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Research into carbon storage in Arctic tundra reveals unexpected insight into ecosystem resiliency

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This image shows the US Arctic LTER greenhouse in peak autumn and early winter. Credit: Sadie Iverson (autumn), and Josh Schimel (winter)

When UC Santa Barbara doctoral student Seeta Sistla and her adviser, environmental studies professor Josh Schimel, went north not long ago to study how long-term warming in the Arctic affects carbon storage, they had made certain assumptions.

"We expected that because of the long-term warming, we would have lost carbon stored in the soil to the atmosphere," said Schimel. The gradual warming, he explained, would accelerate decomposition on the upper layers of what would have previously been frozen or near-frozen earth, releasing the greenhouse gas into the air. Because high latitudes contain nearly half of all global soil carbon in their ancient permafrost — permanently frozen soil — even a few degrees' rise in temperature could be enough to release massive quantities, turning a carbon repository into a carbon emitter.

"The Arctic is the most rapidly warming biome on Earth, so understanding how permafrost soils are reacting to this change is of major concern globally," Sistla said.

To test their hypothesis, the researchers visited the longest-running climate warming study in the tundra, the U.S. Arctic Long-Term Ecological Research site at Toolik Lake in northern Alaska. This ecosystem-warming greenhouse experiment was started in 1989 to observe the effects of sustained warming on the Arctic environment.

What they initially found was typical of Arctic warming: low-lying, shallow-rooted vegetation giving way to taller plants with deeper roots; greater wood shrub dominance; and increased thaw depth. What they weren't expecting was that two decades of slow and steady warming had not changed the amounts of carbon in the soil, despite changes in vegetation and even the soil food web.

The answer to that mystery, according to Sistla, might be found in the finer workings of the ecosystem: Increased plant growth appears to have facilitated stabilizing feedbacks to soil carbon loss. Their research is published in the recent edition of the journal *Nature*.

"We hypothesize that net soil carbon hasn't changed after 20 years because warming-accelerated decomposition has been offset by increased carbon inputs to the soil due to a combination of increased plant growth and changing soil conditions," Sistla said.

The increased plant productivity, caused by the warmer temperatures — on average 2 degrees Celsius in the air and 1 degree in the soil to the permafrost — has increased plant litter inputs to the soil. Unexpectedly, the soils in the greenhouse experiment developed higher winter temperatures, while the summer warming effect declined.

"These changes reflect a complicated feedback," Sistla said. "Shrubs trap more snow than the lower-lying vegetation, creating warmer winter soil temperatures that further stimulate both decomposers and plant growth. Shrubs also increase summer shading, which appears to have reduced decomposer activity in the surface soil by reducing the greenhouse effect during the summer."

The increased plant growth and deeper thaw, meanwhile, also may have enabled increased carbon availability in the deeper mineral layer that overlies the permafrost. In fact, the researchers found the strongest biological effects of warming at depth, a "biotic awakening," with mineral soil decomposers showing more activity, along with the increased carbon stock at that level. "It's a surprising counterbalance," said Schimel. "It may be that those soil systems are not quite as vulnerable to warming as initially expected."

However, whether or not this phenomenon — no net loss of soil carbon despite long-term warming — is a transient phase that will eventually give way to increased decomposition activity and more carbon release, is not yet known. Future studies will include investigation into the mineral soil to determine the age of the carbon, which may in turn yield clues into how the carbon cycle is changing at depth, where the majority of tundra soil carbon is stored.

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According to Sistla and Schimel, this research paradigm validates the NSF LTER program's commitment to supporting long-term experiments, because it creates opportunities for younger scientists to observe effects and condition decades after experiments are established — results that could not have been foreseen when the experiments were started.

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