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On Antarctic Ice: Life at Low Diversity

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Nematodes are tiny, soil-dwelling animals that play a major role in Antarctic ecosystems. Identifying the genes involved in their responses to environmental changes, past and present, may contribute to understanding the carbon cycle.

Colorado State University soil biologist Diana Wall has been working in Antarctica since 1989 and says her excitement has never waned. "We fly into the Dry Valleys in a helicopter, and when you land, there is this vast expanse of soil and mountains and glaciers," she says. "But when that helicopter leaves, what is so striking to me is the lack of sound." It's accompanied by a lack of any movement, save for the wind, and sweeping landscapes devoid of anything green.

Arrival is the culmination of nearly nine months of planning. Long before they set their e-mail to autoreply and boarded a series of flights, Wall and her colleagues plotted the logistics of their short field season. Wall is one of the primary investigators on the McMurdo Long Term Ecological Research (LTER) grant from the National Science Foundation, and she studies the links between soil biodiversity and ecosystem survival. Her group calls themselves the Wormherders because they study nematodes, the animals at the top of the food chain in the McMurdo Dry Valleys.

Wall says in April she's thinking about field sites, helicopter trips, and other arrangements for the following January—not to mention the scientific questions prompting those logistical needs. Of course, the extensive preparation doesn't guarantee that the resulting plan is what actually happens when she finally gets to Antarctica. Scientists who hinge their fieldwork on the coldest, driest continent must maintain sufficient flexibility to punt when weather or other circumstances force them to reassess what they can do and when. Fortunately, they are never at a loss for something to do. Wall says if a helicopter flight is delayed, they may squeeze in a few extra hours in the lab before taking off.

Long-time Antarctica researcher Diana Wall identifies nematodes by species, sex, and age classes at the McMurdo Station lab. Photograph: Breana Simmons.

"If you're in the field and you get stuck, that's also fantastic," she says. Field camps at various locations offer limited shelter and food. The researchers are eager to get soil samples back to the lab for processing, but being on the continent, an 80-kilometer helicopter flight from McMurdo Station on Ross Island, is the point of making the extensive journey.

Studying soil life

Wall and Brigham Young University assistant professor Byron Adams sample and assess the nematode populations of the Dry Valleys to find out what these soil invertebrates may reveal about ecosystem survival. In this stark landscape, just four species of nematodes have been identified. Contrast that with the soils of Colorado, Wall says, where if you scoop up a handful, you're likely to find two dozen nematode species.

Half a dozen years ago, Adams joined Wall in Antarctica because his evolutionary biology experience with nematodes included molecular studies that, Wall recognized, would help answer some of the questions she and others were working on. "We have been very interested in watching how biodiversity changes," she says, and molecular tools have vastly enhanced the group's ability to study what is happening in the soil and what is causing the changes. One way to do that is to use gene sequencing to track changes over broad periods of time.

Adams says that despite the simplicity of the animal population, questions arose that even seasoned nematologists couldn't conclusively answer with traditional morphology. Molecular studies provided answers. Nematodes, he explains, have a rather conservative morphology, so different species can look alike. Multiple samples of *Plectus,* for example, appear the same under the microscope. "The molecules were able to help us see that there's more than one species there," he says. The next step is to determine whether these are new species of *Plectus* or already-named species that haven't previously been found at these sites.

Identifying what is present at the different sites starts the process of determining who the actors are within the ecosystem. "The question itself is, What's the role that biodiversity plays in how this ecosystem functions?" Adams says. To understand that, he tries to figure out which species perform particular functions. Although all nematodes cycle nutrients and facilitate decomposition, some eat only plants, whereas others eat bacteria, cyanobacteria, algae, or some combination of those.

"When you have a really simple ecosystem, knowing the number of species you're working with is even more important," he says, and it also means you can do species-level experiments. "Species really are the currency of biodiversity," Adams says. "When you're talking about species, you're taking about comparable evolutionary units."

At Battleship Promontory in Alatna Valley, Byron Adams takes soil samples. At this particularly remote site he's found the rare nematode Geomonhystera villosa. *Photograph: Emma Broos.*

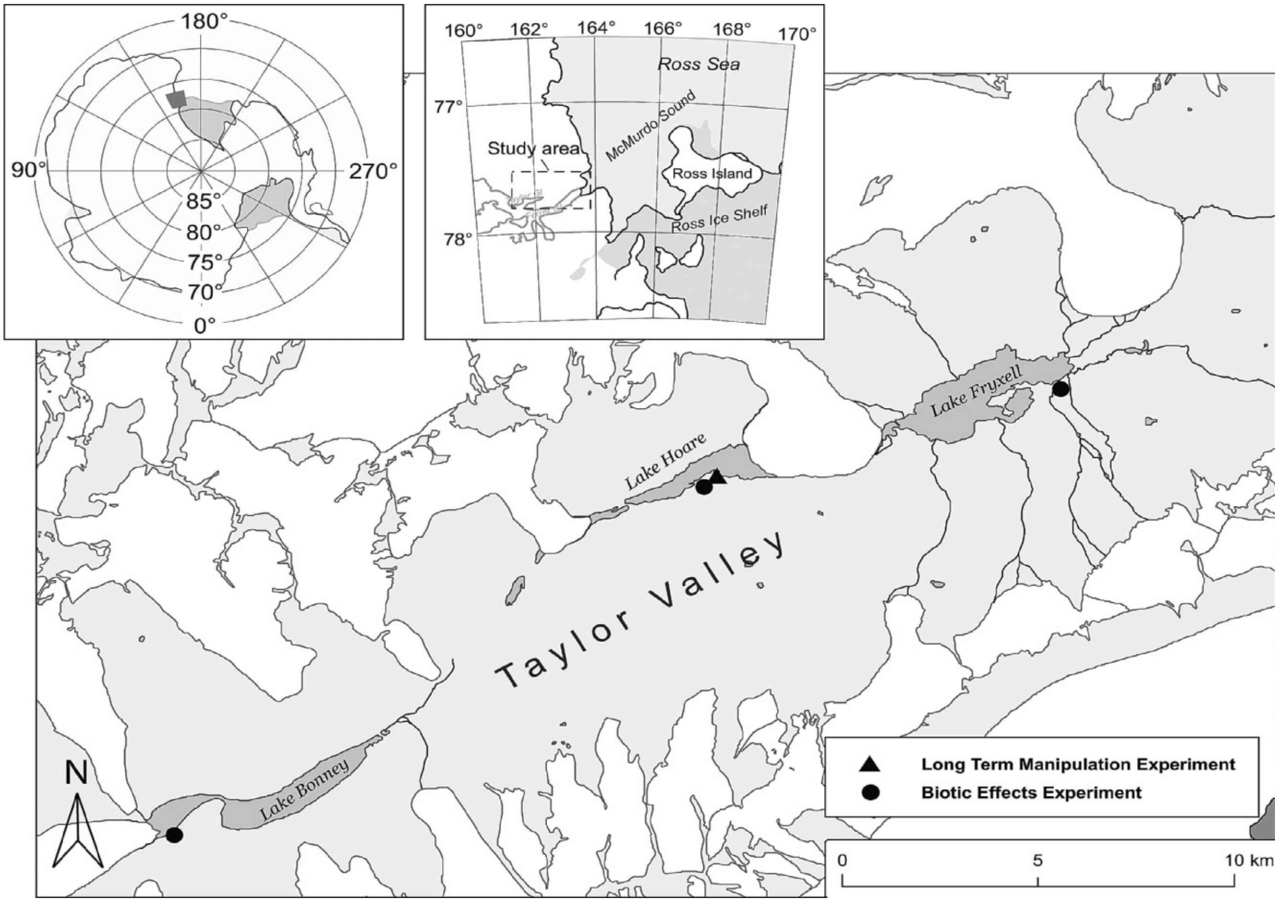
Working in extreme conditions

Adams has placed cone-shaped warming chambers over sections of soil to heat them, he's added water to increase moisture, and, by adding solutions containing nitrogen or carbon, he's tested the effects of those amendments on the system. Samples from the field get worked on first in the McMurdo lab and then again back home.

"We try to do as much analysis as we can while we're on the ice," Wall says. They count all the specimens they collect, and identify species, their life stage, and whether a sample is living or dead. They strive to identify and enumerate the nematodes at a location and document what they know about the populations. To prepare samples for the genetic work done at Adams's lab in Utah, he says, they pull the animals out of the soils or sediments and put individuals in a DNA (deoxyribonucleic acid) extraction solution that will preserve the DNA. Each sample gets put in a tiny tube. At the end of the season, several hundred samples are shipped back to the United States.

"The lab facilities and the laboratory staff down there are just great," Wall says. Adams adds that helicopter pilots and other support staff succeed at giving the scientists the luxury of focusing solely on their work. "Everybody at McMurdo is down there to make sure that your science gets done," he says. "When you're in a remote place, you've got a mountaineer with you," he adds, "and their job is to make sure that you live." Adams says during the austral summer, the temperature typically ranges from right around freezing to about –10 degrees Celsius.

The weather and the remoteness of Antarctica, combined with the short season during which the sun never sets, conspire to form a community of researchers who zealously dedicate themselves to their work. "Every minute you have to do science and interact with your colleagues, you just do it," Adams says. If he's not meeting with the team of researchers with whom he's directly collaborating—and with whom he rarely shares the same physical space—he may be diving into the work of someone else he most likely wouldn't meet at home, such as a glaciologist. "It's like brain candy all the time,"



The Wormherders have worked at sites in Taylor Valley close to Lake Hoare, Lake Fryxell, and Lake Bonney, shown in the map above. Figure by Chris Gardner.

he says. "It's very exciting and gratifying and exhausting."

How the system responds to change

Wall says she and her Antarctic colleagues closely follow what's happening in the Arctic, and their nematode research is also important to biologists at more temperate latitudes. "There's a lot of interest in [whether we] can isolate, down to one species, what their role is in ecosystem functioning."

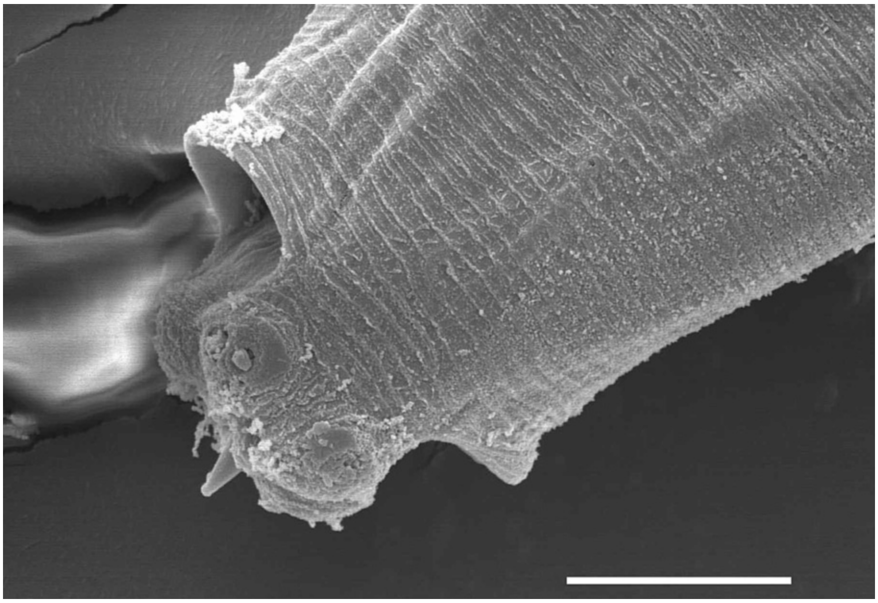
In a new paper she and Adams have coauthored with Ross Virginia of Dartmouth and lead author John Barrett at Virginia Tech, the researchers say nematode biomass accounts for less than 1 percent of soil organic carbon, but it accounts for 5 to 7 percent of soil carbon turnover. Wall says that's equivalent to one or two species of nematodes in Dry Valleys soil doing what hundreds of species of mites, nematodes, millipedes, and other soil invertebrates do in the shortgrass steppe, a region of high biodiversity. One important question Wall's team is pursuing is whether the simple system has built-in redundancy. In the steppe, if one of those species is lost, chances are another would provide the needed functions, she says. "If you have, in a more fragile ecosystem, only one, two, or three species, like we do," Wall asks, "do you have that redundancy built in? What would happen?" The question has urgency.

Two nematode species reacted quite differently to a recent period of documented temperature change. Adams says that about 14 years of cooling in certain parts of Antarctica ended around 2000, and then in 2001 a slight warming prompted a flood in Taylor Valley, one of his research sites. "The glaciers melted a lot, the streams flooded, the lakes filled, and there were huge biological changes that occurred in response to this flood." The dominant nematode of the area, *Scottnema lindsayae,* likes drier soils, and its population decreased. "But another species, *Eudorylaimus,* increased in abundance, with a big bump in hatched juveniles the following year." Documenting this type of change is exciting, Adams says, because it allows him to correlate an environmental condition—in this case a flood event—with species' response.

But *Scottnema*'s decline is actually the continuation of a trend that was occurring during the period of cooling. Wall says that suggests that the one little worm's demise may have major repercussions on the ecosystem.

Knowing what happens to animals after environmental disruptions, including where they go if they leave, could help biologists predict future responses to events such as climate change. Mount Seuss, an elevated area in the Dry Valleys, may offer Adams a chance to study this type of scenario historically. Adams

The most abundant nematode in Taylor Valley, Scottnema lindsayae, *is viewed with a scanning electron microscope. Scale bar is 1 micrometer. Micrograph: Manuel Mundo-Ocampo.*



This scanning electron micrograph shows Eudorylaimus *species from Taylor Valley soils. The scale bar equals 6.67 micrometers. Micrograph: Wade Davidson.*

didn't visit the site this January because of a heavy snowfall, but a colleague, Ian Hogg, was there when the snow came down. "The 60 centimeters of fresh snow caused us considerable difficulty and essentially ended our field sampling," said Hogg, a biologist at the University of Waikato in Hamilton, New Zealand. "However, fortuitously, there was a cache of field equipment for another camp near our site. We were able to locate this cache, and by carefully moving the material, we exposed some bare ground! This is where we were able to get the soil sample for Byron."

Hogg studies springtails and mites, not nematodes, but despite the species' different life history strategies, all of those invertebrates manage to survive in Antarctica. And at one point, the concentration of them at this particular locale seems to have been more diverse than expected. Adams and Hogg, studying the different animals, hope to test a hypothesis that this area once provided a safe refuge for the different species when living conditions in surrounding areas turned hostile. "In most of the Dry Valleys, there is only one species [of springtails]," Hogg says. "However, at Mount Seuss there are three, which is why we think it may be a refuge."

This springtail species, Neocryptopygus nivicolus *(actual size 0.9 mm), is found only in the vicinity of Mount Seuss. Micrograph: Barry O'Brien.*

At Lake Fryxell, Byron Adams and Diana Wall sample their stoichiometry experiment. Photograph: Breana Simmons.

Worm farms are separated from research labs and sleeping tents by frozen Lake Hoare, which Wormherder Steve Blecker is crossing. Canada Glacier is in the background. Photograph: Byron Adams.

Adams says typical soil samples from the Dry Valleys contain one, or occasionally two, nematode species. Not so for the samples from this gym-sized area, which he initially looked at through a microscope at McMurdo station. "We found representatives of every species that's known to exist in the southern part of Victoria Land," he says. Adams will begin genetic work on the Mount Seuss samples soon, but the little they already know makes them very excited.

Hogg adds that further study should help define the area that may have acted as a refuge. "From a conservation perspective, it will be important to ensure that the appropriate area is adequately protected," he says. "This, in turn, will help to maintain genetic variability and maximize the ability of species to respond to environmental change."

Diversity from sequence data

When Adams and his crew in Utah get to work, they take the extracted DNA from the tubes sent back from Antarctica, add appropriate chemicals, and send the samples through a polymerase chain reaction machine. "Poof, voila! You get a tube full of your amplified gene," Adams says. Then an automated sequencer machine reveals the gene sequence. Next, the computational biology begins. As statistical analyses lead to development of lineages and family trees, Adams says, "you get to go back and make inferences about biology.... That's the exciting part." These inferences may address how nematodes disperse, how they partition their resources, or how they're distributed. At this point, Adams says, he can start to speculate about which species were where at what time, how they got there, and why they moved.

"The real power comes when we can start to show that the species that live in Antarctica respond in the same way to the same changes," he says. In a relatively short time, he'll try to find whether there is genetic variation within a given species, and, if so, what conditions might have prompted it. He'll compare nematode

For more information, visit these sites:
www.mcmlter.org/index.html
www.nrel.colostate.edu/projects/soil/index.html
http://nemablog.wordpress.com

data with Hogg's data on other soil invertebrates to build a theory about how the overall ecosystem responded to a particular event. Over a much longer timescale, he can use genetic information to explore adaptations such as an antifreeze protein that allows a nematode to tolerate Antarctica's weather. For this type of study, he would compare the Antarctic species with its closest relative from a temperate Southern Hemisphere location—a nematode that can't handle freezing. He thus begins to trace back evolutionarily how the Antarctic species became adapted to the cold, dark, windy climate.

Adams says that in other locations, it's not possible to study every species in an ecosystem because the sheer volume of samples would be overwhelming. Tim Todd knows about that. He's a researcher at Kansas State University who studies nematodes on the Konza Tall Grass Prairie, another LTER project. Todd estimates that 200 to 300 different nematode species can be found on the prairie. Diana Wall also works on the Konza, in northeastern Kansas, and did some of the early molecular work there. Todd says, "I won't live long enough to know what all of my species are doing out on the prairie, but Diana certainly can [in the Dry Valleys]. She has an opportunity to really nail down what these things are doing, their impact on that ecosystem." In areas of greater biodiversity, Todd says, it's much harder to pinpoint exactly what nematodes are doing.

Wall says the underlying question she considers is, What drives soil diversity? Having experience with highly diverse sites—including the prairie and the Shortgrass Steppe LTER of north-central Colorado—provides her with a radical contrast with the Dry Valleys. She says making comparisons across systems is a valuable aspect of working in the Dry Valleys. "There I can examine the links of soil habitat and evolutionary history and compare [this with] more diverse soil habitats." In fact, she's involved with a global study that is examining soil samples along two longitudinal gradients, from Alaska through Kansas, Costa Rica, and Peru; and from Sweden through Kenya and South Africa, plus New Zealand and Antarctica. The project's goal is to identify worldwide patterns in soil diversity and thereby aid understanding of belowground invertebrates in ecosystem functioning. Wall says work above ground has demonstrated that diversity increases as you move from the poles toward the tropics, but nobody has done corresponding belowground studies. Employing standard techniques across these vast longitudinal gradients, this team aims to determine whether soil organisms follow the same pattern.

Next questions

In April, though Adams had barely begun to get this year's samples unpacked and into his machines, he and Wall and their collaborators had already begun to think about next year. Pursuing the refuge hypothesis will top the priority list for Adams's 2009 field season. Along with Hogg and an international team, Adams says, an effort is under way to conduct a biotic inventory of the region. The goal is to explore the questions of where life might be expected to be found and what kind of life should be there. They also want to know what's driving the presence of animals in various places so they can begin to predict where else in Antarctica those species might be found. The interdisciplinary team will collect many samples from different geological locations. They'll analyze life forms from microbes to invertebrates to algae in what Wall describes as "a biological–geological Strike Force."

"The Valleys are not nearly as sterile as once believed," Wall says. After almost 20 years of studying the belowground life of the Dry Valleys, Wall says she's invigorated by the knowledge that myriad critters—some surviving the hostile environment by assuming a dormant, dehydrated state—are present. "They are just waiting for water, and it is just phenomenal."

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