Microbial awakening restructures high-latitude food webs as permafrost thaws

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Alaska is on the front lines of climate change, experiencing some of the fastest rates of warming of any place in the world. And when temperatures rise in the state's interior—a vast high-latitude region spanning 113 million acres—permafrost there not only thaws, releasing significant amounts of its stored carbon back into the atmosphere where it further accelerates rising temperatures, but also decays.

This decomposition has the potential to infuse above- and below-ground food webs with carbon, which can affect energy flow between these critical ecological linkages and affect the species they support.

One of these species is the tundra vole, one of four Arctic or boreal forest animals that Philip Manlick, a research wildlife biologist with the USDA Forest Service Pacific Northwest Research Station in Juneau, Alaska, examined as part of his study published in the journal *Nature Climate Change*.

Along with collaborators from the University of New Mexico and the University of Texas at Austin, Manlick used a novel technique to quantify the impacts of climate change on energy flow and carbon fluxes between plant-supported above-ground, or green, food webs and microbe-driven below-ground, or brown, food webs using two species of vole, a shrew, and a spider as windows into the complex worlds.

"Understanding how energy moves through food webs helps us understand how ecosystems function and how animals might respond to stressors like climate change," Manlick said. "In Arctic and boreal ecosystems, it's well known that the climate is warming, permafrost is melting, and microbes are flourishing. But we know very little about the impacts of this process on terrestrial food webs and the animals they support."

A novel technique with promise

The novel technique at the heart of the study involved measuring unique carbon isotope "fingerprints" in essential amino acids that only plants, bacteria, and fungi can produce.

Animals can only acquire these molecules through their diets. This allowed these essential amino acids to serve as a biomarker that helped the researchers track how carbon was moving between green and brown food webs, which, ultimately, helped them detect changes.

"Scientists often argue about the importance of animals to ecosystem processes like carbon cycling, but when they eat resources from different food webs, they move carbon between storage pools," Manlick said. "In the future, we think this tool can be used to trace the fate of carbon through food webs to understand the functional roles of animals in ecosystem functions, like nutrient cycling."

The study analyzed bone collagen from museum specimens of tundra and red-backed voles and masked shrews from the Bonanza Creek Experimental Forest near Fairbanks, Alaska, in 1990 and 2021, a sample that represented animals exposed to long-term climate warming.

To study the effects of short-term climate warming on animals, the researchers sampled Arctic wolf spiders near Toolik Lake, Alaska. Some of the spiders were gathered as controls and others were exposed to 2°C warming in outdoor compartmentalized habitats called "mesocosms" in which the scientists could increase temperature on a micro scale to simulate climate warming.

At just over 12,000 acres, and encompassing interior forest and flood-plain habitats, Bonanza Creek Experimental Forest is an ideal site for studying the impacts of climate change on boreal forests and food webs because it provides a long-term record of change in interior Alaska.

It was established by the USDA Forest Service 60 years ago and has been a National Science Foundation Long-term Ecological Research site since 1987. For Manlick, the site offers an opportunity to study how these boreal forest changes are affecting the animals living there and how the animals, themselves, affect forest processes through foraging and food web dynamics.

Significant shift in energy source

Through their isotope analyses, Manlick and his colleagues detected significant changes in carbon assimilation in the mammals—notably a shift from plant-based food webs to fungal-based food webs. In other words, fungi replaced plants as the main energy source—with small mammals, like the shrews, assimilating up to 90% of their total carbon intake from fungal carbon, a more than 40% increase over historical specimens.

The same was true for the Arctic wolf spiders. They, too, shifted from plant-based to fungal-based food webs as the main source of their energy, assimilating more than 50% brown carbon under warming conditions, compared to 26% at control sites.

"Our study presents clear evidence that climate warming alters carbon flow and food web dynamics among above-ground consumers in Arctic tundra and boreal forest ecosystems—across species, ecosystems, and long- and short-term warming scenarios," Manlick said. "And we show that these changes are the consequence of a change from predominantly green, plant-based food webs to brown, microbe-based food webs."

What's behind the shift?

The scientists suspect brown carbon is being transferred to above-ground consumers, like the mammals and spiders, in a series of predation events known as trophic pathways. Increased warming results in increased decomposition in both permafrost on the tundra and in boreal forests; fungi feed on this decomposing plant matter and are, in turn, consumed by arthropods, mites, and earthworms that transfer the fungal carbon upward in the food web where they, in turn, are consumed by the voles, shrews, and spiders.

"Climate warming significantly alters the flow of energy through food webs, such that animals who were historically supported by plant-based food webs are now supported by fungal-based food webs derived from below-ground decomposition," Manlick said.

Animals can alter carbon cycling

Manlick and his colleagues' work underscores that animals serve as a crucial link between green and brown food webs; it also shows that climate warming alters this link across species in the Arctic and in boreal forests. The potential implications of these climate-induced shifts are greater than the small size of these species might imply.

"Shifts in these interactions can have indirect effects on nutrient cycling and ecosystem function," Manlick said.

For example, if voles are getting more of their energy from below-ground sources, they may be consuming fewer plants, which could increase carbon storage in above-ground ecosystems.

"Much of the current work in high latitudes has focused on 'Arctic greening,' or the idea that climate warming is leading to more plant growth and greener ecosystems. We found the exact opposite pattern—food webs are 'browning,'" he said.

Moving forward, Manlick plans to study why these patterns in plants and animals differ and what it means for the future of these rapidly changing ecosystems.

More information: Climate warming restructures food webs and carbon flow in high-latitude ecosystems, *Nature Climate Change* (2024).
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