Minuscule microbes wield enormous power over the Great Lakes, but many species remain a mystery

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Near the deepest spot in Lake Michigan, the crew aboard the research vessel Blue Heron lowers a device outfitted with a cluster of 8-liter bottles into the dark blue waters until it disappears from sight.

After a 10-minute descent, the metal-framed contraption known as a rosette finally lands on the muddy bottom roughly 860 feet below the surface. Between Green Bay and Traverse City, Mich., lies a place devoid of sunlight, deep enough to completely submerge a 74-floor skyscraper and where temperatures still hover around 39 degrees.

On the trawler's deck, marine techs reverse the winch, and the rosette lurches upward, deploying canisters to retrieve water samples from the abyss.

While the lake water appears crystal clear, the team of scientists from the University of Chicago know it's teeming with life. Each drop contains a plethora of species so small that dozens could fit on a speck the width of a strand of human hair.

"When most people look out on the lake, they think about fish," said Maria Hernandez Limon, a graduate student studying microbiology at U. of C. "But there are orders of magnitude more bacteria."

Despite their minuscule size, microorganisms—including, bacteria, viruses and algae—are among the most prolific environmental regulators on the planet. These tiny, single-celled species wield the ability to alter the Earth's climate, spread human disease, regulate the metabolism of animals and some serve as the building block of the aquatic food chain. In the Great Lakes—which provide drinking water for 48 million people and support a $7 billion recreational fishery—researchers know next to nothing about some of the most abundant microbes.

As Great Lakes climate trends make harmful algae blooms more likely and raise questions about how other microorganisms may behave, this research has taken on a sense of urgency.

In 2012, Maureen Coleman, an assistant professor of earth sciences at U.

of C., started the first long-term study of microorganisms across the five Great Lakes to better understand what microbes are present in the region and what role they play in the environment.

So far, after analyzing four years' worth of samples, the team has discovered around 160 new species. With funding from the National Science Foundation, U. of C. scientists embarked on a six-day sampling expedition from Milwaukee to Duluth, Minnesota. The research vessel steamed to lake trout spawning reefs colonized by invasive mussels, along the Straits of Mackinac, up the misty St. Marys River, through the Soo Locks and onto a cold and foggy Lake Superior.

"We don't often appreciate the microbes around us, but the Great Lakes are full of them," Coleman said. "Every drop of water you swallow when you are swimming in Lake Michigan has about 1 million bacterial cells and 10 million viruses. Our goal is to understand who's there and what are they doing, and then eventually to understand how they're changing over time."

This research has taken on greater importance as some microscopic organisms have shown an ability to swiftly proliferate, sometimes with disastrous consequences. For the past two decades, massive toxic cyanobacteria blooms have overtaken the western basin of Lake Erie every spring, a phenomenon visible from space and one that rendered drinking water unsafe for consumption in Toledo in 2014.

"I always thought this was a problem for Lake Erie and none of the other Great Lakes," said Coleman, whose team has found new species of cyanobacteria in lakes Superior and Erie. "But sadly that's not the case. Even last summer there were harmful algal blooms in Lake Superior near the Apostle Islands, and that's perhaps where we think of the most pristine environment in the Great Lakes. The fact that they're happening in Lake Superior, which is the least affected by human influence, is really scary.

"I think we need to understand how that microbial ecosystem gets out of balance to the point that one toxic species can make such a big impact on us. I think harmful algae blooms are sobering, and we're increasingly seeing them on lakes of all kinds."

Cyanobacteria captures sunlight and produces much of the Earth's oxygen, similar to plants. However, some kinds of cyanobacteria also produce toxins, which can cause liver damage if consumed by humans in drinking water, and scientists still don't fully understand the triggers.

"It could be to kill their competitors, if a lot of other microbes are competing for the same nutrients," Coleman said. "So one strain might make this toxic compound to kill other bacteria, but it, itself, might have immunity from it."

Toxins are mostly produced in the summer, causing some scientists to ponder whether sunlight or temperature have any bearing.

This year, historic rainfalls across the region have washed nutrients from sewage and farm fields into waterways feeding into Lake Erie and the Gulf of Mexico, where exceptionally large algae blooms and low-oxygen conditions known as dead zones are forecast. In a warming world, areas like the Midwest are expected to see heavier rainfall, more flooding and balmier water temperatures, perhaps a recipe for better incubation for some bacteria.

"In general, we think chemistry speeds up and things grow faster as temperatures get warm," Coleman said. "But it's not going to affect every microbe equally. There is no true framework to predict what's going to happen."

Scientists can identify colorful cyanobacteria because of their fluorescent pigment, which they use to capture different wavelengths of sunlight. However, many Great Lakes microbes remain a mystery because they aren't noticeably distinct when observed under a microscope.

Relatively more is known about the vibrant community of microorganisms that reside near the surface of the lakes, including those that use sunlight for energy. Those living in the bottom waters—cold, desolate areas with few nutrients—remain obscure.

After collecting lake water from hundreds of feet below the surface in opaque bottles, U. of C. researchers rushed the samples into a dark lab space below deck where only a single red light bulb glowed. The team swiftly circulated the lake water through filters to collect a smattering of microbes on a mesh pad, which they tucked into vials and immersed in a tank of liquid nitrogen to flash-freeze them.

By sequencing the DNA of the microbes found on the hundreds of filters, scientists will be able to identify the species they've collected and what their genes allow them to do. By quickly freezing some specimens, further testing will be able to tell scientists whether the microbes were producing toxins or performing photosynthesis or some other action near the time they were collected.

One of the researchers, Justin Podowski, a U. of C. graduate student, initially studied microbiology and astronomy in hopes of furthering the search for extraterrestrial life. Podowski was captivated by microbes' ability to survive in a range of harsh conditions like hot springs, volcanic craters, Antarctic permafrost and ocean floors.

Somehow, even without oxygen, and regardless of temperature, saltiness or pH, these organisms could still persevere. Perhaps, the conditions on other planets wouldn't be an obstacle either.

But the Grayslake native later learned he didn't need a rover or high-powered telescope to find a new species. Podowski was on the brink of discovery in his own backyard, where he grew to appreciate that surviving in the deep, remote regions of the Great Lakes can be a remarkable feat on its own.

"In the deep water, there's little light or nutrients, but there's still plenty of bacteria," Podowski said. "We want to know how they make a living."

A number of these deep-water microorganisms, known as nitrifiers, get energy by processing nitrogen from animal excrement and are generally extremely sensitive to sunlight. Podowski and the U. of C. researchers, however, have detected a new species of bacteria that appears to be an anomaly.

"Despite the fact that it lives in the really deep waters, it has an enzyme that we think may allow it to use sunlight as a form of energy," Podowski said. "That's something that's really cool and novel, because in this field of studying nitrifying microorganisms, there is a lot of good evidence that says they are inhibited by light. You can take an isolated nitrifier and grow it and expose it to light, and it stops growing."

While the process of breaking down nitrogen compounds protects water quality, it can lead to the production of potent greenhouse gases, like nitrous oxide, a heat-trapping gas 300 times more powerful than carbon dioxide.

As trillions of quagga mussels have spread across lakes Michigan and Huron, the invasive species has consumed much of the plankton, polluting the lake bottom with their waste and possibly providing these microbes a greater energy source.

Podowski is studying what influence, if any, the quagga mussel excrement will have on the microbial populations of the lake, including the abundance or behavior of nitrogen-processing microbes.

As enigmatic as microorganisms can be, it can be even trickier to trace their origins. The Great Lakes, which were formed by glaciers at the end of the last ice age 10,000 years ago, are still relatively new compared with other bodies of water. Yet, they share the same microbial composition with lakes around the world.

It's unclear how some of the microbes discovered by U. of C. scientists came to reside here. There's a possibility they have evolved from existing species, especially considering bacteria are paragons of adaptability.

Severe flooding continues to flush microorganisms from the soil into the Great Lakes, which could alter their composition.

U. of C. scientists believe there is also some crossover from oceans, perhaps from microbes stowing away in the ballast water of transiting ships.

"Traditionally, we've found it's hard to go from seawater to freshwater and vice versa. But we've found these marine bacteria, and we don't know what they are doing," Coleman said.

Another possibility is these microbes have simply eluded human detection until now.

If that were the case, it wouldn't be a surprise to Coleman. As an undergraduate, her textbooks taught there were five kingdoms of life: plants, animals, bacteria, fungi and protists. Since then, a sixth kingdom known as archaea—consisting only of single-celled microbes—is widely recognized.

It wasn't until the 1980s that Coleman's future Ph.D. adviser at Massachusetts Institute of Technology, Penny Chisholm, discovered the ocean cyanobacteria known as Prochlorococcus, which is believed to be one of the most abundant microbes on Earth. With research just beginning in the Great Lakes, the possibilities seem boundless.

"We've essentially reconstructed the entire tree of life, and now we think about it in an entirely different way. We're discovering new phyla of microbes—the next largest category below kingdoms," Coleman said. "These are huge new groups that are ancient and that we've never recognized before. The textbooks are being entirely rewritten."

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