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SCIENCE

Runaway global warming becomes a concern as permafrost melts

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Dying trees in boreal forests point at odd angles as the melting ground underneath them turns to a boggy, greenhouse gas-emitting mush. Photo by Gayathri Vaidyanathan.

This is the second of a four-part series. Read the first part [here](#).

GOOSE LAKE, Northwest Territories -- In a fragile landscape where footsteps leave an imprint for years, Jennifer Baltzer stood and surveyed the surrounding bog of green sphagnum moss. Black spruce trees tilted here and there like drunkards.

Using a metal rod, Baltzer, an ecologist with Wilfrid Laurier University in Waterloo, Ontario, pierced the ground near a spruce.

"You are jamming into ice there," she said. Without that freeze, the unstable spruce trees would entirely lose their footing and drown.



An occasional series on one of the more ominous problems in climate change: tracking the declining ability of forests, land and oceans to store carbon dioxide as the Earth warms.

Goose Lake is at the knife's edge of climate change. Half a century ago, this region, which is 250 miles from the Arctic Circle, used to contain mostly permafrost, or perennially frozen ground. Today, the ground has partially thawed and the region is predominantly wetland.

The rapid changes have been catalyzed by climate change, which has warmed these environs by 4 degrees Fahrenheit in the past half-century. Scientists worry that, as permafrost thaws, a portion of the carbon stored in the northernmost ecosystems will be released to the atmosphere and trigger runaway global warming. The biggest threat at present is posed not by the frozen tundras of the Arctic, but by the soils of the boreal -- the southern reaches of the deep freeze in Canada, Alaska and other parts of the world -- like at Goose Lake, where the permafrost is thin and sporadic,

the soil temperature close to melting point, and the land already disturbed by oil and gas exploration.

Baltzer and her fellow scientists are based at a nearby research camp named Scotty Creek, where they are studying how permafrost melt is reverberating through the landscape. They begin each March, snowmobiling like lynxes over blankets of snow. As the sun gets stronger and the ice melts, lakes become transport routes for canoeing graduate students. By September, snow blankets the ground again and the scientists pull up their tents, dismantle their makeshift bench press (two 40-pound sandbags hung on a log) and head home for the year.

Scotty Creek is the only research station located in the western boreal taiga of Canada. It is part of FORESTGeo, a global effort spearheaded by the Smithsonian Tropical Research Institute to understand how global warming is altering the planet's forests. It is one of the few groundtruthing stations for NASA's ABoVE (Arctic Boreal Vulnerability Experiment) initiative, meant to help understand how a warming sub-Arctic will respond to climate change in the next century.

Climate models say that if humans continue emitting at present-day rates, between 37 and 174 gigatons of carbon could be lost from permafrost by 2100, according to a [study](#) published in April in *Nature*. Most of the release would be in the form of CO₂ and methane. President Obama highlighted the risk at a conference in Alaska this August.

"If we do nothing, temperatures in Alaska are projected to rise between 6 and 12 degrees by the end of the century, triggering more melting, more fires, more thawing of the permafrost, a negative feedback loop, a cycle -- warming leading to more warming -- that we do not want to be a part of," he said.

Plunging into a warming unknown

At Scotty Creek, Baltzer, 37, chatted with her fellow scientists in the weather haven, a semi-permanent shelter that doubles as a kitchen and meeting hall. In 2014, a fire had ravaged the forest across Goose Lake, turning all aboveground vegetation to charcoal. Baltzer had installed experimental stations at the burn site to track the forest's recovery.

Bill Quinton, a hydrologist at Wilfrid Laurier, mentioned that his experiments at the burn site might overlap with Baltzer's. Baltzer asked him to eliminate the overlap, and he agreed.

Baltzer is consumed by her research in the boreal and the Arctic. This summer, she spent six weeks on field trips studying how the Northwest Territories' 2014 fire season, the worst on record, had affected the boreal ecosystem. She is running three research projects and is coordinating with the Smithsonian and NASA on two of them. The punishing schedule keeps her away from her two young daughters.



Why is this woman smiling? Jennifer Baltzer runs three research projects where melting permafrost could bring on runaway climate change. Photo by Gayathri Vaidyanathan.

When Baltzer speaks about her research, her words seem to be directly lifted from a grant proposal.

"[The boreal] is such a large biome on the planet and, as a consequence, changes in that system have direct impacts on the global climate," she said one evening, sitting on a dock jutting out into Goose Lake. Flies flitted around, and a loon laughed in the background.

"I'm not doing a very good job explaining this," she said suddenly, with a sigh.

The boreal covers 5.3 million square miles in Europe, Asia and North America, and is an ancient carbon sink. About 20,000 years ago, ice sheets that had covered all of Canada rolled back into the Arctic. Coniferous forests rapidly expanded northward, their roots firmly planted on permafrost.

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As the planet entered the summer-like Holocene Epoch 11,500 years ago, some of the southern reaches of the permafrost thawed and forests there turned to bogs and fens, which are known in Canada as muskeg. In that sense, the boreal has always been a shifting landscape.

Quinton, 50, arrived at Goose Lake with a colleague in 1999, on a helicopter. The region is at the delta of the Mackenzie River, where members of the Jean Marie River First Nation tribe traditionally hunt moose and caribou. From the air, the land appears as muskeg and ever more muskeg, separated by stands of conifers.

Fens are peculiar surfaces. They consist of blankets of sedges and sphagnum with mostly open water beneath. The helicopter pilot was a novice. He hovered 10 feet above the ground and shouted to the scientists, "OK, throw your stuff out! Now!"

Quinton looked at his colleague, who stared back. They threw out their backpacks, which landed on the fen with a splash and quickly sank in. The scientists jumped out and sank waist-deep. "Oh, my God! This is awful," Quinton shouted.

He spotted conifers that seemed to be on stable ground. This is due to a quirk of permafrost. The freeze lifts soil out of the wetland to form plateaus that are dry enough for trees to grow on. Without permafrost plateaus, tree roots would drown.

"If the trees can stand, I can stand," he thought. The scientists walked to the plateau and established their research station, named after a Scottish hermit who lived and died around here.

In addition to rooting trees, the permafrost serves as a reservoir of carbon. One **study** estimates that there is roughly 1,095 gigatons stored in the boreal, about 95 percent of it contained in the soil. An unquantified fraction of that occurs in frozen, peat-rich soils similar to Scotty Creek. Overall, the boreal is one of the largest carbon sinks in the world.

Bogs where forests stood

Scientists are concerned that permafrost will thaw and the deep carbon reserves consisting of the remnants of partially decayed, ancient vegetation will dry out and decompose, releasing carbon to the atmosphere. But they have struggled to accurately model the scale of the problem, with certainty so low that the information is useless to policymakers.

Climate modelers, who use computers to mathematically represent the Earth and project its future, do not use these values in their simulations. Their models at present find that nations can emit 485 gigatons more of CO₂ before the world approaches the threshold of dangerous climate change. But without the permafrost releases, this carbon budget may be an overestimate.

April brings the onset of spring thaw to Goose Lake, and the start of the growing season, which has advanced by a day and a half every decade since the 1980s. Temperatures have warmed by 4 degrees Fahrenheit since 1970. Wintertime temperatures have increased by 7.3 F.

The warming has triggered a chain reaction in this frozen, peat-rich landscape, which also occurs in circumpolar Asia and Europe. Permafrost, which typically occurs 1.6 feet below ground here, has plunged to 10 feet at places and disappeared entirely elsewhere. Permafrost plateaus have collapsed and formed bogs.

Since 1947, 30 percent of land at Goose Lake has switched from boreal forest to wetland. The rate of forest loss in the early 21st century was three times as high as in the previous decades, Baltzer said. She has done a census of every tree at a nearby 50-acre plot to see if there are any changes in species composition over time. She is also tracking changes in soil carbon and the rate of photosynthesis. She will redo the measurements in five years' time to track any changes.

"The landscape is reorganizing due to permafrost thaw," Quinton said.

But thaw does not automatically translate to a net loss of carbon at Scotty Creek. Oliver Sonnentag, 41, an atmospheric scientist and wannabe float plane pilot, keeps a close eye on the CO₂ and methane entering and exiting the site from a monitoring station on top of a \$90,000, 165-foot-tall tower. This August, he dispatched his field technician, Karoline Wischnewski, to clean the sensors. A large spider appeared above her on the harness rope, and Wischnewski eyed it. She is usually unfazed by the challenges of living in the north, an attitude reflected in a wooden plaque she has hung at the weather haven that reads, "Life isn't living with the ponies."

"I don't like spiders," she shouted down to Sonnentag, and then calmly polished the sensors. The measurements here follow the protocols established through FLUXNET, a global network of 500 sites tracking local changes in the CO₂, water and energy balance in order to construct a detailed picture of Earth system changes. Sonnentag said this tower was particularly difficult to install, since it is founded in permafrost that is susceptible to degradation. Over three years, the ground has subsided by 20 centimeters.

"If the permafrost [completely] thaws out, then this thing has no foundation, it is gone," he said, standing at the base of the tower.

Sonnentag is also tracking the amount of carbon carried in channels of water, as bogs drain into the Mackenzie River, which joins the Arctic Ocean. Sonnentag thinks that, overall, the landscape changes at Scotty Creek have released as much carbon as its plants are taking up for photosynthesis. The sphagnum moss, particularly, is thriving.



The weather haven, the combination kitchen and meeting hall for scientists who examine fast-changing life in the tundra. Photo by Gayathri Vaidyanathan.

Fires help a CO₂ sink to become a source

"Overall, these preliminary results suggest that there is more methane coming out, but at the same time, more CO₂ is taken up," he said. Once the bogs drain out and dry in the future, they may become sources of CO₂.

The complexity of the carbon balance at Scotty Creek illustrates why it is difficult to predict whether the boreal sink will become a source of carbon as the planet warms. There are two large, opposing trends that will determine its fate, said Steven Wofsy, an environmental scientist at Harvard University, in an interview last October.

The northern edge of the boreal is expanding into the treeless tundra in places, responding to a longer growing season and warmer temperatures. And at intermediate locations, like Goose Lake, bogs are ramping up CO₂ uptake.

But at the southern edge of the boreal, farther south than Scotty Creek, where temperature changes are outpacing precipitation, trees are dying. Throughout the circumpolar boreal, wildfires, which are a quick way to turn trapped soil carbon into CO₂, have become more frequent and are burning larger areas.

"A big concern about what is happening is that you've got drier conditions that promotes more frequent big fire years and more severe fires," Baltzer said.

Scientists witnessed this threat at Scotty Creek in June 2014, when lightning set off a fire on a permafrost plateau during a record drought and fire season. The province dispatched tankers to fight the blaze, and when it was done, the ground was scorched. The scientists set up experiments to see whether the blackened ground would speed thawing. Quinton is studying the flow of water in the ecosystem, and Baltzer is looking at how vegetation recovers after a wildfire at this site and 30 others across the Northwest Territories.

The scientists and graduate students, who sometimes spend months with each other at this remote camp without modern distractions, incessantly tease each other.

This August, at the burn site, blackened twigs and sticks poked out of the black ground. Flecks of green suggested plants were finding a foothold. At the edge of the burn site, the permafrost plateau had collapsed into bog. The bright orange of fire retardant was hardly visible.

So far, the scientists have found that the permafrost layer has dropped almost 8 inches within months, Quinton said. The buzz of a drone filled the air, and the machine came into view, high over the canopy, maneuvered by a graduate student photographing landscape changes.

"It is Baltzer, her eye in the sky," Quinton said. "I'm afraid there's going to be a loudspeaker on it, 'Quinton, back to the camp!'"

Tomorrow: When the warming tundra burns.

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