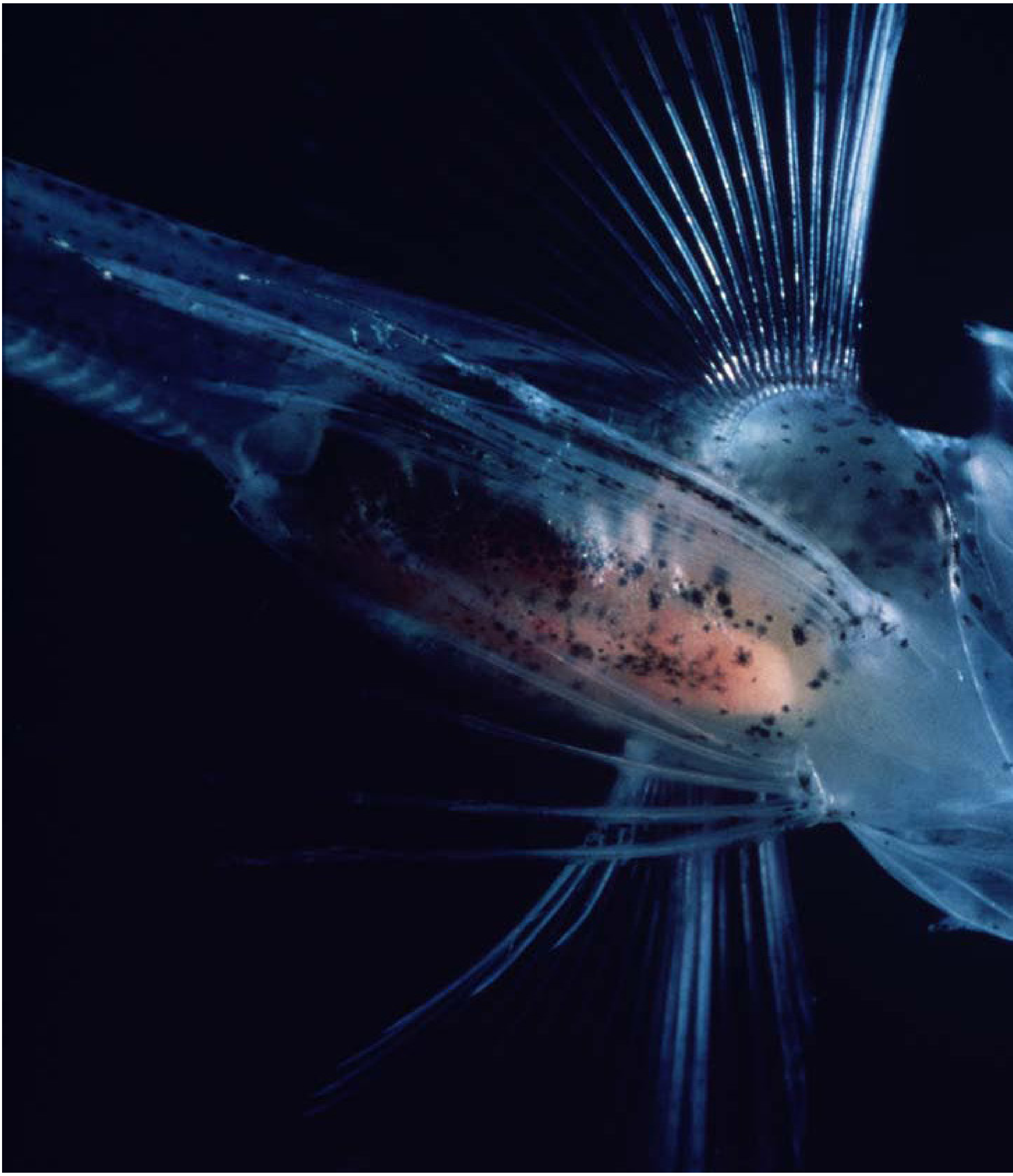
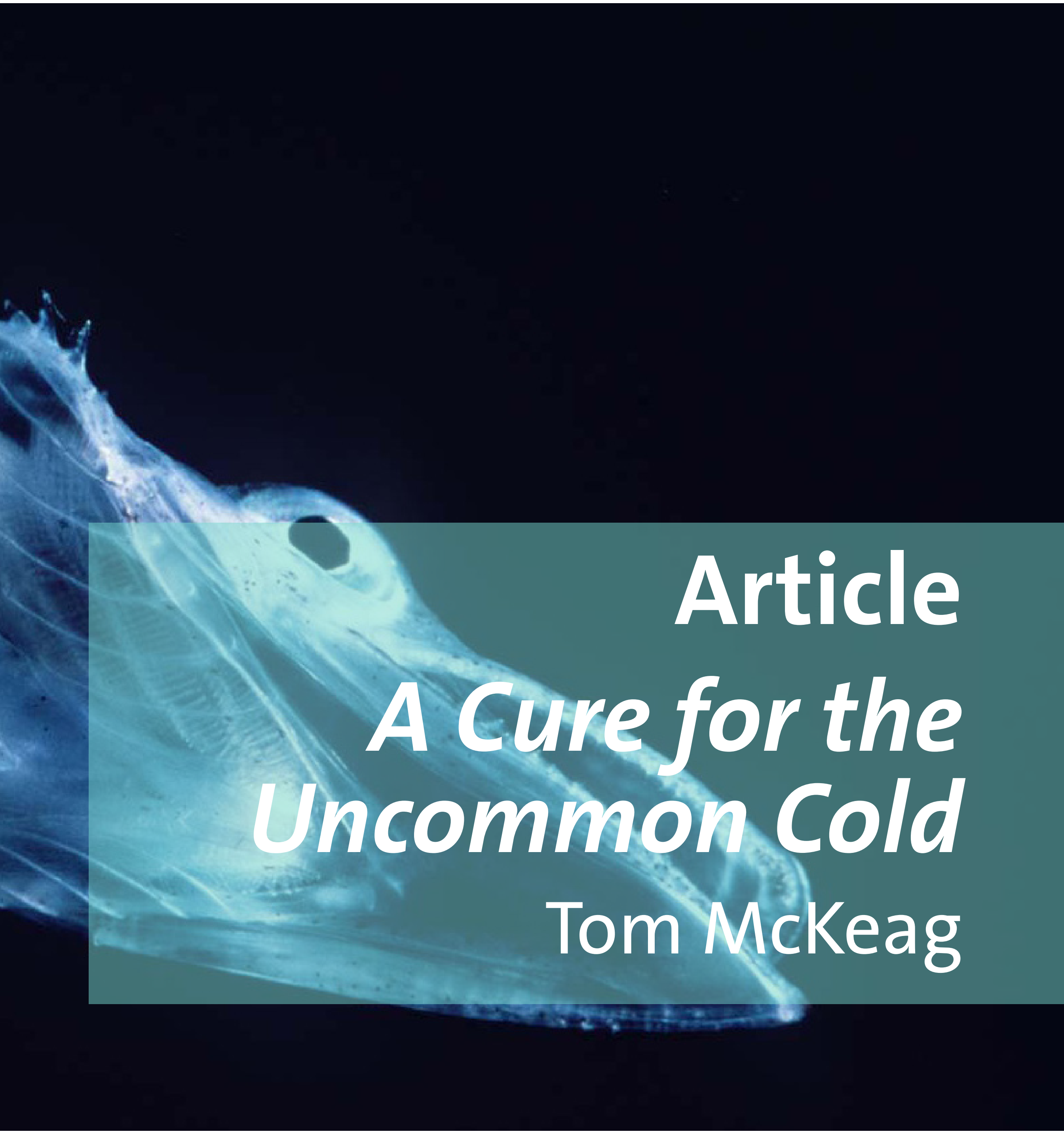


An icefish off the coast of Antarctica
Photo: Wikimedia Commons



Article
A Cure for the Uncommon Cold

Tom McKeag

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Article
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Author:
Tom McKeag

A Cure for the Uncommon Cold

When Arthur DeVries arrived at McMurdo Station in 1961, he was fresh from Stanford University where he had signed up for a 13-month stint to study the respiratory metabolism of the endemic Notothenioid fishes found in McMurdo Sound, Antarctica. Notothenioids are Antarctic icefish, a suborder of the order of Perciformes. This order is the most numerous order of vertebrates in the world and includes perch, cichlids, and sea bass. Five families of Notothenioid fish dominate the Southern Ocean, comprising over 90 percent of the fish biomass of the region. They are a key part of an entire ecosystem, but that ecosystem would not exist in its robust form if they had not evolved a way to beat the extreme cold of these polar waters. DeVries would eventually find out how.

McMurdo station is at the southern tip of Ross Island, the largest of three U.S. science installations in Antarctica. Established in 1958, McMurdo had all the features of any work camp on the edge of raw nature, with few embellishments beyond generators, supply pallets and Quonset huts. The research community there existed in defiance of the climate, rather than because of it: recorded temperature extremes are as low as minus 50 degrees Celsius and average annual temperatures reside at minus 18 degrees Celsius.

Despite the conditions, DeVries thrived in the close-knit academic atmosphere and the rugged fieldwork of catching, stocking and analyzing fish. The challenges of his temporary job there, however, would lead him unexpectedly to a ground-breaking discovery and a lifetime of polar science. Some of the fish he was catching and holding in tanks were dying, while others were not. His zeal to solve his problem and his curiosity to find its causes would lead to an entire branch of research. As he told *Scientia Publications*,

> “During these experiments I noticed that a deep water Notothenioid fish would freeze to death if any ice was present in our refrigerated salt water while those caught in the shallow water survived in the presence of ice. I decided to investigate why there was a difference in these species living in water of the same temperature (-1.9°C) for my PhD thesis research at Stanford. I investigated what compounds were responsible for their capability to avoid freezing in this environment while fishes in temperate waters would freeze to death at -0.8°C. My study culminated in the discovery of the antifreeze glycoproteins, the compounds responsible for their extreme freeze avoidance.”

The Antarctic icefish DeVries was studying are in a special club of organisms with the ability to live at low-temperature extremes. Some of these organisms, like the North American Wood Frog, are able to recover from freezing, and some, like the icefish, survive by avoiding being frozen. A great range of creatures from insects to diatoms to fungi and bacteria are also in this group that uses so-called ice-binding proteins (IBP) to sur-

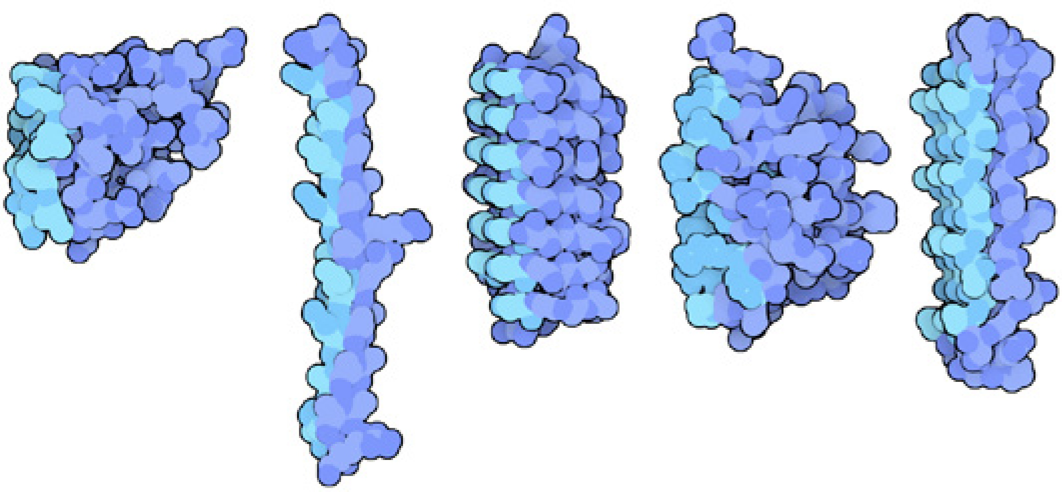
McMurdo Sound Sea Ice | Photo: Bruce McKinlay, 2011 | Flickr cc

McMurdo Station 2011 | Photo: Bruce McKinlay, 2011 | Flickr cc

vive. They use one of five general mechanisms for this: producing antifreeze; structuring ice where, for instance, an alga will create a more moderate liquid pocket within ice; adhering to ice, such as certain bacteria do; nucleating ice; and inhibiting ice recrystallization. Recrystallization is the consolidation of small ice crystals into bigger ones as they are attracted by hydrogen bonding in a cascade effect.

The icefish have evolved the first strategy of creating their own antifreeze. Antifreeze proteins (AFP) can be defined as any ice-binding proteins that depress the hysteresis freezing point below the hysteresis melting point, thereby creating a "thermal hysteresis gap". They are typically alpha helix glycoproteins also known as antifreeze glycoproteins (AFGP) or thermal hysteresis proteins (THP). Thermal hysteresis is the separation of freezing and melting temperatures. The fish are able to lower the point at which the water inside them freezes, while the point at which it melts remains the same (more on surprising developments on this later). To understand how this works requires a brief discussion of water itself.

Water is the universal medium on earth, with unique properties essential to a wide range of livable conditions and is a critical part of living things themselves. No other common material exists naturally on our planet in all three phases, liquid, solid and gas. Strong covalent bonds hold oxygen and hydrogen atoms together in a single molecule, but weaker hydrogen bonds connect water molecules to each other. The polar nature of the molecule, with oxygen negative and hydrogen positive, allows it to bind readily to other molecules, making for an excellent and universal solvent. Water has a high thermal capacity, which might be described as a reticence to change temperatures despite its surroundings. This creates an important moderating influence on climate at many scales. It has been estimated



Several different antifreeze proteins (left to right: the ocean pout, the winter flounder, and three very active proteins from insects, the yellow mealworm beetle, the spruce budworm moth, and the snow flea, with the ice-binding portions in lighter blue).
Graphic: David S. Goodsell and the RCSB PDB | CC-BY-4.0

that our oceans can absorb one thousand times the heat as our atmosphere without significantly changing temperature. Most of the increased heat of global climate change, for example, has been absorbed by the earth's oceans.

When water becomes colder, its density follows a predictable material trend, growing denser with each drop in temperature, until 4 degrees C. When water turns to ice it becomes lighter, less dense (approximately 9%) as the hydrogen atoms link to form a crystal lattice structure. This characteristic allows ice to float on top of its denser liquid phase, making overwintering aquatic life possible around the globe, including in the Antarctic Ocean. The expansion of water in the change from liquid to the solid phase can also be a powerful disruptive force; able to split granite.

This force can be equally straining at the intracellular and cellular level. Expansion of solid water inside of cells may cause them to burst, and the freezing of the intercellular spaces causes water loss and ion and metabolite buildup as ice forms. This water imbalance prompts a flow of liquid out of the cells and into the spaces between. This can lead to a toxic concentration of ions within the cell or a significant loss of pressure resistance and cell collapse.

A range of organisms across kingdoms has adapted to temperatures that freeze water: plants, yeasts, bacteria, and animals like fish and insects. They employ different stratagems, but all must live by the physical rules of their environments, especially the characteristics of water.

When salt is dissolved in water it lowers its freezing point. Seawater, therefore, has slightly different properties than fresh as the dissolved salts (3.5% for typical seawater) lower the freezing point to minus 1.9 degrees C. This is called freezing point depression and is a common evolved stratagem for many cold climate dwellers or psychrophiles. DeVries realized that the freezing point depression exhibited in his surviving shallow water fish could not be explained solely by common body salts in the serum of the fish. He devised a series of experiments to differentiate the chemical makeup of his two types of fish and isolated the glycoproteins that were key to his discovery. The proteins were attaching themselves to ice crystals within the blood of the fish and preventing them from growing. This, combined with body salts, allowed the fish to maintain liquid blood at minus 2.5 degrees C.

What he and his colleagues eventually found out was that these glycoproteins were binding to ice crystals irreversibly in a process they termed adsorption-inhibition (DeVries and Raymond, 1977). This is a so-called "step pinning" process in which crucial physical sequences necessary for freezing are interrupted or curtailed. In this case, the AFP's were binding to small nascent ice crystals and forcing ice formation into smaller spaces between adsorption sites thereby bending the ice lattice's growth front into a curve. This created a higher surface free energy and effectively lowered the freezing point in a phenomenon called the Gibbs-Thomson effect.

AFP's are typically small compound proteins with an eccentric load of the amino acid threonine. Threonine has a hydrophilic surface that water molecules attach to weakly. This adsorption inhibits the microcrystals from coalescing into larger crystals and keeps the water in the liquid state.


1cm

The lichen *Xanthoria elegans* can continue to photosynthesize at −24 °C | Photo: Jason Hollinger, 2009 | CC BY-SA 3.0

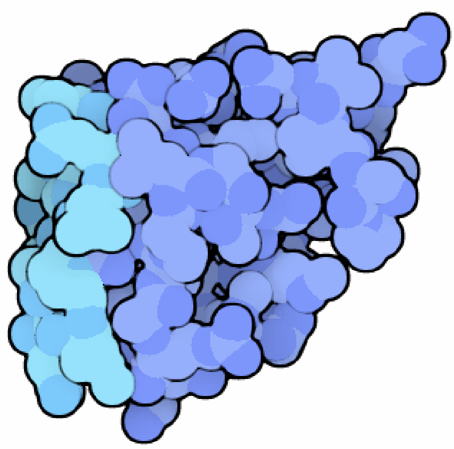
It appears that these small ice crystals remain in the fish for their lifetimes, but this is still being studied. While there is no evidence that the fish are adversely affected by the year-round presence of the crystals, DeVries believes that they must have a mechanism to void them. One surprising recent discovery has been that the presence of the AFP's make the crystals resist melting; higher temperatures are needed to melt them as well as lower temperatures needed to form them.

What is not known, according to DeVries, is just how these proteins are able to recognize solid phase water molecules within this liquid environment and preferentially bind to them. How they prevent growth is also still be investigated, with the adsorption-inhibition model still open to debate and refinement. Nonetheless, there is no refuting this as a successful survival strategy. Indeed, it is an example of convergence, often an indicator, if not a guarantee, of effective and durable solutions in nature. Two genetically distinct populations of fish, one in the Arctic (the Arctic Cod) and one in the Antarctic (Notothenioids), have developed these techniques.

The discovery of these anti-freeze proteins may have touched off an entire research industry into their abilities, but do they perform as well as their commercial namesake? It seems that they do, as a matter of fact much better by an order of magnitude. The reason is the selectivity that they exhibit in attaching to the small ice crystals. Ethylene glycol, the green liquid typically used in car radiators, works by mass action effect, disrupting hydrogen bonding by the chemical equivalent of carpet bombing. Although it is not persistent, the chemical is a moderately toxic poison. When swallowed it is converted into oxalic acid by ethanol hydrogenase. Oxalic acid is highly toxic, affecting the central nervous system, heart, lungs and kidneys. It is responsible for tens of thousands of animal poisonings and thousands of human poisonings each year. Ethylene glycol has been demonstrated as a developmental toxicant in higher doses in rats.

Propylene glycol with metal nanoparticles has been developed as a safer alternative to ethylene glycol, but lacks the efficiency of the AFP's. It is cheaper, however, readily available and uses a material already employed in the food industry and approved by the FDA.

Despite decades of research into the mechanism of these proteins, industry applications remain few, with proteins from the Arctic pout fish used in ice cream to prevent recrystallization, and AFP's and growth hormones introduced to transgenic farmed salmon for cold-weather hardiness and increased growth. It is in the biomedical field, however, where the use of these proteins promises the most rewards and challenges.



Ocean pout antifreeze protein
Graphic: David S. Goodsell and the RCSB PDB | CC-BY-4.0

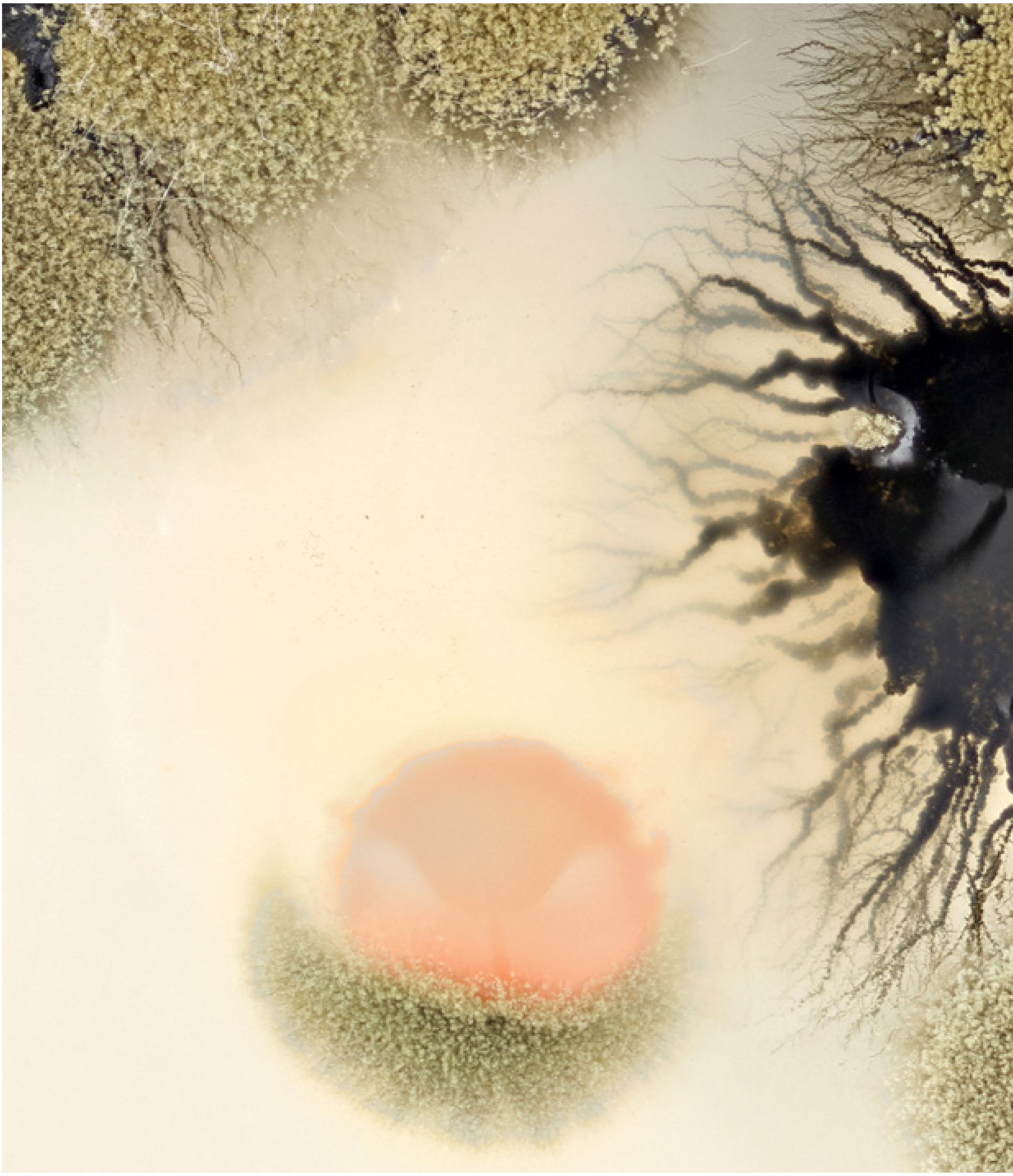
Transporting and transplanting organs, preserving human bodies for the future miracles of medicine (cryonics), and performing surgery are all endeavors where AFP's could play a revolutionary role. Single cells, like sperm and eggs, are routinely frozen and stored, but larger tissue is more difficult to preserve. AFP's have been employed successfully to preserve rat and pig hearts in below freezing temperatures. In one experiment, researchers removed a rat heart, preserved it in sterile water and AFP's at minus 1.3 degrees C for 24 hours, then transplanted the warmed up (non-pumping) heart into a new rat.

Notwithstanding these early successes and the great promise of AFP's, the technology of preserving human organs still lags far behind the medical demand. The US Department of Health and Human Services estimates that approximately 21 patients a day die waiting for an organ that is not available. Lungs remain usable for only twelve hours and hearts only four or five, using the current techniques. The toxicity of cryoprotectants and the disruptive effects of thawing are two of the most challenging problems. While vitrification is an effective technique of quick freezing of organs to a glass state, most techniques rely on pumping the cells full of toxic chemicals, and it is in the thawing where damage is most severe. Differential warming causes splintering and fracturing of material subjected to opposing forces. One University of Minnesota team, however, is working on a method of using nanoparticles to gently and uniformly heat organs back to living temperatures. The magnetic nanoparticles are excited to activity (and heat) by radio waves in a process the team calls "nanowarming", and the technique has been used successfully on clusters of cells.

Other research teams are looking elsewhere in nature for even more effective anti-freeze compounds. One is a glycolipid found in a freeze-tolerant Alaskan beetle, *Upis ceramboides* which allows the insect to endure temperatures of minus 60 degrees C and still recover. Cell and Tissue Systems of South Carolina is employing it successfully in the preservation of tissues for days at below zero temperatures without deterioration, according to the company. The glycolipid appears to coat the membrane of the cell, armoring it against external ice and sealing it against the osmotic draw of liquid from the cell.

Whether using a protein or a glycolipid, lowering freezing temperatures or enduring being frozen, pumping themselves full of cryoprotectants, sealing themselves up or drying themselves out, nature's organisms of all domains have come to live with the uncommon cold. It is still up to human researchers to fully unlock these secrets and put them to use in the better preservation of life. ×

Upis ceramboides
Photo: alaskanent, 2006 | Flickr cc



Household fungi: *Cladosporium sphaerospermum* (green "mold"), *Sporobolomyces roseus* (pink yeast), and *Aureobasidium pullulans* (black alien-looking fungus)
Photo: Matt Bertone©, 2017 | Flickr

Article

Strange Worlds in Familiar Places

Clint Penick

vol 4 | 2017

Article:
Strange Worlds in Familiar Places

Author:
Clint Penick

There is a feeling among young biologists that in order to make big discoveries, you have to leave your home and travel someplace far away. You should save up for the most expensive plane ticket you can afford and fly to the Amazon or the Serengeti—for me, it was the Western Ghats of India. But the longer I've been working as a biologist, the more I find myself fascinated by species close at hand. Big discoveries don't just happen far from home. They can happen in your neighborhood, inside your house, or literally under your nose.

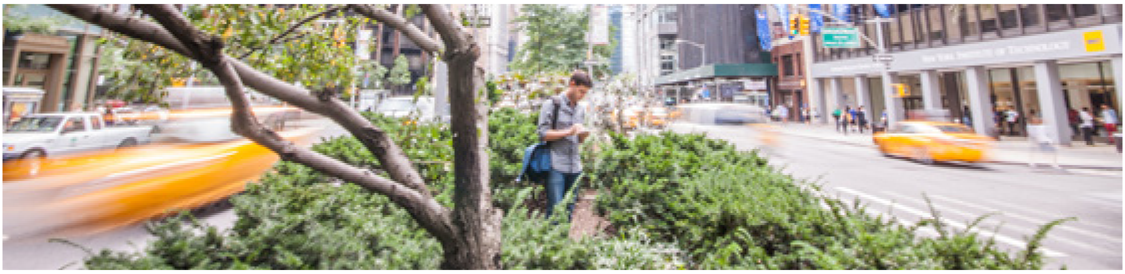
Clint Penick
Photo: Lauren Nichols© | YourWildLife.org, 2014 | Flickr

Take, for example, New York. It's the largest city in the United States with a population of 8.5 million. Nearly every square inch of New York has been walked over, mapped, landscaped, dug up, or investigated. There is literally a database cataloging every crack in the sidewalk, and it's updated every year. In a city that is known down to its sidewalk cracks, what could possibly be left to discover?

That is the question I asked myself when I first travelled to New York to do research. I study ants. What's great about ants is that you can study them pretty much anywhere. While there are 8.5 million people living in New York, there are 16 *billion* ants—that's 2000 ants for person. Ants in New York are not only abundant, but they're also diverse. My colleagues and I have identified over 40 species in Manhattan alone. A survey of Black Rock Forest, a relatively pristine habitat just north of the city, found only 33 species.

After working in New York for several years, we thought it would be interesting to compare the species we were collecting in the city with those that had been collected throughout the city's past. The American Museum of Natural History is located right next to Central Park and houses one of the largest and oldest insect collections in the world. But there was one problem: when we contacted the American Museum to ask if we could look through their collection, they realized that they didn't have a single ant collected from the city. Since Manhattan was first settled by the Dutch in 1609, we were the first to look.

Even though no one had studied the ants in New York before we arrived, it's safe to say that some of the city's earliest residents would have been familiar with pavement ants, my main study or-



ganism. Pavement ants have been living alongside humans for thousands of years, likely drawing back to the Roman Empire. They are originally from Europe but have followed humans around the globe wherever we have built cities in temperate regions. Pavement ants have even made it aboard the International Space Station.

Despite being one of the most common ants in the world, pavement ants barely have a valid scientific name. They were first described over 250 years ago by Carl Linnaeus—the father of modern taxonomy—and given the name *Tetramorium caespitum*. But a reinvestigation of the species in 2006 found that what was thought to be one species is at least seven. The species that made its way to New York is now known as *Tetramorium* "species E." Presumably species A-D prefer country life.

Each spring, pavement ants emerge from their nests to engage in what is perhaps the longest-running turf war in Manhattan. It's a common sight on Broadway where I work: piles of black ants fighting each other on the sidewalk. If you get down and look closely, you'll see pairs of ants grappling with each other. Even though pavement ants have a stinger, they never use them in these fights. Instead, they fight one-on-one, and very few ants die. Why? They're counting the workers in their neighboring colonies. If one colony realizes that they outnumber their opponent, then they expand their territory in that direction. Pavement ant colonies respect their territory boundaries all year until the next spring, when the fighting starts all over again.

For the most part, pavement ants go unnoticed by the city's residents. I have been working on pavement ants in Manhattan for five years, and not once has someone walking down the sidewalk stopped to ask me what I'm doing. This is in spite of the fact that I spend most of my time hunched over the pavement huffing ants through a mouth-powered vacuum that looks more like drug paraphernalia than a scientific instrument. But even though most New Yorkers don't pay much attention to ant biologists or the ants we study, that doesn't mean ants don't have an important impact on the city.

While most ants scavenge the forest floor looking for dead insects or sources of honeydew, pavement ants specialize on the food we drop on the sidewalk. My own work has discovered that pavement ants are among the city's best at exploiting human food sources. On Broadway alone, we estimate that pavement ants eat the equivalent of 60,000 hot dogs per year. Research by my colleague Elsa Youngsteadt, who

Clint Penick in New York
Photo: Lauren Nichols© | YourWildLife.org, 2014 | Flickr

Ant's view | Photo: Professor Bop, 2009 | Flickr cc


Home Bum Joe
NOAH

works at NC State University, found that ants are even better at scavenging sidewalk trash than rats in some parts of the city. Most New Yorkers can agree that having more ants in the city beats having more rats.

Our research in New York is ongoing, but we've already made discoveries that no one would have expected. After the first survey of ants in New York in 2006, my colleague Amy Savage, who is a professor at Rutgers University–Camden, found a species of ant in New York that no one had seen in North America before. After Amy's discovery, The *New York Post* dubbed it the "New York *Ruffi*-ant," and we are still learning about its biology and behavior. How did it get here? And what is it doing in the city? No one knows.

New discoveries don't just happen in cities like New York, but they can happen inside a regular home like that of Rob Dunn in Raleigh, North Carolina. Rob had been hosting a guest at his house who also happened to be a well-known insect photographer. One evening, the photographer ran upstairs from the basement exclaiming that he had made a discovery. Did Rob know, he asked, that he had cave crickets living inside his basement? Yes, cave crickets—those bizarre insects that live deep inside caves and rarely venture outside on their own.

A regular person might be terrified to learn that they had some strange race of troglodytic crickets living in their basement, but Rob was not a regular person. Rob is a professor at NC State University who studies the ecology of familiar environments. It was while working in Rob's lab that I first began studying the ants of New York. So, when Rob heard he had cave crickets living in his basement, his response was to ask everyone he knew to check their own basements. He reached out to friends and colleagues, and then he cast a wider net across Facebook and Twitter.

Within two weeks, Rob had developed a nearly complete distribution map of cave crickets in basements across North America—a task that would usually take months, if not years, for a scientist working on their own. The crickets, it turned out, were a species from Japan that had rarely been documented in the United States. How did Japanese cave crickets get here? And why did it take so long for someone to notice them? Rob wasn't sure, but it was a sign that there were likely other strange species hiding in our houses.

Most studies on house insects have focused on a small group of pests—roaches, termites, ants, bed bugs, clothing moths, and flour beetles. After discovering cave crickets in his basement, Rob decided it would be worth looking into what other insects might be living in our houses, especially those that we usually don't notice. Rob teamed up with two other scientists, Michelle Trautwein and Matt Bertone, both of whom are experts on flies. Flies, of course, are also common in houses, and Michelle bet they would find more species of flies in houses than anything else.

Starting with that bet, the team began looking for people who would let a team of entomologists crawl around their houses to look for bugs. They thought it might be difficult to find enough

House fly (*Muscidae*)

Photo: Matt Bertone©, 2014 | Flickr

House centipede | Photo: brian.gratwicke, 2015 | Flickr cc

willing participants to get a good sample size, but they misjudged—many more people signed up to have their houses sampled than the team could manage. In the end, they settled on 50 houses, and instead of focusing on insects exclusively, they decided to collect all arthropods, which includes spiders, centipedes, or anything with an exoskeleton.

"We think of our homes as sterile environments," said Matt, "but they're not." In the average house, the team found 200 arthropods and up to 128 different arthropod families. For comparison, the average college-level entomology course requires students to find just 70 families over an entire semester. Who would have thought a student could find all of the insects they needed within their own house? There were only five rooms out of 554 rooms they sampled that did not contain any arthropods. And even more surprising was that they found relatively few species we think of as pests. Termites, fleas, and German cockroaches were exceedingly rare, and they found no bed bugs.

Like pavement ants, some of the most common household insects have been living with humans for centuries, or even millennia. Flour beetles have been found in stored grain from ancient Egyptian tombs dating back to 2500 BC, while camel crickets are the only insect known to be featured in cave paintings. "We share our space with many different species, most of which are benign," said Matt. "The fact that you don't know they're there only highlights how little we interact with them."

Some of the species that Matt did find in houses were incredibly bizarre. Take, for example, the house centipede. "I used to keep house centipedes as pets when I was younger," said Matt, "but my mom was terrified of them because they're so leggy." Unlike other centipedes, house centipedes have compound eyes and move extremely fast to run down prey. They feed on common house insects, such as flies, bed bugs, termites, and cockroaches. They can devour several insects in just a few minutes. While they're in the midst of eating one insect, they can catch and hold another with their many legs to save for later.

Another predator that lives inside houses is the spitting spider. "I had only read about spitting spiders in books when I was younger, so I was excited when I finally found one," said Matt. Spitting spiders catch their prey by spitting a venomous silk. In high-speed footage, the spiders can be seen swaying back and forth as they spit their venom-laced silk in a crisscrossed "Z" pattern. The silk is actually shot from their "chelicerae," which are appendages that function as spider jaws. The whole attack sequence is over in a 1/700th of a second. Spitting spiders are actually related to brown recluses, but they don't pose a threat to humans. Even brown recluses, said Matt, don't deserve the fear that most people give them. "Brown recluse bites are not very common, and most people who get bitten heal up and have no issues without medical treatment."

The most diverse group of arthropods in houses were the flies, which Michelle had predicted, but the most common arthropods were carpet beetles. As their name suggests, carpet beetles used to destroy carpet when we used wool before modern synthetics. Now, carpet beetles mainly feed on hair, dead insects, or other debris found in houses. "They were just everywhere,"

Varied carpet beetle (*Dermestidae*) | Photo: Matt Bertone©, 2014 | Flickr

said Matt. “We would collect dead insects, and when we’d get back to the lab, we’d find a live carpet beetle living inside a fly, eating it from the inside out.” The larvae are covered in specialized hairs that serve as protection similar to porcupines. Once, when Matt tried to feed a carpet beetle larva to a spitting spider, he got to see the hairs in action. “When the spider tried to attack the carpet beetle, it got a mouth full of hairs and the larva got away,” said Matt. The adults feed on pollen and flower nectar, and they leave houses in spring to search for flowers outdoors.

We often think of homes as comfortable and safe environments, but for arthropods, that’s not always be the case. Homes receive no rain and can be as dry as a desert. North Carolina has a lot of smoky brown cockroaches, for example, but they’re not one of the typical pest species. When they get into houses, they usually end up dying because they’re not able to find the food and moisture they need to survive. It’s the same for most centipedes. Typical soil-dwelling centipedes live in high-humidity environments, and they end up drying out indoors rather quickly. House centipedes and German cockroaches, on the other hand, do well in dry environments and are common in homes.

Homes contain microhabitats that are as hot, acidic, basic, or salty as anywhere on Earth. Amy Savage, who worked with me on New York ants, studied “extremophiles” that live in houses. Extremophiles are microbes that are adapted to extreme habitats, such as hydrothermal vents or chemical springs. Instead of travelling to the bottom of the ocean, Amy searched for extremophiles inside ovens, dishwashers, washing machines, freezers, and cat litter boxes.

In all of these places, Amy found life. Living inside someone’s house, Amy found bacteria from the genus *Brevundimonas*, which are thought to be one of the few organisms that could survive the low temperatures and ionizing radiation of Mars. Inside someone’s dishwasher, Amy found *Helcococcus*, which are bacteria that can eat dish detergent. Another genus, *Sejongia*, was living inside someone’s freezer but has been more commonly found in Antarctic ice. If there are regions of Antarctica that we know better than our own homes, then what else have we not discovered?

Megan Thoemmes had recently graduated from college when she asked Rob Dunn for a job. In response, Rob posed a challenge: if Megan could find five face mites within a week, then she was hired. Megan agreed, but she had a few questions. What did a face mite look like? How would you go about catching one? And, should she be concerned about whether or not her face was covered in mites?

Face mites were first discovered in 1841 by Frederick Henle. Henle was a German anatomist who spent long hours working with cadavers and giving names to our internal parts (he is perhaps best known as the namesake for the “loop of Henle,” part of the kidney that helps us concentrate our urine). In the midst of his work on human anatomy, Henle found a strange organism living inside a gland in someone’s ear canal. Rather than speculate what this organism might be, he simply reported it for others to study.

Face mite (*Demodex*)

Photo: Rob Dunn Lab©, 2014 | http://robdunnlab.com/projects/meet-your-mites/

Megan Thoemmes sampling E.O.Wilson | Photo courtesy of Clint Penick

Another German scientist, Gustav Simon, found the same organism a year later while looking at acne spots under a microscope. The organism had a small body with eight legs and a long, fat tail. Simon wasn't sure if it was an animal or not until he saw it move under the microscope. He promptly identified it as a mite. Finally, the mite was given a formal scientific name the following year, *Demodex folliculorum*, by famed scientist Richard Owen, who is better known for coining the term "dinosaur."

You might think that the discovery of a new animal living on the human face would have inspired a flurry of research, but new research came slowly. It took nearly a hundred years before a Russian scientist discovered that there was actually a second mite species living on the human face—*Demodex brevis*, a shorter, stumpier cousin to *D. folliculorum*. But for those researchers who looked for mites, they almost always found them. Face mites were more common on adults than infants, and they were present on every ethnic group that scientists investigated—from white Europeans to Australian aborigines.

All of this gave Megan a pretty good idea about what she was looking for, but she still didn't know how to find them. Because the mites lived deep inside our pores, they are not easy to collect. They spend most of the day hiding and only come out to mate at night (yes, mites have sex on our faces while we're sleeping). Past researchers had primarily sampled mites from cadavers. The great thing about cadavers is that you can scrape them as hard as you want. But how do you collect mites from deep inside the pores of a living person? And who is going to let you scrape their face after you tell them you're looking for mites?

Megan began asking everyone she knew if she could try to find mites on their faces. "I probably sampled 100 people during that first week until I finally found one," said Megan. "And the first one I found was from my own face." After she found that first mite on her face, Megan says she didn't sleep for four days. "Even though I only found one mite that week, though, Rob gave me the job anyway."

Megan began hosting "Meet Your Mites" events at the NC Museum of Natural Sciences, and her mite scraping technique improved. She once caught a mite in the process of giving birth. "Their eggs are one-third the size of their body," said Megan. But still, she was only finding mites on one out of every six people. If Megan was really going to study face mites, then she needed a new technique.

That's when Megan and her team decided to look for mite DNA instead of the mites themselves. "When we started sampling DNA," said Megan, "that blew the project wide open." Face mites are strange in that they have no anus. They continue to eat until they die, and then their dead bodies begin to decompose and release their feces—and their DNA—across your skin. Knowing this is one reason why it took Megan four days to sleep again after finding her first face mite.

Instead of finding mites on only some people, Megan and her team found mite DNA on every adult they sampled. And because they sequenced mite DNA, they could also study relationships between mites and the people they inhabited. Husbands and wives had more similar mites than strangers, suggesting couples share mites over time. But the strongest similarity was

Face mite (*Demodex*)
Photo: Rob Dunn Lab©, 2014 | http://robdunnlab.com/projects/meet-your-mites/

between parents and their children. Even people who had moved to the United States from abroad still maintained their native mite populations over multiple generations. The history of our mites can therefore tell us something about our own history.

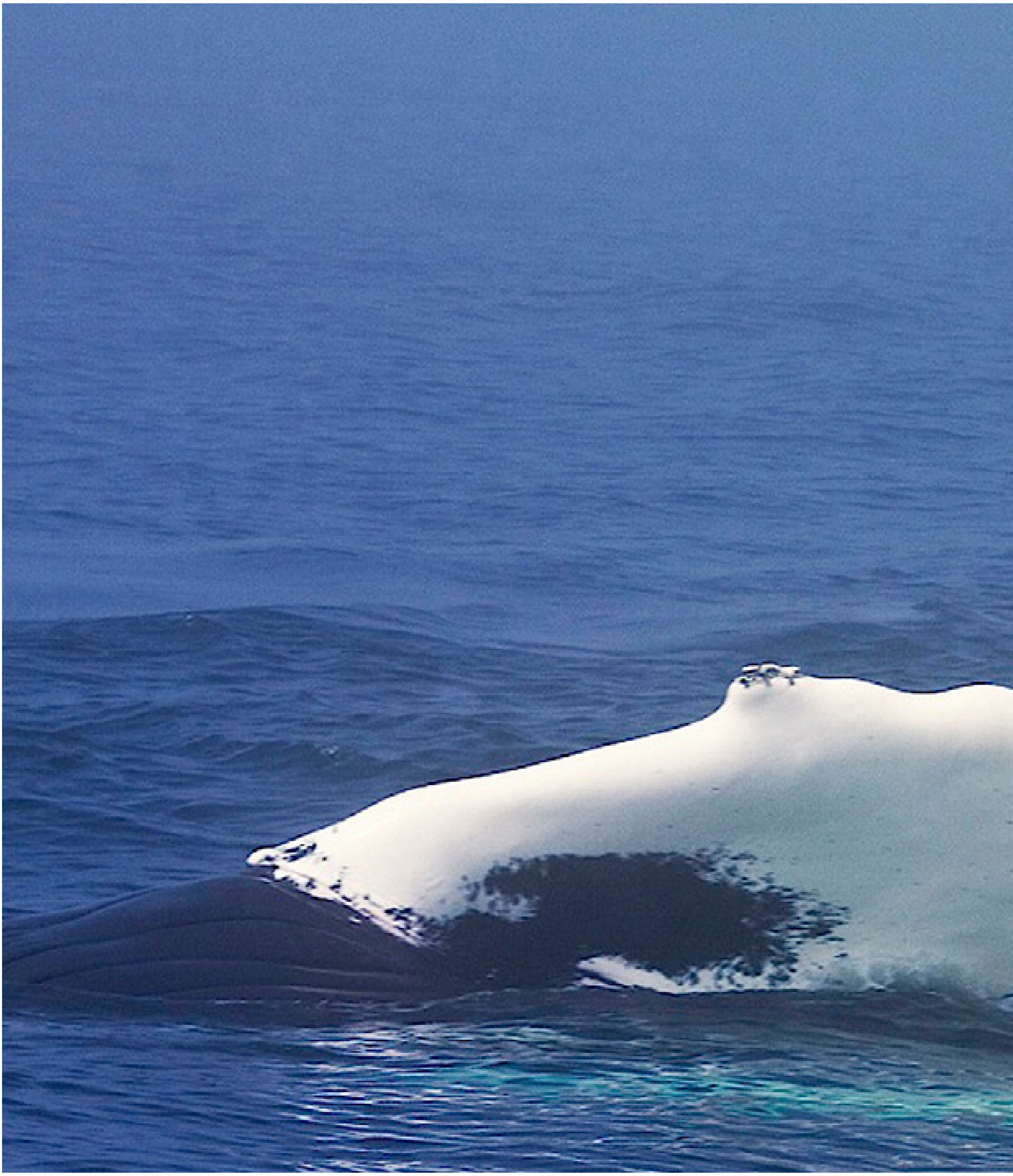
Over time, Megan became more comfortable with her mites. "I was horrified at first, but the more I studied them, the less grossed out I became," said Megan. "Now I kind of like my mites." Face mites have been associated with some skin conditions, like rosacea, but it's unclear whether or not they actually cause these diseases. As far as we know right now, they don't cause any harm. And we're not the only animals that have them. Most mammals have mites, and each mammal seems to have at least one of their own *Demodex* species.

There are still many questions to answer about face mites. For instance, no one knows exactly how many mites are on a single person. "It's safe to say that we're harboring thousands," said Megan, "but we don't know for sure." We also don't know all of the regions on our bodies that mites inhabit. They are common on the face, genitals, and mammary tissue, but they could be other places that have yet to be sampled. But what's even more surprising is that we might not know all the mite species that live on us. Only a small fraction of the world's people has been sampled for mites, and there is evidence that humans could have three mite species instead of just two. Even on our own bodies, there is still much that we do not know.

For the first time in human history, there are more people living in cities than anywhere else. There are great benefits to city-living—cities are often greener and more efficient at serving public needs than communities in rural areas. But there are also downsides. People living in cities no longer experience nature in the way that our ancestors had throughout most of our history. Nature has become a place we visit on vacation or experience through television documentaries. We are more likely to think of those species that we encounter in our daily lives as pests or simply uninspiring.

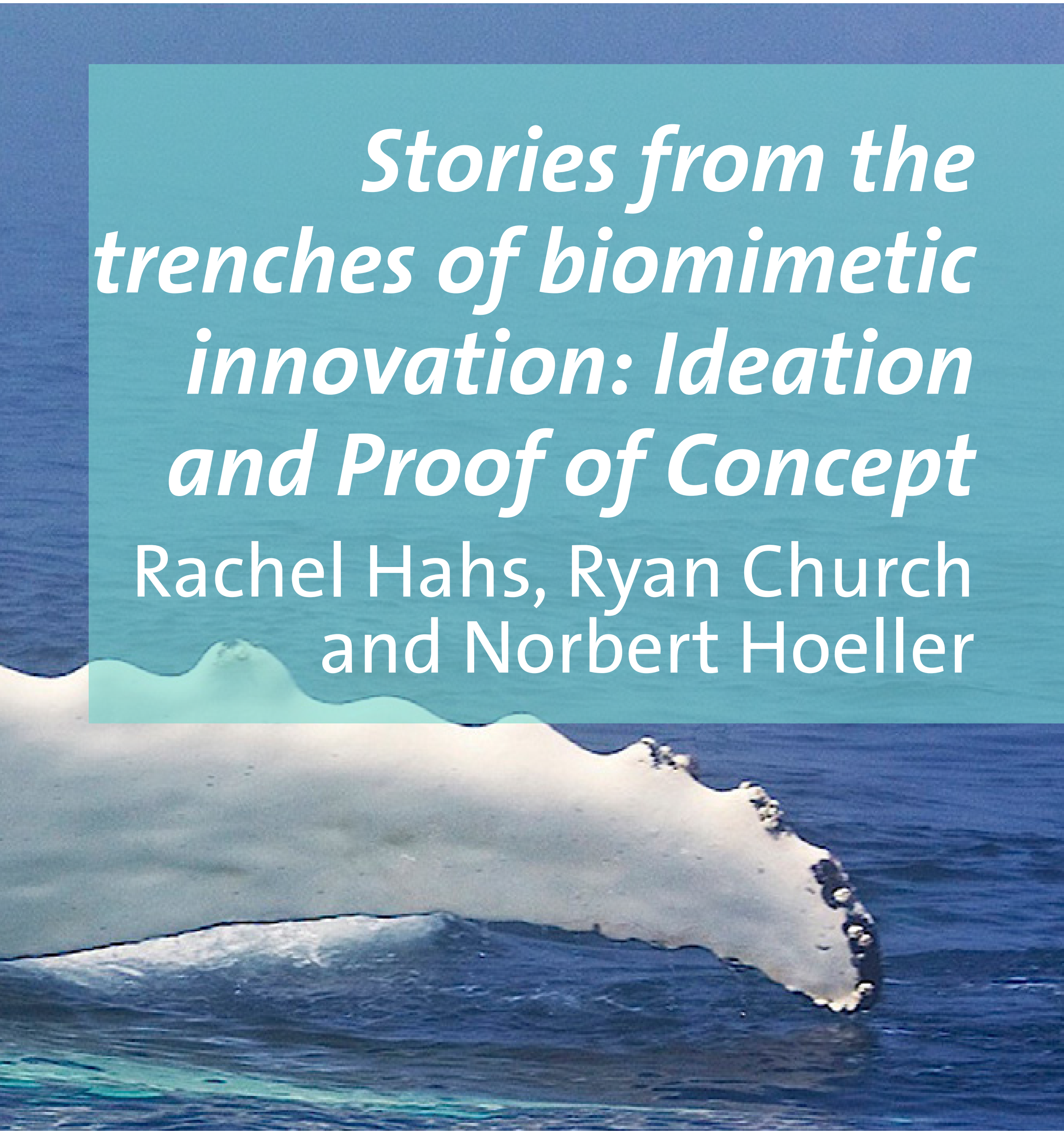
Herein lies what Rob Dunn calls the "pigeon paradox." The charismatic species we learn about through nature documentaries are under threat, and conservation efforts require increasing public support. People are more likely to take conservation action when they have had direct experiences with nature. But because most people live in cities, those experiences will be through contact with urban species. This is the pigeon paradox: that the fate of the world's rarest and most charismatic species depends on how we interact with the world's most common—pigeons, pavement ants, carpet beetles, and face mites.

While these species might be common, they are not uninspiring. We do ourselves a disservice to ignore them. ×



Humpback Whale - *Megatera novaeangliae*

Photo: Gregory "Slobirdr" Smith, 2010 | flickr cc



Stories from the trenches of biomimetic innovation: Ideation and Proof of Concept

Rachel Hahs, Ryan Church and Norbert Hoeller

Biomimicry is one of the hardest disciplines to practice, in part because at first glance it seems very easy. But the practice of biomimicry wears a cloak of camouflage. While innovators might discover solutions using biomimicry that promise to revolutionize an industry, the path to getting to market, let alone starting a revolution, is anything but obvious. Examples of successful, commercially viable biomimicry products or services are limited in part because innovation itself is hard, and innovation developed using biomimicry can face unique challenges and opportunities.

The risks associated with biomimetic innovation can lead to failure in the face of seemingly unprecedented promise. If the biomimicry process is managed well, however, the potential benefits can be leveraged to add tremendous upside. Understanding the risks/rewards associated with biomimetic innovation can lead to stronger value propositions and more sustainable business models.

Regardless if an innovator employs biomimicry to develop the value proposition, an understanding of the market and end customer cannot be shelved for later. The innovator must be aware of the dangers posed by the entrepreneurial "Valley of Death", the pre-commercialization phase of any entrepreneurial venture before it starts generating meaningful revenues, or risk running out of cash.

This is the first in a series of three articles that will explore the commonalities among biomimetic success stories, while also looking at failures to understand why certain biomimetic innovations make it, while others don't. The answers are far from obvious. The articles will follow four case studies through the following three phases of development:

- Ideation and proof of concept
- Developing a viable business model and market entry strategy
- Commercialization and market impact

The case studies cover a variety of inspiring innovations from products and services to systems-level interventions. We hope to provide the reader with an understanding of some of the unique challenges that biomimicry innovators face, including lessons learned from mistakes as well as examples that demonstrate how hurdles have been overcome to achieve success. We hope this information adds critical insight into the tools required in a biomimicry innovator's toolbox to successfully navigate towards commercially viable products.

This article will examine the specific drivers that a start-up faces when it decides to add a biomimetic design approach, starting with the moment of inspiration all the way to the first prototype.

Wind Energy

Originating at least two thousand years ago for grinding grain, wind power evolved to pump the polders of the Netherlands and prevent flooding, to the present industrial giants that power our homes and businesses. Back in the 16th century, windmills had four rotors, each with a wooden

Fraser Island Whales | Photo: Michael Dawes, 2008 | Flickr cc lattice panel covered in stretched canvas fabric. These windmills operated on the principle of drag due to the wind hitting the rotor with a glancing blow. Today, most wind turbines have three rotors, constructed from composite materials that can withstand the forces involved, and operate on the principle of lift, where the pressure difference between each side of the airfoil creates torque, and thus power.

Today, technology advancements drive the performance and the economics of wind power. The industry has come to the point where even half a percentage point in efficiency can make the difference in a competitive tender process for new procurement. Biomimetic design has started to play a role, with large companies like Siemens branding some innovations as bio-inspired. Sadly, as with many large industrial companies, 'biomimicry' and related concepts are sometimes used more by marketing departments than research departments. There are some companies, typically small startups, who have used a bio-inspired approach in R&D. We will examine these drivers through the experiences and outcomes of two players in the wind industry: WhalePower and BiomeRenewables.

WhalePower

Dr. Fish runs the Liquid Life Lab at West Chester University (https://www.wcupa.edu/sciences-mathematics/biology/fFish/research.aspx), and has a keen interest in biomimetics and the three-dimensional geometry of biological control surfaces, including the stability, maneuverability and jet propulsion mechanisms of aquatic animals. Around 2000, Dr. Frank Fish was intrigued by a carving of a humpback whale that showed tubercles, or bumps, on the leading edge of the flippers. He understood that humpback whales can change directions quite quickly - more so than other large whales.

Computational fluid dynamics (CFD) analysis by Dr. Phil Watts of Applied Fluids Engineering (http://www.appliedfluids.com/) indicated humpback whales can adjust the inclination of their flippers to a greater degree than other whales. The tubercles were allowing for increased inclination angles without the flow separating, creating drag and stalling. Dr. Fish and Dr. Watts, patented the idea of a scalloped leading edge on a generalized wing (https://whalepowercorp.wordpress.com/the-science/).

With this initial CFD completed, the next step was to investigate the detailed process using a prototype and determine the applicability of this discovery in industry. With Dr. Laurens Howle, a fluid-dynamicist from Duke University (http://mems.duke.edu/faculty/laurens-howle), they prototyped the new concept of a scalloped wing and tested it at the US Naval Academy's wind tunnel. These experiments compared airfoils in the shape of a humpback's flipper, with and without tubercles. This presented a challenge as the original inspiration was optimized for an aquatic environment. Studies in air, with a density 800 times less than water, would require an in-depth knowledge of the physical mechanisms at play.

The researchers choose wind tunnel testing because the aviation and the wind industry were growing rapidly at the time with expanding funding opportunities. With aviation, especially military aircraft, increased maneuverability could be a great opportunity, but the application of tubercles would need to be translated with great care. A lack of maneuverability of wind turbine blades does not affect this industry - quite the opposite.

With the study compete, Miklosovic, Murray, Howle, and Fish (2004) reported no difference in lift when the blade's inclination (angle of attack) was inclined below 10 degrees, a decrease in performance between 10-13 degrees, and an increase in lift between 13-20 degrees. This suggested applications for tubercles in high-performance lifting surfaces, such as autonomous aircraft and underwater vehicles. These results were corroborated by a team from Harvard University led by Ernst van Nierop (2008). The tubercle technology was transferred to WhalePower Corporation for commercialization. The decision to focus on the wind industry, where blades are never inclined more than 10 degrees, would present challenges in the next phase of development.

The PowerCone - BiomeRenewables

Ryan Church founded BiomeRenewables in 2015 to develop biomimetic renewable energy technologies by combining his background in biological research and science with business experience gained through an MDes (design-oriented MBA) degree. He attended a wind conference in Dusseldorf, Germany, with two ideas in his head for how he could improve the efficiency of wind turbines. The first was to put serrations on the leading edge of the blade, mimicking the fimbriae serrations on an owl's wing that helps to reduce noise by breaking up turbulent air into micro-turbules (a concept slightly different than that of Dr. Fish and WhalePower). The second idea was to create a specialized winglet for wind turbine blades that mimicked the raked wingtips of a hawk.

While at the conference, two researchers from the Danish Technical University (DTU) mentioned the problem of rotor-root leakage (RRL), caused by a low-pressure area around the hub, which can represent 5% of the direct swept area of the rotor. Due to the low resistance to flow, the air tends to rush in towards this area, impacting turbine performance. Church knew a structure needed to be placed at the center of the turbine, but what geometry should the structure take on, and what phenomena should it be based on?

Trying different paddle strokes while canoeing led Church to observe energy dissipation, vortex creation and turbulence formation in nature. Combining his observations with research into the Navier-Stokes equation, Karman vortices, Kolmogorov's 5/3 Power Law, and Richardson energy cascades, he developed time-dependent energy transfer (TDET), a new concept in physics and fluid dynamics: for a given fluid, there can only be a certain amount of force put into it over a given timeframe before turbulence will result. The nosecone for the high-speed Shinkansen trains uses TDET intuitively to reduce sonic booms when the train enters tunnels. The result was an applied mathematical threshold equation (Church, pending publication).

Church began thinking about a structure that would obey the laws of TDET and correct the problem of RRL in wind turbines. Inspired by observations of falling maple keys (samaras), he developed a tri-bladed structure that would fit in the center of a modern wind turbine, in the re-

Humpback Whale *Megaptera novaeangliae* | Photo: Sylke Rohrlach, 2014 | Flickr cc

gion affected by RRL. The challenge was to create an inexpensive experiment that would provide a proof-of-concept. Using a small functional wind turbine model, desk fan, and wind tunnel he made of plywood, he tested dozens of different biomimetic nose cone structures, using a volt/amp meter to measure performance differences. A few designs stood-out - they matched the natural model of the maple key in relation to its geometry, the TDET principle and Church's equation that predicted the optimum length scale. In these simple models, the biomimetic nose cone achieved a 30% increase in performance.

The result was the PowerCone (https://zqjournal.org/editions/zq16.html p. 88). Church applied for a patent, started a rigorous testing campaign to determine the impact in larger scale models, and launched into a journey that will be described in the next two articles.

Green Chemistry

We hear about the dangers of formaldehyde and flame retardants in our homes, bisphenol A (BPA) and phthalates used in the plastics for baby products and food packaging, and the long-term effects of petroleum-based plastics in our environment that choke marine life and form huge toxic gyres in the oceans. Each of these issues are rooted in the challenges related to the raw materials we use to create chemicals and the energy-intensive processes we rely on to manufacture them. So what alternatives do we have?

For years some chemists have been looking to nature for green chemistry blueprints to develop and manufacture non-toxic and environmentally benign chemicals for a wide range of materials and products. In contrast to conventional modern industrial chemistry, nature does chemistry at ambient temperatures using water as a solvent, self-assembling molecules from the ground up with a small subset of the periodic table. At the end of its life, the material then is broken down into benign, life-friendly constituents, to be recycled into the fabric of life again.

Molecular Heat Eater, Trulstech, Inc.

In the late 1990s, Trulstech, Inc., an innovation company out of Sweden headed by Mats Nilsson, was contacted by Procter & Gamble about developing an eco-flame retardant that could be applied by consumers in their homes. Nilsson's interest was piqued. How was it that no one had developed an alternative chemical structure and approach to flame retardants given the substantial health concerns posed by existing flame retardants (http://greensciencepolicy.org/topics/flame-retardants/#POP)?

The Trulstech team was a diverse group of innovators with backgrounds in physics and chemistry with significant experience in developing solutions for the communications industry, but no experience in the flame retardant industry. They conducted a year of intensive research on existing approaches to flame retardants. Nilsson and his team decided to address the two challenges of migration of flame retardants into the environment and toxicity. The team focused on developing a non-toxic product concept that was chemically bonded to the host material and initiated a chemical reaction in the presence of fire. This approach conflicted with P&G's search for an inert (not chemically bonded) flame retard-

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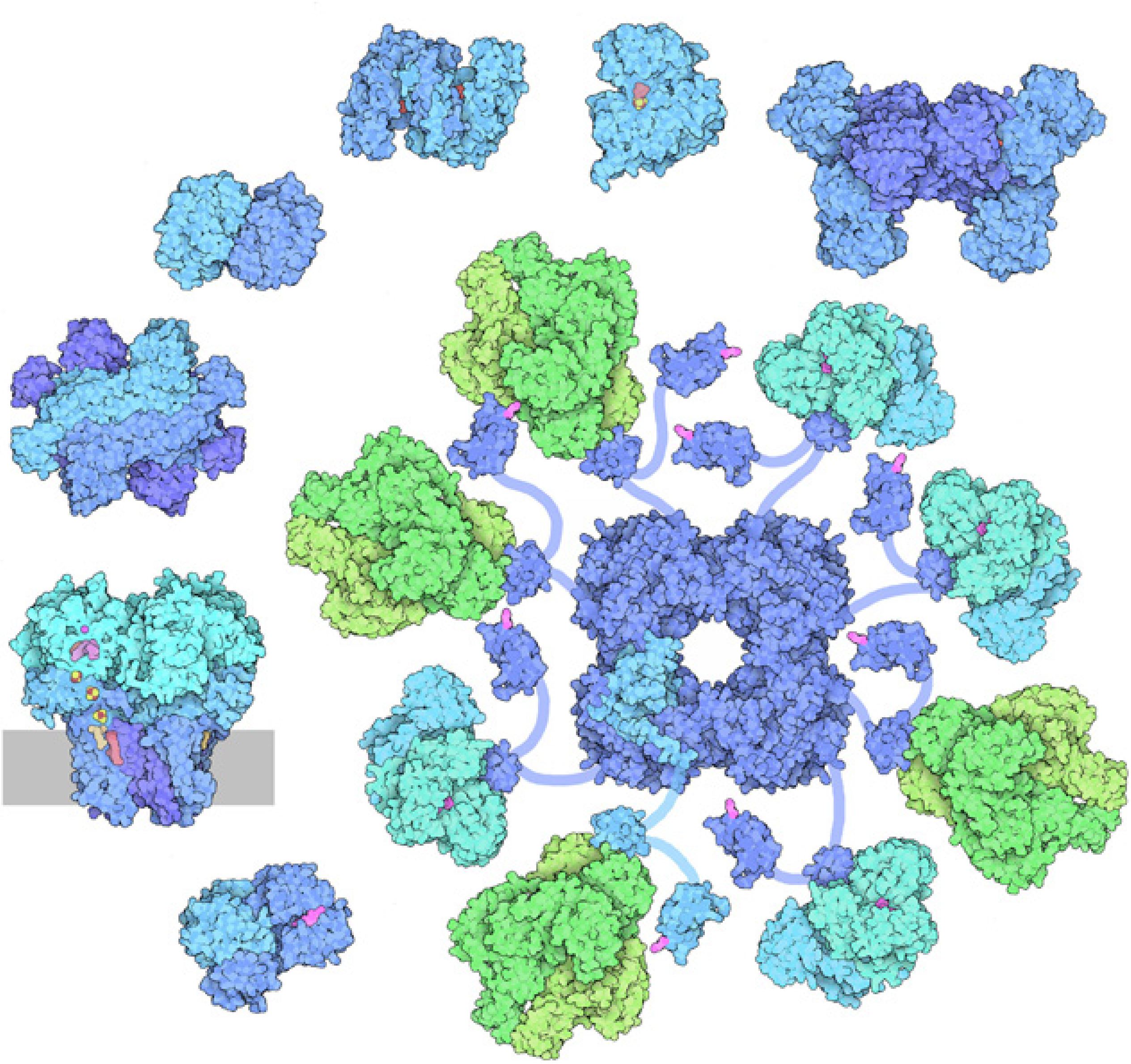
Article:
Stories from the Trenches

Authors:
Ryan Church, Rachel Hahs, and
Norbert Hoeller



Enzymes of the citric acid cycle.

Graphics: David S. Goodsell and the RCSB PDB | CC-BY-4.0

ant, and P&G lost interest in the Trulstech effort. However, given the potential upside, the team continued to brainstorm new approaches to the chemistry behind flame retardants.

Inspired by a team member's question about how the body handles both high and low pH chemicals without damage during digestion, Nilsson reached out to a friend who was a microbiologist at the Nobel Institute to learn more about how the body handles heat at a cellular level. He realized that cellular respiration is basically a combustion process, and a cell's strategy for handling the process was a step-by-step guide to a new approach that both cools and extinguishes heat. The team isolated the relevant part of cellular respiration known as the Krebs or citric acid cycle as the natural model they would try to emulate. But Nilsson's team didn't stop there - the team challenged themselves to innovate a chemical structure that was completely harmless while still maintaining both cooling and extinguishing properties.

In a self-funded effort, the team experimented with developing new chemical structures. Within seven months, their experimentation resulted in what Nilsson called a lucky result - a successful first-generation proof of concept of a completely non-toxic flame retardant, chemically bonded to a host material, that both cools and extinguishes in the presence of fire, mimicking the Krebs cycle process and life-friendly chemistry.

The Molecular Heat Eater® (MHE® https://www.trulstech.com/products-1/mhe-ff-%26-pff) family of flame retardants uses food-based raw materials, such as those found in grapes and flour. Each MHE® flame retardant is modified according to the host material properties, so that it decomposes as a result of the chemical reaction triggered by a fire, releasing only water vapor (which cools) and carbon dioxide (which displaces the fire's fuel - oxygen), and trapping remaining host materials in an intumescent char. MHE® is completely non-toxic when used in approved quantities during manufacture, processing, useful life, and decomposition, representing a paradigm shift in the flame retardant industry.

The Trulstech team's success in creating a novel and completely non-toxic flame retardant was the result of curiosity and an openness to ask about, search for and pursue completely unconventional approaches to putting out fires; a team with diverse backgrounds which enabled them to translate the natural model into flame retardant chemistry; a commitment to addressing health risks posed by conventional flame retardants; and, existing company resources that allowed them to pursue the research and development of the product.

Nilsson and his team were now ready to try to break into the flame retardant market. However, despite the accolades MHE® received for the non-toxic nature of their product (http://www.trulstech.com), with no experience in the flame retardant industry to inform their approach, the Trulstech team would struggle to gain a foothold in the market.

Built Environment

Adapting to Rising Water Levels

Severe flooding has been a recurring problem throughout history – floods and deluge myths are common in cultures across the world. In the early days, humans had no choice but to adapt, building houses on high land or stilts. Flooding is destructive and constructive – the silt carried by annual Nile floods maintained the fertility of the soil. Flooding can also naturally raise ground levels. The Tiber flooded Rome as late as 1937, depositing enough silt that much of Rome is constructed on 5 to 10 meters of fill, with buildings successively constructed on top of older buildings. It is not unusual to see ancient arches and tops of columns poking up through the floor of churches.

Our growing technological capability has enabled us to constrain and control water through dikes, levees, locks, dams and seawalls ('hard' infrastructure). The Dutch have been reclaiming land and pushing back the sea for over 800 years. The Netherlands is a delta where several European rivers empty into the North Sea. Strong coastal defenses have been built to protect low lying areas from high seas. The disastrous flooding from the North Sea in 1953 spurred a major project to strengthen defenses.

Although effective, it fostered a shift in thinking that underscored the dangers of water and a greater reliance on 'hard' infrastructure for safety. However, by the 1990s, the Dutch were experiencing flooding "from the rear" due to rising river levels. Heavy rainfall and snowmelt increased river flows to the point that some dikes were nearly breached in 1993 and 1995. A trend toward 'canalization' of rivers exacerbated the issue by increasing local flow rates which then shifted flooding downstream.

'Hard' infrastructure built to protect human development from flooding is effective until it fails, often with catastrophic consequences, such as the 2005 New Orleans floods from Hurricane Katrina and the storm surge from Hurricane Sandy that flooded New York City in 2012. Continually strengthening and raising the dikes became increasingly costly, not only in economic terms but also through destruction of both the natural and human landscape. Flood defenses also isolate communities from the water, contributing to people either ignoring water or fearing it.

The Netherlands government launched the "Room for the River" project (https://www.dutchwatersector.com/news/room-for-the-river-programme) in 2006 to help the landscape cope with increasing volumes of water through 'soft' infrastructure that works with natural forces to accommodate rather than constrain water. The goal was not only to protect the four million residents of low lying areas but also increase space for natural, recreational, and economic activities. A variety of measures were used to provide greater space for water storage, including lowering dikes and moving them away from the rivers to expand floodplains, as well as traditional building methods such as as 'terp' mounds" that raised settlements above flood levels.

The "Room for the River" project is part of a broader "Building with Nature" initiative that sprung from a Dutch decision in 1990 to implement solutions that were "soft where possible, hard where necessary" (https://www.dutchwatersector.com/news/building-with-nature). It assumes humans are part of nature and emphasizes the dynamic interaction between natural, engineered and societal systems. The key factors are resilience, long-term sustainability, adaptability, multi-functionality, integration, and economic viability. "Building with Nature" incorporates strategies for dealing with uncer-

The Netherlands, Deventer, June 28, 2016. High water in the rivers Waal, Rhine and IJssel. “Room for the River” shows that the water can find its way without causing any nuisance. | Photo: https://beeldbank.rws.nl, Rijkswaterstaat , Ruimte voor de Rivier / Werry Crone

De-polderisation (aerial photo) Luchtfoto Noordwaard 2016 | Photo: https://beeldbank.rws.nl, Rijkswaterstaat / Your captain

tainty - our knowledge of how complex natural, technical and social systems interact and evolve remains rudimentary, requiring long-term trans-disciplinary research and stakeholder engagement. Lastly, "Building with Nature" projects create opportunities for encouraging ecosystem goods and services, where humans benefit directly and indirectly from ecosystem functions.

The concept of "Nature-Based Solutions" (NBS, https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions) provides a broader context for "Building with Nature" by exploring how working with nature can help us adapt to climate change and mitigate its impacts. NBS is being promoted by the European Commission and the International Union for Conservation of Nature (IUCN) as an approach to sustainable development, with funding for NBS projects provided through Horizon 2020. NBS takes a holistic approach that recognizes the complexity of socio-ecological systems and the interrelationships among environmental, social, and economic aspects. Key elements include dealing with uncertainty, engaging multiple stakeholders, applying multi-/trans-disciplinary knowledge, developing common understanding, and engaging in long-term monitoring and evaluation.

A fundamental challenge facing "Building with Nature" solutions is that they often replace known flood defenses that perform predictably (up to the point of failure) with methods that have few precedents, involve significant uncertainty and deliver results in subtle ways. We tend to underestimate the risks of what we know, and overestimate the risks of things we do not understand. We also associate 'hard' infrastructure with progress, while 'soft' infrastructure seems like a return to bygone times.

Our limited understanding of socio-ecological systems requires a significant investment in research, modelling, and monitoring. 'Soft' infrastructure is not a 'build and forget' solution – it evolves over time and may require periodic adjustments. The ongoing collaboration of research and practice deepens our understanding and encourages adaption to changing conditions in a proactive fashion.

'Soft' infrastructure tends to deliver multi-functional benefits, which is both a strength and a challenge. Any one benefit may be insufficient to justify the costs given the level of uncertainty. The viability of the project depends on engaging multiple stakeholders who have diverse interests. A clear communication plan covering all aspects of the project is required, along with sufficient time to establish a common understanding and build confidence. As in any project, there are invariably winners and losers, requiring trade-offs between stakeholders. However, many of the issues can be identified and resolved in a proactive manner early in the project. In contrast, failures in 'hard' infrastructure can overwhelm our ability to respond. A collaborative and open approach can help build strong public support that extends throughout the life of the project.

The "Room for the River" project expanded the flow capacity of the Rhine river from 15,000 m3/sec in 2007 to 16,000 m3/sec at the completion of the project in 2015, increasing the country's resilience to flooding while enhancing cultural and ecological aspects. The next article will explore how the concepts of working with nature were implemented in the Netherlands and other countries.

Observations

These case studies cover a wide range of innovations that to date show varying degrees of commercial promise. Although they share the challenges and opportunities of any innovation, some of the case studies suggest that biomimetic innovation may have unique attributes.

1. It is essential to get the science right, particularly when dealing with biological knowledge. In addition to the challenges of communicating across disciplines, biological information is often not in a format that is readily usable in a technical context, and thus lateral thinking and associative memory is an asset. The context of the natural model or phenomenon may be very different from the target domain, which can further inhibit a successful knowledge transfer. Successful biomimetic innovation often benefits from repeatedly returning to the biological inspiration to validate assumptions and resolve challenges.

2. It is important to understand the technical as well as business expectations and requirements of the target market during ideation and development of the proof of concept. Having a clear target market in mind early in the project can focus research efforts, which in turn may help redefine the problem to be solved and fine-tune the solution to meet market needs. Anecdotal evidence suggests that some biomimetic innovators, driven by the potential power of the biomimetic concept to create transformational change, want to perfect their solution before exploring viable business opportunities. However, this approach may make it harder to pivot in response to market feedback at later stages and thus delay exit from the "Valley of Death".

3. Multi-disciplinary collaboration is hard in any situation. Differences in language and approach between biology and engineering can exacerbate the problem during the ideation and proof of concept stage, especially if some participants do not 'get' biomimicry. Successful biomimetic innovators recognize both the challenges and opportunities for collaboration, leveraging diversity and working to develop a high level of engagement and commitment early in the project.

The next article in this series will follow the course of the four case studies through developing business models and market entry strategies. ×

Article
Stories from the Trenches of Biomimetic Innovation

Authors:
Ryan Church, Rachel Hahs, and Norbert Hoeller

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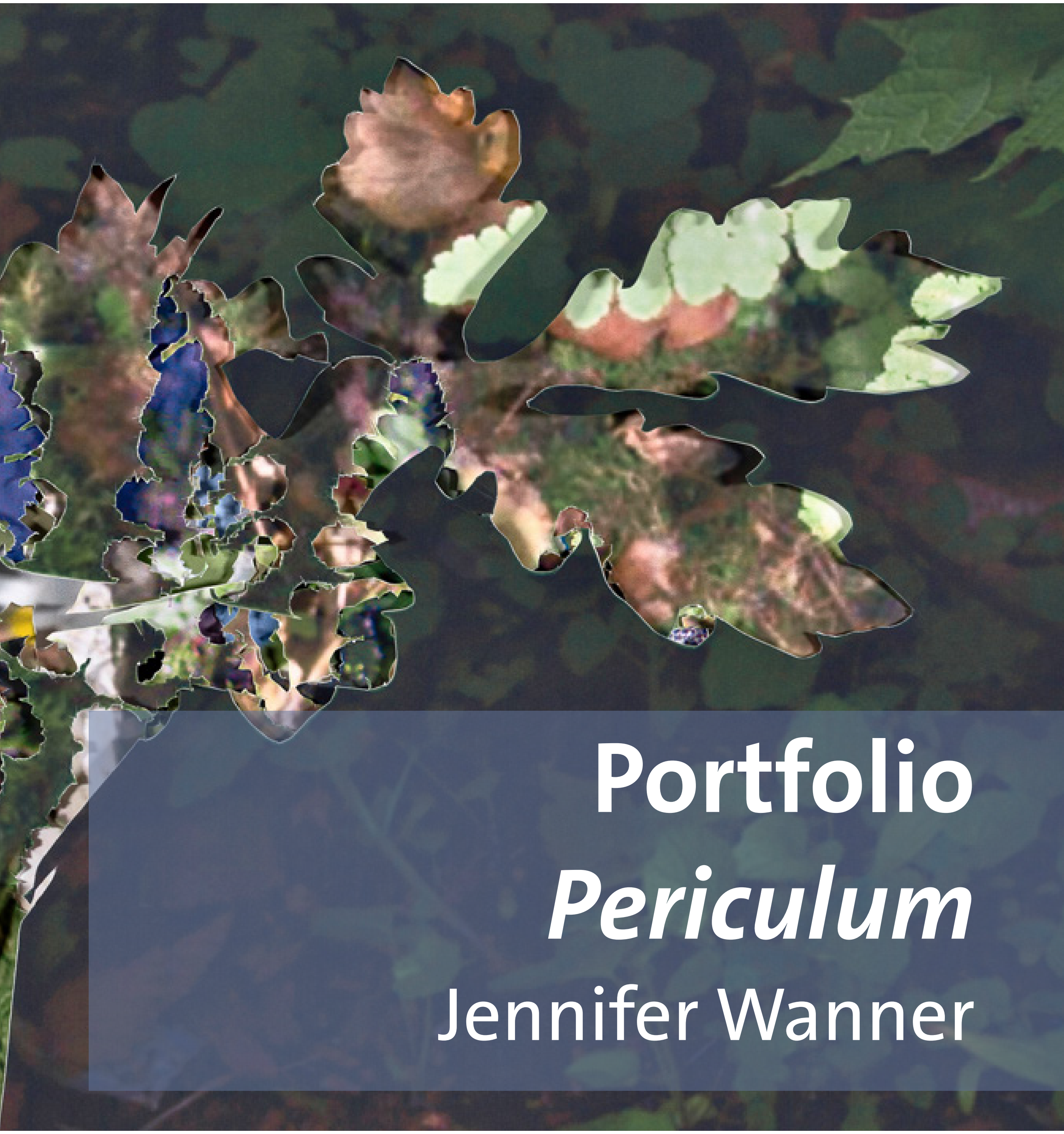
Ryan A. Church is the Founder and CEO/CTO at BiomeRenewables Inc., where they are developing biologically-inspired renewable energy technologies. They are launching in the wind industry with the PowerCone, an enhancement technology that enables nine world-firsts in the wind industry with initial indications suggesting that this technology could break the Betz Limit. He has given university lectures and advised governments in both Canada and Europe as a thought-leader in the field of renewable energy and biomimicry. Recently, Church was nominated as a Forbes 30 under 30 in Energy.

Rachel Hahs is Certified Biomimicry Professional and sustainability expert working to expand the sustainability discussion to business strategy, innovation, product development and systems where significant sustainability and competitive advantage gains await. Building on ten years' experience at URS Corporation focusing on sustainability in business operations where inefficiencies are largely the result of poor design upstream, she is interested in how the use of biomimicry in innovation can result in disruptive cascading sustainable system innovations that can accelerate our transition to a sustainable future.

High key seeds | Photo: k.landerholm, 2013 | Flickr cc

Absentia – Ontario #23

Jennifer Wanner, 2017



Portfolio

Periculum

Jennifer Wanner

Jennifer Wanner is a Canadian multidisciplinary artist based in Calgary, Alberta. Her art practice examines botanical art and nature cinema in a world dominated by "second nature" – a virtual simulation of pristine "first nature" wrought by the revolution in information, biotechnologies, and consumer culture. She employs watercolour painting, collage, photography, and stop-motion animation to explore how both art historical constructs and scientific objective means of observing the natural world have shaped our western concept of nature. Her work attempts to operate between two Romantic realms: fascination with mastery over natural processes and unease with what our technology might unleash.

Could you tell us about this series?

In the collage series Periculum – Latin for trial, proof, danger, peril, risk, liability – I collected, and printed on inkjet paper Internet images of the most endangered and threatened plant species throughout Canada. I then carefully cut the image of the plant away from its original photographic context, and recombined these specimens into a new "rescued" plant species, generating a self-contained, collaged plant form for each of the 13 Canadian provinces and territories, plus one plant form to represent all of Canada.

As a species, humans are constantly driven to develop technologies and organizational systems that attempt to counteract the negative effects we have inflicted upon the natural world. With my proposition to "genetically collage" all of the provincial and territorial plant species at risk together into one specimen, we would only have to concern ourselves with protecting one plant species rather than a diverse range of them – a system of "efficiency". These collaged botanicals act as another futile and preposterous proposal to help restore and protect what we are on the verge of destroying.

What kind of techniques do you use for your work?

Collage is the primary technique that I use because of its similarities to genetic transfer science in both language and gesture. An image or gene is removed from its original context and is "transferred" and "spliced" onto another one to generate a new "modified" whole. Some of my projects are stand-alone collage works, while others, such as my watercolours, stop-motion animations, and photographs, are based on collages I have made.

How has your art/style changed since you first started?

Graduate school was a turning point in my work. I went in as a watercolourist and came out a stop-motion animator. Since then I have been using a variety of media to communicate my ideas.

How does photography influence the way you see the world? Do you feel that you see things around you differently?

My work relies on the appropriation of other photographers' images. I conduct "virtual" fieldwork on the Internet, so I am constantly being exposed to how other people frame the natural world. The Berlin-based artist and writer Hito Steyerl talks about the "uncertainty principle of modern documentarism", which focuses on the "intensity of the problem of truth" at this moment in time, and that "the significance of documentary form lies more in how they are organized than what they depict." This idea of the formal re-arrangement of images causes me to view both the virtual world, as well as reality, as one big abstracted collage.

Who/what inspires you creatively? What do you 'feed' on the most?

I am an avid viewer of nature films, in particular the pioneering underwater films of Jean Painlevé (1902 – 89). I also gain inspiration and enthusiasm from listening to other artists and curators speak about their own work.

What are you working on right now? Any exciting projects you want to tell us about?

At the completion of the Periculum project I was left with over six hundred 8 ½" x 11" sheets of ink-jet paper offcuts of endangered Canadian plants, which I discovered were not easily recyclable. These offcuts are what have become the basis of my new series of enlarged photographs of collages and stop-motion animation entitled Absentia, which refers to the phrase "death in absentia" used when the death of a person is legally declared in the "absence" of their remains; not unlike when a species is declared extinct.

What is the last book you enjoyed?

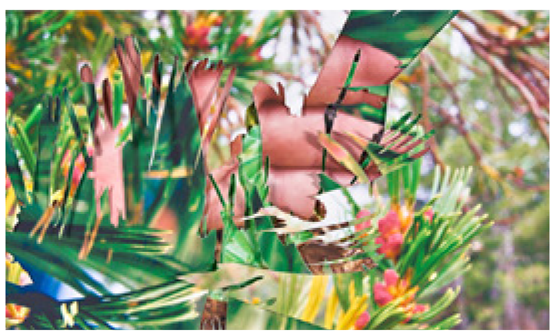
I was introduced to an engaging book by philosopher and cognitive scientist Alva Noë entitled Strange Tools: Art and Human Nature during a recent residency/workshop I attended at the University of Lethbridge.

What are your favorite 3-5 websites, and why?

I have spent a great deal of time on the Canadian federal government's Species at Risk Public Registry website (https://www.sararegistry.gc.ca) for my research. I secretly love clicking on the tick boxes and searching their database. In order to revive my inspiration for my work I like to visit the National Film Board of Canada's website (https://www.nfb.ca), in particular their animation genre. I spend a great deal of time surfing the web for my projects, so during my off-time I like to be away from my computer reading magazines, such as *Border Crossings*, to give me a sense of what is going on in the world of art.

What's your favorite motto or quotation?

David Suzuki succinctly describes why we are facing the global catastrophe of climate change when he states, "We're in a giant car heading towards a brick wall and everyone's arguing over where they're going to sit." ×



Absentia (detail) – BC #40
Jennifer Wanner, 2017

Periculum – British Columbia, 2015

Periculum – Alberta (Permutation #2), 2017

Periculum – Saskatchewan (Permutation #2), 2017

Periculum – Yukon, 2014

Periculum – Quebec, 2014

Periculum – New Brunswick, 2015

***Periculum – Northwest Territories*, 2014**

Periculum – Ontario, 2014

Periculum – Newfoundland and Labrador, 2014

Periculum – Manitoba, 2015

Periculum – Nova Scotia, 2014

Periculum – Prince Edward Island, 2015

Field Guide to *Periculum – Canada*, 2015

1. Furbish's Lousewort (*Pedicularis furbishiae*), New Brunswick

In 1980 this perennial herb was the first plant in Canada to be designated as nationally endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Lousewort was thought to have been extinct until surveys in Maine were done for a dam project in 1977; therefore, it is considered a Lazarus taxon (a species believed to be extinct, only to reappear).

2. Yukon Draba (*Draba yukonensis*), Yukon

This small herbaceous biennial mustard is endemic to one meadow complex in southwestern Yukon and found nowhere else on earth. It is endangered due to industrial activities, nearby human habitation, invasive species and trampling by humans and forest encroachment. It has no legal protection in Canada.

3. Hairy Braya (*Braya pilosa*), Northwest Territories

Hairy Braya is an extremely rare endemic plant that is believed to be a glacial relic and is only found in an area that remained ice-free during the last ice age. It is endangered by the loss of habitat through very rapid coastal erosion and saline wash resulting from storm surges and permafrost melting.

4. Eastern Mountain Avens (*Geum peckii*), Nova Scotia

This endangered perennial herb occurs only in eastern North America. Its habitat has declined due to encroachment by woody vegetation that has been exacerbated by the artificial drainage of sites, trampling by nesting gulls, all-terrain vehicles, road maintenance and residential/tourism development. Fewer than 9,000 mature individuals remain with most found on private land.

5. Gulf of St. Lawrence Aster (*Symphyotrichum laurentianum*), Prince Edward Island

This threatened annual halophyte (a plant that grows in high saline waters) is a rare endemic of the Gulf of St. Lawrence and is found in Prince Edward Island, Québec and New Brunswick. Threats to this aster are both natural, such as flooding, overwash and competition from other plants, and anthropogenic such as development and recreation vehicles.

6. Barrens Willow (*Salix jejuna*), Newfoundland and Labrador

The Barrens willow is endemic to the limestone barrens of the Great Northern Peninsula of Newfoundland, and plays a significant role as a food source or shelter to a number of invertebrate species. It is endangered by habitat loss and degradation from land use activities. An individual specimen may live up to 100 years.

7. American Ginseng (*Panax quinquefolius*), Ontario

This long-lived forest perennial is found in Ontario and Québec. Aboriginal people have used it for a wide range of medicinal purposes, including a cure-all when other treatments have failed. The main threats to this endangered species are its small population sizes with low reproductive potential, habitat loss and degradation associated with clearing, logging, grazing and harvesting for commercial purposes.

8. Porsild's Bryum (*Haplodontium macrocarpum*), Nunavut

This threatened moss is found in Nunavut, British Columbia, Alberta, Newfoundland and Labrador. Its disjoined distribution is believed to represent the remnants of a much wider range that was fragmented by glaciation. The main threats to this species are drought, wildfire, temperature extremes, recreational activities and industrial activity. Only one out of 10 known locations is protected.

9. Green-scaled Willow (*Salix chlorolepis*), Québec

This threatened species is only found in Gaspésie Provincial Park. However, one important population site is highly exposed to pedestrian traffic because some hikers take shortcuts around obstacles, thereby trampling the willow.

10. Limber Pine (*Pinus flexilis*), Alberta

Limber pine is a slow-growing, long-lived endangered species that occurs in Alberta and British Columbia. The oldest tree on record in Alberta is 991 years old. These trees can provide us with climate change information that dates back farther than any historical records. Threats to the species include White Pine Blister Rust (an introduced pathogen), Mountain Pine Beetle and climate change. Two-thirds of Limber Pine trees are expected to be lost over the next 100 years.

11. Western Prairie Fringed-orchid (*Platanthera praeclara*), Manitoba

The Tall Grass Prairie Preserve in southeastern Manitoba is the only Canadian site for this endangered species and contains 50 percent of the world's population. Threats to the species include loss of native prairie habitat, draining of wetlands, herbicide applications, illegal removal of plants, overgrazing and annual haying before plants have produced seed.

12. Victoria's Owl-clover (*Castilleja victoriae*), British Columbia

Victoria's Owl-clover is a newly described species (2007) that was previously misidentified as Paintbrush Owl-clover. Approximately 98 percent of the global population of this small, endangered annual herb is found on one Canadian site. The primary threats are habitat loss and/or degradation due to urban/residential development, recreational activities and invasive species.

13. Slender Mouse-ear-cress (*Halimolobos virgata*), Saskatchewan

This threatened biennial (a plant that takes two years to grow from seed to fruition and then dies) from the mustard family is found in Alberta and Saskatchewan. It appears to be unable to grow on previously turned soil. Other limiting factors include the loss of habitat as a result of urban and industrial development (such as oil and gas activities) and agriculture, invasion by non-native species, all-terrain vehicle recreation and other human activities. ×

Species at Risk Public Registry, Government of Canada, 25 August 2017, https://www.sararegistry.gc.ca/search/SpeciesSearch_e.cfm

Periculum – Nunavut, 2014

Great Lakes in Sunglint

Photo: NASA's Marshall Space Flight Center, 2012 | Flickr cc

World *Interview* Great Lakes Biomimicry

vol 4 | 2017

World
Interview

Authors:
Great Lakes Biomimicy Co-Directors: Trisha Brown, Christine Hockman, and Carol Thaler

How did you get started?

It all started with people gathering around discussions about building a network that lifted our region's assets and sparked changes in sustainability. We wanted to craft a new identity for Northeast Ohio – changing our reputation from "the place where the river burned" to a place where a healthy economy and environment thrive. Biomimicry became the focus because it's a tool to help us get beyond sustainability. It leads to healing and creating of a thriving ecosystem. Catalysts like Holly Harlan and Paul Alsenas created the conditions for biomimicry to weave into the community. Then in 2010, Tom Tyrrell and Don Knechtges started Great Lakes Biomimicry, began to introduce biomimicry to the business community and recruit influential board members. In 2012 at The University of Akron, the interest of evolutionary biologist Dr. Peter Niewiarowski and President Luis Proenza's Achieving Distinction Award created the Biomimicry Research and Innovation Center. Our collaboration with the university built the world's only Biomimicry PhD Fellowship Program. A snowball kept rolling and gathering mass and speed. Fast forward to today, and over 100 people have helped us grow in some way, and more than 30,000 volunteer hours have been provided to support our work.

What is your mission statement?

Great Lakes Biomimicry creates the conditions for innovation inspired by nature.

Are you structured via a specific organizational model?

Organized in the United States as a 501(c)(3) non-profit organization, we have a 12-member Board of Directors, three Co-Directors, eight collaborators and many project partners.

What other organizations are you linked to?

We work with 16 Educational Partners, 7 Corporate Fellow Sponsors, 4 Industry and Government organizations, 13 Funders, and 11 organizations that provide direct assistance to us, and that we call Service Partners.

What initiatives are you working on?

Providing Innovation Services to businesses and organizations through the Great Lakes Biomimicry Innovation Playbook™ – helping businesses explore new opportunities, solve problems and drive sustainability.

Working closely with The University of Akron to recruit sponsors for the Biomimicry PhD Fellowship Program

Convening the Corporate Innovation Council, composed of Biomimicry Fellows and Sponsors. Quarterly meetings allow for peer learning, idea sharing, networking, and trust building between corporate, industry and non-profit organizations. Innovation Sessions provide a unique opportunity for the Sponsors to work on a common challenge, resulting in a joint discovery and learning across organizations.

Spittlebug | Photo: Yogendra174, 2016 | Flickr cc

Spittoon | Photo: limowreck666, 2006 | Flickr cc

Delivering Professional Education to help organizations accelerate the adoption, integration and application of biomimicry.

Partnering with informal science institutions and offering community programs for general audiences to spark interest in the emerging field of biomimicry.

What success stories can you share?

We have something very special in the Great Lakes Region – a thriving biomimicry ecosystem connecting education, business and industry.

Through our collaborative Biomimicry PhD Fellowship program at The University of Akron:

Bor-Kai (Bill) Hsiung, who was sponsored by Sherwin-Williams, led game-changing research inspired by blue tarantulas that could revolutionize how colors are manufactured. He successfully designed and manufactured a proof-of-concept prototype that has commercialization potential resulting from biological research.

Emily Kennedy, sponsored by GOJO Industries, influenced biologically-based improvements for energy-efficient soap dispensers, protective topical treatments, versatile dispenser brackets and infection control products/processes. She was a co-inventor on four GOJO patent applications.

Another result of students researching and working in this program is that Bill and Emily also formed Hedgemon, an early startup business in Cleveland that is developing a hedgehog-inspired product for use in helmets as concussion prevention.

Through our Corporate Innovation Council:

Companies that sponsor Biomimicry PhD Fellows meet quarterly to discuss their unique experiences, challenges and ideas about incorporating biomimicry into their work. Collaborations are forged so companies can work together to solve problems.

Unique Innovation Sessions allow members to work together in a space without boundaries, leading to new ways of thinking and excitement around biomimicry's potential. Read about our 2016 Innovation Session with GOJO Industries and University Hospitals at http://gojo.com/en/Newsroom/Blog/2017/Nature-Inspired-Innovation-Creating-Sustainable-Value?noredirect=1.

To our knowledge, no other location in the world has achieved this significant level of corporate collaboration around biomimicry and innovation.

What are your plans for the future?

To change the world – starting with the Great Lakes Region. We want to grow our impact, so that countless organizations build with nature in mind, enhance their resiliency, and transform their workplaces into thriving places. We are also expanding into the organizational development realm with our partner, TimeZero. In 2018, together we'll offer an Organizations as Living Systems workshop, teaching a biomimetic Living Systems Approach to designing, developing and leading organizations and teams.

Tarántula Azul [Greenbottle Blue Tarantula] (*Chromatopelma cyanopubescens*) | Photo: barloventomagico, 2013 | Flickr cc

Self-forming Streams | Photo: Dan Mecklenburg, Jon Witter, & Jessica D'Ambrosio, Ohio State University, 2011 | Flickr cc

What inhibitors to success have you experienced?

Biomimicry isn't an easy sell to some people because it is so new. Therefore, we are continually seeking to be on solid financial ground. It is sort of a hummingbird kind of life... getting just enough to keep on going but never being totally financially comfortable. Many times, you can't even get in the door to talk to someone about biomimicry – a long-term problem solving tool – because they are too busy meeting short-term deadlines. While many people want change in our environmental, education and economic systems, there is also an underlying anxiousness about change that results in them taking no action.

How are you sustained financially?

We have been fortunate to receive grant funding from regional foundations and significant donations from board members. We receive payments from the sponsors of The University of Akron Biomimicry PhD Fellows that allows us to convene the Corporate Innovation Council and provide support to the organizations that wish to educate their staff about biomimicry. We have sustained ourselves through the help of generous service partners, the donation of volunteered time by team members, and by working at below-market rates. Our Professional Education – especially the Value of Biomimicry workshops done in-house for companies – and Innovation Services are revenue generators for us, and we're excited to expand these services and impact more people.

What is your geographical "reach", where are your members, meeting places, project locations?

We operate in Northeast Ohio, including the metropolitan areas surrounding Akron and Cleveland; however, our client base is expanding into the Great Lakes region.

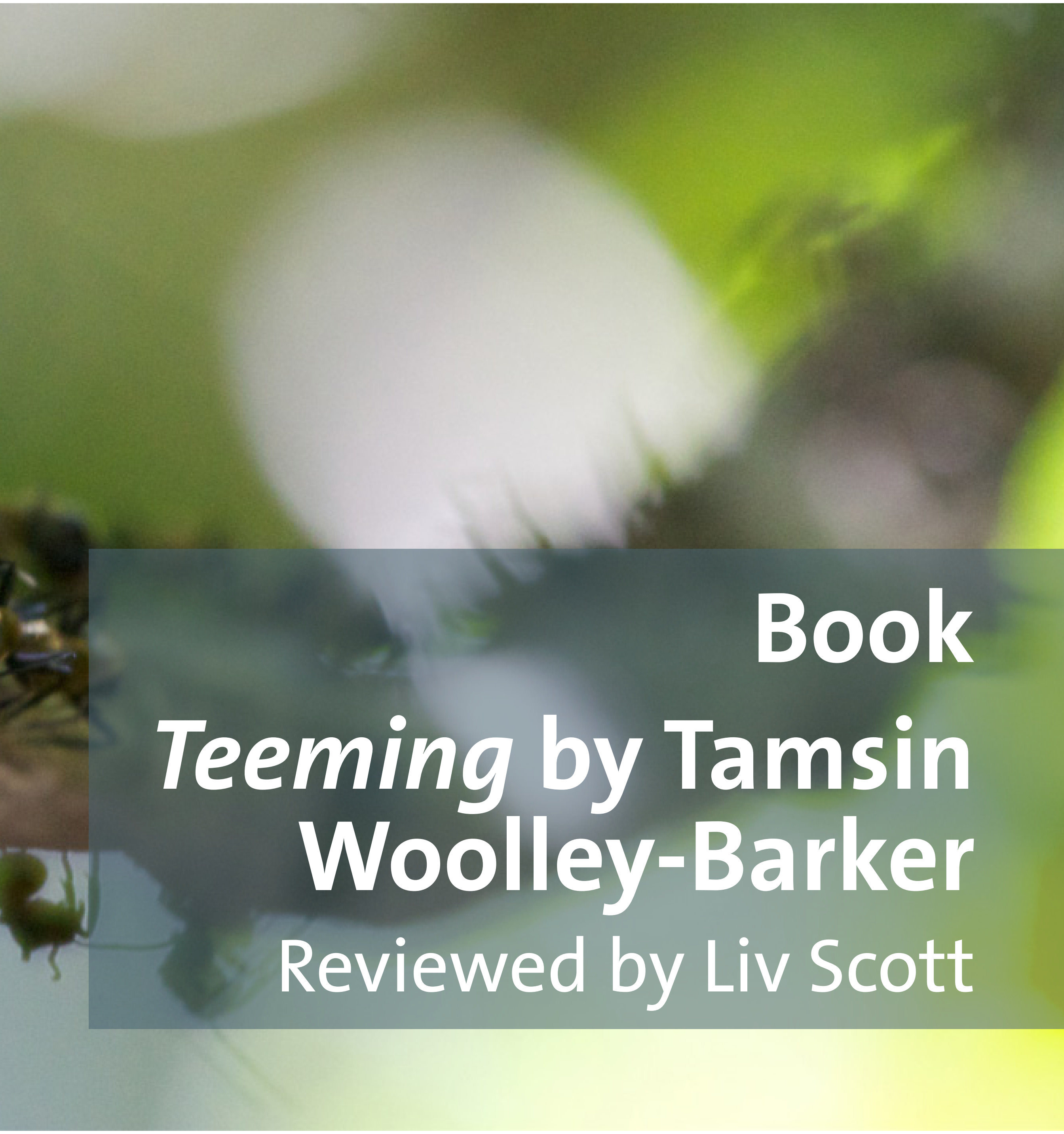
What is the best thing that you've done within the last year? Ever?

Starting a program with The University of Akron that provides the only place in the world (yes – the world!) to study biomimicry at the PhD level. The program has been a magnet for some of the brightest students around the globe (including a Fulbright scholar) who now live, study and work in Northeast Ohio. One of our sponsors, Kimberly-Clark, is located in Wisconsin, so it's great having a biomimicry champion outside of Northeast Ohio in our group.

To say that we're proud of this accomplishment would be an understatement. Just consider the possibilities of unleashing more and more of these graduates into the world. It creates a brighter future, and one that's sure to hold solutions for some of our biggest challenges, like climate change. And if these solutions spark from the Biomimicry Belt, we can put another feather in our region's cap (after studying that feather's design and function first, of course). ×

Ants

Photo: qmnonic, 2011 | Flickr cc



Book

Teeming by Tamsin Woolley-Barker

Reviewed by Liv Scott

vol 4 | 2017

Book
Teeming by Tamsin Wooley-Barker

Reviewer:
Liv Scott

Teeming: how superorganisms work to build infinite wealth in a finite world (and your company can too)

Teeming, by Dr. Tamsin Woolley-Barker, explores how principles derived from social organisms can help businesses optimize wealth on a finite planet. Rooted in a strong biological and anthropological background, *Teeming* provides a "new and deeply biological way to do business" as well as "organize our entire global society" (p. xxiv). While this book is intended for business leaders, the content is beneficial for any leader attempting to foster innovation and promote change. Woolley-Barker's extensive background in sociobiology, which she describes as "society with the skin peeled off" (p. xix), provides an alternative perspective for how structural changes can prompt "organizations to adapt continuously, nimbly, with no fossilized, rigid, slow and costly layer of management ..." (p. xxv), spurring both innovation and wealth.

Early on, Woolley-Barker defines her concept of superorganisms as a "group of genetically distinct individuals of the same species, where members take on different tasks ... and no one survives on their own for long" (p. 31). Not only does this categorization include humans, but also captures diverse organisms such as mycelial fungi, ants, orcas, and apes. The author centers the book on our own evolutionary place within nature and describes us as ant-like apes. As the name implies, we are a combination of the traits present in both organisms. For instance, the social insects "distribute their processing power among themselves" (p. 58), beyond the social hierarchies of apes. Additionally, we have the ape's social capabilities to be "political, shortsighted, self-serving, affectionate ... and emotional" (p. 64), making us our own unique superorganism. However, Woolley-Barker argues that social and connective technologies are part of our evolutionary progression. "Today, our smart phones are practically part of our bodies—human antennae, physical extensions of our two-way always-on communications" (p. 62). Therefore, part of this book describes how to better use our technology based on lessons from social insects and mycelial networks.

Structure

The book takes into consideration the tight schedule of business leaders by beginning with an abridged list of twelve deep patterns derived from studying superorganisms, arranged into five components. As a further aid, Woolley-Barker includes italicized key points throughout each component's chapter. Overall, the book is arranged into six parts, with the first examining the current problems of corporations as well as the benefit of looking to superorgan-

The Search | Photo: Property#1, 2007 | Flickr cc

Tree Ant Nest | Photo: PacificKlaus, 2011 | Flickr cc isms through the lens of our place in evolutionary history. The following five parts break down each component into its patterns and explore their utility with examples from the natural and business world.

The first part of the book introduces superorganisms, the problem of infinite growth on a finite planet, and describes why corporations should structure themselves on living systems and not machines. Woolley-Barker explains how evolution works and explores biomimicry and complex adaptive systems as tools for developing solutions. However, most of this part describes how humanity fits within the evolutionary framework of superorganisms.

The second part of the book discusses the basic concept called collective intelligence, which "describes how superorganisms work together on a daily basis, building regenerative wealth from the bottom up" (p. 6). The five principles which lead to this collective intelligence include: encourage self-organized networks, pool apparently insignificant parts into something greater, cultivate variety and independence, communicate through always open two-way conversation and lastly, trigger tipping points with simple rules and feedback loops. There are two main takeaways from this chapter. First, how to create an organization that builds from the bottom up and requires no central control to accomplish tasks, but rather relies on the signals from surrounding agents. Second, how accumulating large quantities of "scraps", whether they be data or physical material, allows corporations to generate wealth, which begins to address building wealth despite finite resources.

The third part of the book discusses the concept of swarm creativity to "create infinite, enduring value in the world" (p. 131). This section includes three principles: align action around the shared goal of a better future, launch multiple low-investment experiments concurrently, and tune the network to increase or decrease innovation. The author discusses each of these three principles, and how superorganisms are created evolutionarily by having "to cross the inbreeding valley of death" (p. 161), which few species survive because of low fitness and diversity. However, as the group loses diversity internally, it will cease competing at the individual level and instead compete between groups. This is when the most collaborative group of individuals will survive and begin differentiating labor. Any source of new genetic diversity which enters these groups will rapidly spur innovation throughout the population. Therefore, the author uses biomimicry to promote the notion of collaborating on a common goal and changing network structures to utilize multiple groups and foster variations of innovative ideas.

The fourth part addresses two principles: combine specialized teams together when needed, and distribute leadership to integrate local vision with global vision. This section includes a discussion of the difference between specialists and generalists in nature, and how teams need to have a combination of these types to integrate a depth of knowledge with a global perspective. Chapter 25 specifies the six roles that a superorganism leader plays for the social dynamics and idea nurturing of a team, including: focus on a shared mission, cultivate diversity

Bullant on watch duty | Photo: jeans Photos, 2011 | Flickr cc

and independence, distill and disseminate the big picture, catalyze consensus, increase social unity, suppress dominance, and resolve conflict.

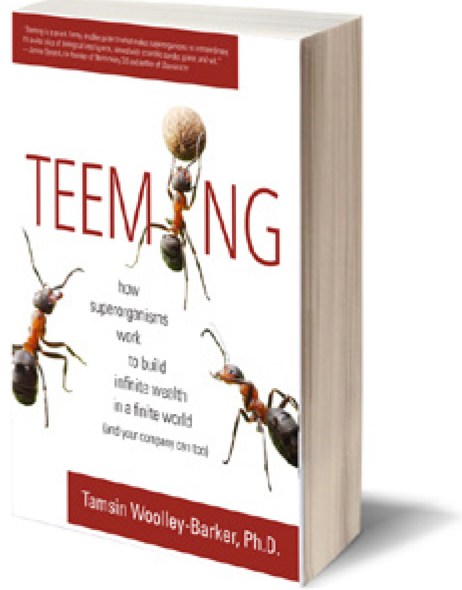
The fifth part addresses the concept of reciprocity and sharing, which involves one principle: share the work and wealth, but protect it from parasites. This part takes a deeper look at humanity both in looking at social capital and the ways that people cheat others or use force to dominate others, and how ultimately this dynamic is unsustainable for building greater wealth. The author uses both the failure of the Tragedy of the Commons as well as game theory's examination of the Prisoner's Dilemma to discuss humanity's ability to respond and thrive through collaboration and discouraging cheaters.

The final part looks at regenerative value, which addresses the goal of the book's subtitle, building with renewable resources to generate compounding wealth. These closing chapters optimistically address climate change and our ability to follow the biomimicry principle, "Life will make conditions conducive to Life, and so will we" (p. 288).

Discussion of Book

Woolley-Barker pulls together a wide range of subject matter using humor and anecdotes, which at times can distract from the twelve principles the book seeks to describe. The book discusses seemingly diverse topics as the Sharing Economy, Generation X thru Z, the Tragedy of the Commons, and game theory 's insight on the Prisoner's Dilemma. These topics are woven between the author's personal stories and examples from the non-human world. Due to this conversational writing style, the purpose of the chapters and the principles begin to fall to the wayside causing the book to become less a guide for businesses and more of a scientific commentary on the current evolutionary status of humanity in the dawn of technology.

While this book is intended for businesses, the principles do not appear new for businesses, but rather supports the current business trajectory with biological evidence. In other words, the business examples demonstrate the changes taking place within business rather than a biomimetic redesign of corporate structures. One example of this biomimetic perspective on society is the not-for-profit Rising Billions, which



supports the entrepreneurship of the global poor. The "vision of the Rising Billions is alluring, because even a billion pennies a day adds up ... I think of this approach as the Lichen Strategy" (p. 92). The author then proceeds to explain lichen and further discuss microfinancing and crowd-sourcing. While readers may know about one of these topics, this book builds connections. While the content and principles may not be new to the business or biomimetic community, this book provides a translation between these two communities within the context of current social trends.

This book does an excellent job explaining how evolution works and the role of competition and collaboration within natural selection. The author discusses the relationship of the two, using competition and collaboration to demonstrate how biology can be useful for businesses. "I know first-hand that predation and parasitism are real, and that every group of collaborators needs to protect their collective wealth against them. Competition does drive life's radical innovations ..." (p. xvi). This is a common theme throughout the book, how collaboration is utilized to gain a competitive advantage within the non-human world.

A biomimetic book intended for businesses could be useful for discussing their role in the face of climate change, but this book tiptoes around the topic. The author opens the book with the statement "This is not a tree-hugging book ..." (p. xv). All the examples throughout the book discuss how businesses can continue to practice as usual with only a shift in organizational structure. The role of businesses in the face of climate change is reserved for the end of the book where the overall statement is "creating conditions suitable for life" (p. 284) and thus nurturing the next generation. The author uses termites to demonstrate that conditions for life are a byproduct of compounding wealth to make the next generation more successful. Once again this is not a novel perspective or role for businesses, and opens the question whose life are we making conditions suitable for. The author compares our production of waste to photosynthetic bacteria, which created oxygen in an anaerobic environment and caused a mass extinction – ecosystem engineers are often both disruptive (creating niches) and destructive. However, once again the author does not critique our behavior or offer any answers beyond the vague advice to create conditions for life. By equating us to photosynthetic bacteria as an organism that altered the planet, the book offers a biological excuse for our behavior, yet unlike the bacteria, the changes we are making to the planet are not only leading to the extinction of many species but also rising climate related human deaths in the most vulnerable populations of the globe.

This book does not address the most pressing issue, climate change, that has led people to question the problem the author seeks to address: businesses seeking to create infinite wealth on a finite planet, where resources are shared across a diverse body of people and organisms. Though the book reserves the last few chapters to instill a sense of urgency, it offers no course for businesses to embrace the needed radical change.

The book addresses capitalism as merely requiring an adjustment in strategy in order to continue to spread globally. "Global organizations are increasingly realizing that American-style capitalism doesn't play everywhere" (p. 101). The au-

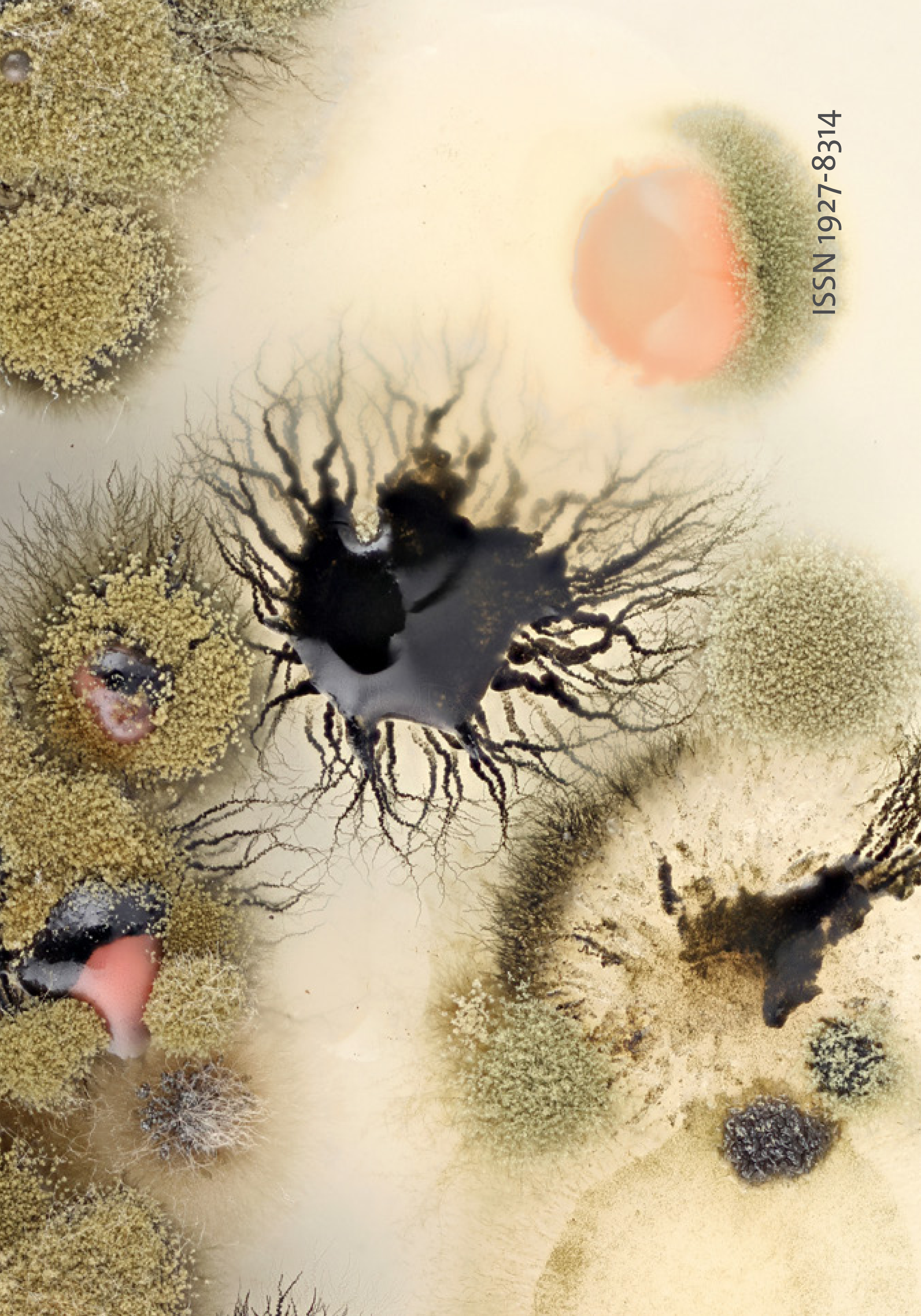
Green Ant Nest | Photo: geoff.whalan, 2016 | Flickr cc thor uses mycelium as an example of companies having central headquarters, but locally specialized platforms. The book prompts businesses to “Imagine the brand loyalty and value that would build—if capitalism isn’t done to people, from afar, but by and for them, where they live” (p. 102). Even though the book poses the question, *how would the fungi do it?*, the author does not question the value of capitalism or the ethics of spreading a dominant society’s ideology that has been criticized for climate change across the globe.

There are additional instances in this book where mimicking lessons learned within biology enter ethically gray and dangerous zones. In discussing how ranking our social interactions through an app could foster the creation of extra-cooperative social groups, the author adds the comment, “Don’t shoot officer—look at my stars!” (p. 261). This demonstrates the dissonance between the changes the book suggests for businesses and their impact on societies with historic power structures. The author addresses eugenics and the ethical implications of science, uses biology as a reason for valuing diversity, and values culture as what makes us human and distinct from apes. Nonetheless, the book seems incomplete because these concepts do not permeate the discussion on the globalization of companies or provide an ethical framework for why the author chooses to use particular biological examples to support business concepts, such as relating mycelium to global colonization.

Overall, this book provides a business-oriented introduction to biomimicry though examining current trends such as the Sharing Economy, the rise in B corporations, and the use of social technologies. While reading the book is enjoyable due to the anecdotal conversation-style writing and entertaining explanations, there is no index and a limited notes section, which requires the reader to take Woolley-Barker’s word for many examples and concepts. Even though the book is intended for businesses, biomimicry proponents can benefit from its clarity in describing the role of competition and collaboration in the natural world. Additionally, both groups can enjoy the ability of Woolley-Barker to bridge these two fields within the context of present trends, though it will be up to the reader to imagine the future. ×

Woolley-Barker, T. (2017). *Teeming: How Superorganisms Work Together to Build Infinite Wealth on a Finite Planet*. Ashland, Oregon: White Cloud Press.

Liv Scott was born and raised in New York City. She became interested in the ways urban areas and people could remain cognizant of their relationship to nature, and develop resilient systems to bounce back from the effects of climate change. After graduating from Oberlin College with an Environmental Studies and Biology double major, Liv is building an educational platform to deepen relationships people have with their environment. This multi-media “bioexplorer” project will examine the intersection of biological lessons in resilience, systems design, and social justice through looking at the changing global food system.



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