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TUNDRA'S BURNING

Lightning and fires on the Arctic tundra seem to be on the rise. Jane Qiu meets the researchers learning from the scorched earth in Alaska.

More than 20,000 lightning strikes were recorded on the North Slope of Alaska in 2007. Some struck the vast stretches of lakes; some hit the treeless tundra. And one of them torched into life the largest and longest-lasting tundra fire recorded in the state's history. The blaze, which started near the Anaktuvuk River on 16 July, burned 7,000 hectares a day at its peak, and eventually consumed 100,000 hectares, an area larger than that of New York City. It finally stopped burning in early October, smothered by thick snow.

Two years later, the scars left by the blaze are all too apparent from a helicopter circling over the region. So too is the area's quick recovery. Tussock grass, the predominant vegetation in northern Alaska, sends up vibrant green shoots from scorched meristems. Its white flowers bloom over the deeply blackened soil like a dust of snow, stretching to a hazy horizon. It is surprisingly beautiful.

This is more than a view of nature's swift destruction and renewal; it is also a site of intense research. "The Anaktuvuk River fire is a large natural experiment," says Gaius Shaver, an ecologist at the Marine Biological Laboratory in Woods Hole, Massachusetts, who leads an effort funded by the US National Science Foundation to study the fire's environmental impact.

to study how the entire ecosystem responds to major disturbances." Scientists from ten research groups have been flying into the burned area from the nearby Toolik research station to assess how the fire has shifted the carbon balance and affected the hill slopes, valleys, streams and lakes in the region.

Understanding the effect of fires on the Arctic tundra may become more important as the climate gets warmer. Tundra fires used to be rare events, but higher temperatures and a more arid climate seem to be changing that. According to the US Bureau of Land Management in Washington DC, the frequency of lightning on the North Slope has increased tenfold in the past decade. And many researchers fear that the increased lightning may increase the fire risk. Of the 26 recorded fires on the North Slope since 1950, close to one-third has taken place in the past three years — and the region burned in the Anaktuvuk River fire alone constitutes more than half of the total burned area.

Just as climate change may fuel fires, fires may accelerate climate change. These vast areas of tundra store about 14% of the world's soil carbon at the surface alone. Fires could release a large amount of that, either directly through combustion or indirectly by modifying the tundra ecosystem. Many of the studies in Alaska

"Tundra fires could significantly impact the carbon balance of the Arctic and exacerbate global warming," Shaver says.

The first pulse

One of the first researchers to arrive in the area after the fire was Cody Johnson, an aquatic ecologist at Utah State University in Logan, along with a small team. The razed landscape had been buried under snow all winter. And it still wasn't exactly camping season when, in May 2008, they flew out to Dimple Lake in northern Alaska, at 69° latitude and 200 miles north of the Arctic circle. The crew landed in skis, dragged their heavy equipment to the lake shore, set up camp and waited in sub-zero temperatures for the first snow melt.

After two weeks, Johnson could see the land for the first time. "The surface was covered in a thick layer of ash," he says. "There was a pungent smell of the burn in the air." Underneath the ash they found a blackened land with islands of yellow tussock trunks sticking out. These many-layered skirts of grass are so thick and packed so tightly that the core never dried out, saving them from the fire.

The main purpose of Johnson's camping trip was to study the movement of burned materials, especially ash, nutrients and sediments, into streams and lakes, and its effect on the ecothe soil together have burned, these nutrients and sediments can be readily flushed out. A boost in nutrient levels could stimulate the rate of primary production — the production of organic compounds from the fixing of carbon dioxide during photosynthesis. By contrast, additional sediments could partly offset this effect by smothering algae, the key player in carbon fixation. Working out the net outcome of these and other interconnecting processes on carbon is no mean feat.

George Kling, a lake ecologist at the University of Michigan in Ann Arbor, says that the lakes in the Arctic, already supersaturated with carbon, are a net source of carbon dioxide and methane — they release more of these gases than they can store. He and others have shown that when carbon moves from land into lakes, some 20% of the Arctic carbon sink is re-released[1]. "You can think of the aquatic system as a release valve, which leaks carbon from land to water and then back to the atmosphere," says Kling, who is collaborating with Johnson. "Major disturbances such as the Anaktuvuk River fire could turn that trickle into a large flood and cause much greater movement of carbon."

The researchers predicted that the biggest inflow of nutrients after the fire would be from the snow run-off. "We wanted to capture that first pulse," says Johnson. Every day they sampled what went into the streams and how much of those materials ended up in rivers and lakes. Their initial results, which have not yet been published, show that streams in the burned areas dumped up to five times more sediment into Dimple Lake than those in unburned ones, but carried only twice as much carbon. Puzzled by the discrepancy, Kling and his colleagues looked at the quality of the water that leached out from the soil and found that microbes performed decomposition seven times faster in water from the burned area than in unaffected sites. "It seems that carbon is released into the atmosphere through microbial decomposition before it reaches the streams," says Kling.

Johnson and his team weren't camping alone for long. In June 2008, Michelle Mack, an ecologist at the University of Florida in Gainesville, flew to the burned area with a handful of colleagues to reconstruct how much carbon and nitrogen were there before the fire, and to calculate how much carbon was released into the atmosphere during and after

measuring sticks, they estimated the depth of the soil before the fire. They also gauged the carbon concentration in the soil from unburned sites at the same climate and elevation as the burned area.

The blaze generated a big carbon cloud. Mack found that the fire emitted 1.8 million tonnes of carbon dioxide into the atmosphere, equivalent to about 0.03% of the annual global carbon emission due to human activity. "That amount was certainly large enough to change the carbon balance of the entire North Slope for 2007," Shaver says.

Burning up

The burned area continues to pump carbon into the atmosphere, says Adrian Rocha, an ecologist working in Shaver's group. To measure the net carbon flux, Rocha and his colleagues set up a meteorological tower in a severely burned area, a moderately burned one and an unburned control site. They found that, within a radius of one kilometre around the tower, the severely burned site released 80 grams of carbon per square metre during the summer months, whereas the unburned tundra was absorbing 50 grams of carbon per square metre. They suspect that, in the burned area, the rate of carbon fixation by photosynthesis dropped because so many plants were destroyed, and that was outweighed by the rate of carbon being released by microbial decomposition in warmer soil. Now Rocha is extrapolating the results to a larger area. He is using a satellite instrument called the Moderate Resolution Imaging Spectroradiometer (MODIS) to measure how green the land surface is, and is building a model to correlate the greenness to the type of tundra vegetation[2].

Once he has a good model, he will be able to estimate the carbon flux of the entire burned area for different periods after the fire.

Mack found that 60% of the initial carbon emission was from the burning of organic plant and animal material in the soil — which is usually pretty wet on the tundra and doesn't make an efficient fire fuel. The rest came from mosses, lichens and other plant materials on the tundra surface. The organic matter in soil insulates the permafrost — the permanently frozen ground — underneath, and any reduction in the soil depth could mean that the underlying permafrost warms and thaws, with big repercussions for the ecosystem. At the end of June 2009, the permafrost had thawed to a depth of 40 centimetres in severely burned areas, compared with 18 centimetres in unburned sites. Permafrost thaw can be exacerbated by the fire-blackened surface, something else that Rocha and his colleagues are measuring.

Researchers have been trying to understand the impact of permafrost thaw on carbon exchange for some time. A study by Edward Schuur, an ecologist at the University of Florida, and his colleagues, showed that there was net carbon loss from a tundra landscape that had undergone permafrost thaw for more than several decades[3]. The world's permafrost contains twice as much carbon as its atmosphere; it would be bad news if even a fraction of that were released[4].

The accelerated melting of permafrost caused by the Anaktuvuk River fire has carved more visible changes out of the landscape. The newly softened soil can collapse or slide away, creating a landscape that is pock-marked with hollows known as thermokarsts. Johnson noticed thermokarsts forming in autumn 2008, and they had grown much bigger when he went back this summer. He watched one, on the shore of Horn Lake, double in width to 200 metres in two


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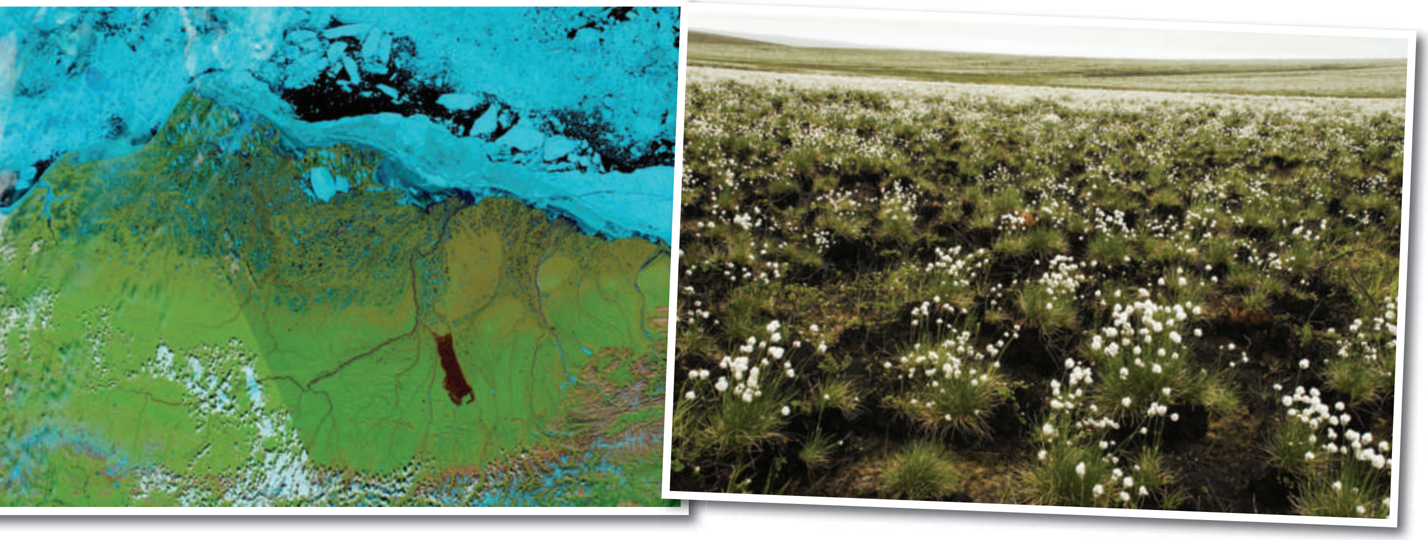

Studies are exploring the 100,000 hectares burned in the Anaktuvuk River fire (brown rectangle, left); cotton-grass flowers were one of the first signs of recovery.

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now been dubbed 'the valley of thermokarsts', there are about a dozen on each slope. "It's a muddy holocaust," says Kling.

Many fear that major disturbances to the Arctic, such as fires and the resulting thermokarsts, could change the vegetation on the tundra, so they are monitoring it closely as it rebounds. Tussocks are amazingly resilient and even the most severely burned ones sprouted as soon as the spring kicked in last year. Sphagnum moss and fruticose lichens, the 'down jacket' of the tundra that insulates the soil from incoming heat, have shown no sign of recovery. In their place are patches of copper-wire moss, with its red stems and golden, hanging capsules, and liverwort, holding up its peculiar umbrella-shaped reproductive organs.

Spread of the shrubbery

The researchers worry that exposed mineral soil and more nutrient availability after fires will favour the expansion of species such as shrubs. This, too, could alter the net carbon exchange: studies of experimental plots show that more nutrients are associated with more shrubs and a net loss of soil carbon. But there are issues beyond that. Shrubs are drier and woodier so burn better than most other tundra vegetation — more shrubs growing after this fire could therefore push up the risk of future ones. "Shrub expansion could be a positive feedback to climate change and fire frequency and severity," says Charles Racine, an ecologist who has been studying fires in Alaska since 1977, and who has retired from the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire.

In collaboration with Randi Jandt of the Alaska Fire Service at Fort Wainwright, Racine and his colleagues have documented

fire on the Seward Peninsular in northwestern Alaska, which left less severe damage than the Anaktuvuk River fire even though a similarly large area was burned[5]. Thirty-two years after the fire, there is still no sight of the sphagnum moss or fruticose lichens, which before the fire covered 20% and 7% of the surface, respectively. By contrast, the area covered by willow, a deciduous shrub, rose from 5% in 1973 to 25% in 2001 and to about 40% this year. Philip Higuera, a palaeoecologist at the University of Idaho in Moscow, Idaho, and his colleagues looked further back in history. By analysing the pollen and charcoal contents in sediments from lakes in northern–central Alaska that are 15,000 years old, they found that an increase in fire frequency coincided with the vegetation transition from herbs to shrubs around 14,000 years ago[6].

Whatever fuelled the blazes of the past, researchers are keen to find out what kept the Anaktuvuk River fire burning, and how others could be predicted in the future. The summer of 2007 saw the record high temperature and record low precipitation north of the Brooks mountain range, resulting in extremely dry soil[7]. Yet there were two other fires near the Anaktuvuk River that went out rapidly.

Nancy French, an expert on remote sensing at the Michigan Tech Research Institute in Ann Arbor, and her collaborators, including Jandt and Racine, are hoping to get a grant from NASA to map past tundra fires across Alaska and Canada using satellite data. "There is an urgent need to have a comprehensive record of tundra fires, so we could be in a better position to predict tundra fire regimes in the future," she says. The researchers plan to correlate tundra fires with weather conditions, and to construct computer models to calculate carbon emission during a fire, predict vegetation recovery and test how climate change could affect fires in the tundra.

For the researchers at Anaktuvuk River, meanwhile, the tundra is changing almost daily. On the northeastern bank of Dimple Lake, a massive patch of soil has slumped into the water, muddying the turquoise with grey. Farther up the shore, the cotton grass ripples across the hill in a breeze. This is the scene after just one lightning strike sparked a fire. And researchers can be confident that lightning will strike again. ■

Jane Qiu, a recipient of the 2009 Marine Biological Laboratory Logan Science Journalism Fellowship, writes for *Nature* from Beijing.

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Soil softened by fire can collapse, creating

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