Microscopic fungi enhance soil carbon storage in new landscapes created by shrinking Arctic glaciers

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The study's authors – researchers Juan Carlos Trejos-Espeleta and Dr. James Bradley, at the study site: the forefield of Midtre Lovénbreen glacier, Svalbard. Credit: James A. Bradley

Melting Arctic glaciers are in rapid recession, and microscopic organisms colonize the newly exposed landscapes. Dr. James Bradley, Honorary Reader in Arctic Biogeochemistry in the School of Biological and Behavioral Sciences at Queen Mary University of London, and his team, have revealed that yeasts play an important role in soil formation in the Arctic after glaciers have melted away.

Roughly 10% of Earth's land surface is covered by glacial ice. However, glaciers are retreating ever further and ever faster because of global warming. As they do, they expose new landscapes which, for many thousands of years, have been covered in ice.

After the glacial ice is gone, microscopic lifeforms colonize the now accessible bedrock, accumulating nutrients and forming new soils and ecosystems. As soil can be a significant carbon store under the right circumstances, how exactly new soils form after the melting of glaciers is a question of great scientific and societal relevance.

To study the formation of Arctic soils, a team led by Dr. Bradley traveled to Svalbard—an archipelago of islands roughly halfway between the North Pole and Norway's northern coast, and well above the Arctic circle. Here, the climate is warming seven times faster than the rest of the world, and glaciers are in rapid decline.

The barren landscapes that are exposed offer very little to support any form of life: the rocky terrain is lacking nutrients, temperatures drop to well below freezing for months on end, and because of its high latitude, there is a complete lack of sunlight during the winter polar night. The very first pioneer colonizers of the inhospitable terrain are microorganisms such as bacteria and fungi.

These microbes determine how much carbon and nitrogen can be stored in the soils—but very little is known about the exact processes behind this nutrient stabilization through microbial activity. Bradley and his team studied these soils to better understand how microbes contribute to the process of soil formation when glaciers vanish.

The results of the study, in which other researchers from Germany, the United States, and Switzerland were involved, have been published in the journal *Proceedings of the National Academy of Sciences* (*PNAS*).

Timeline of colonization

The research focuses on the forefield of Midtre Lovénbreen, a retreating valley glacier in the northwest of Spitsbergen. Dr. James Bradley, who first worked at the site in 2013, said, "A decade ago I was walking on top of the ice and drilling ice cores into the glacier. When we returned in 2021, the glacier had shrunk and instead of ice there were barren, seemingly lifeless soils."

But upon laboratory-based analyses of these soils, the researchers found that they contain incredibly diverse communities of microbes, the smallest and simplest forms of life on Earth.

The newly exposed areas are ideal for researching incremental changes in the soil as they are a natural laboratory for observing the various stages of soil development. The soil closer to the glacier margin is the youngest, and soil further away from the retreating glacier is incrementally older—where more time has passed allowing life to colonize the terrain.

"These are some of the most pristine, delicate, and vulnerable ecosystems on the planet, and they are rapidly colonized by specialized microbes, even though they are subject to extremes in temperature, light, water and nutrient availability," said Dr. Bradley.

Adjusting to the midnight sun and the often changeable weather, the scientists spent weeks working on the rocky and uneven terrain of the glacier forefield, surrounded by crevassed ice, a fjord home to minke whales and seals, and tundra shared by Arctic foxes, reindeer and polar bears. The researchers are trained in recognizing polar bear behaviors and safe handling of firearms, in case of an encounter with a bear while working in the remote Arctic environment.

Pioneer fungi sequester carbon in the soil

Bradley's team investigated the microbial composition of the soils by DNA analysis, while also measuring the cycling and flow of carbon and nitrogen. Through experiments involving isotope labeled amino acids, they were able to precisely follow the microbial assimilation and metabolism of organic carbon.

"We were especially interested in what proportion of carbon microorganisms lock in the soil as biomass and how much they release back into the atmosphere as carbon dioxide," says Juan Carlos Trejos-Espeleta, the lead author of the study from Ludwig Maximilian University of Munich, Germany.

Their main focus was on fungi—a group of microorganisms that are known to be often better adapted than bacteria at storing a lot of carbon in the soil and keeping it there. The ratio of fungi to bacteria is an important indicator of carbon storage: More fungi mean more carbon in the soil, while more bacteria generally lead to the soil emitting more CO_2.

"In high Arctic ecosystems, the variety of fungi is particularly high compared to that of plants, which increases the likelihood that fungal communities could play a key role there as ecosystem engineers," said author Professor William Orsi, from Ludwig Maximilian University of

Munich, Germany.

Discovering more about the carbon assimilation processes of fungal and bacterial populations and carbon flow processes in the ecosystem is crucial for making accurate predictions about how terrestrial ecosystems in the Arctic will respond to future warming.

And indeed, the researchers were able to show that fungi—or more precisely, specific basidiomycete yeasts—play a decisive role in the early stabilization of the assimilated carbon. According to the study, they are the fungal pioneers in the young postglacial soils and make a decisive contribution to the enrichment of organic carbon.

"We found that these specialized fungi are not only able to colonize the harsh Arctic landscapes before any other more complex life, but that they also provide a foothold for soil to develop by building up a base of organic carbon which other life can use," said Dr. Bradley.

In older soil, bacteria increasingly dominate amino acid assimilation, leading to a significant reduction in the formation of biomass and an increase in CO_2 emissions from respiration.

"Our results demonstrate that fungi will play a critical role in future carbon storage in Arctic soils as glaciers shrink further and more of Earth's surface area is covered by soil," summarizes Prof. Orsi.

More information: Orsi, William D. et al, Principal role of fungi in soil carbon stabilization during early pedogenesis in the high Arctic, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2402689121

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