What's brown and soggy and could save the world?

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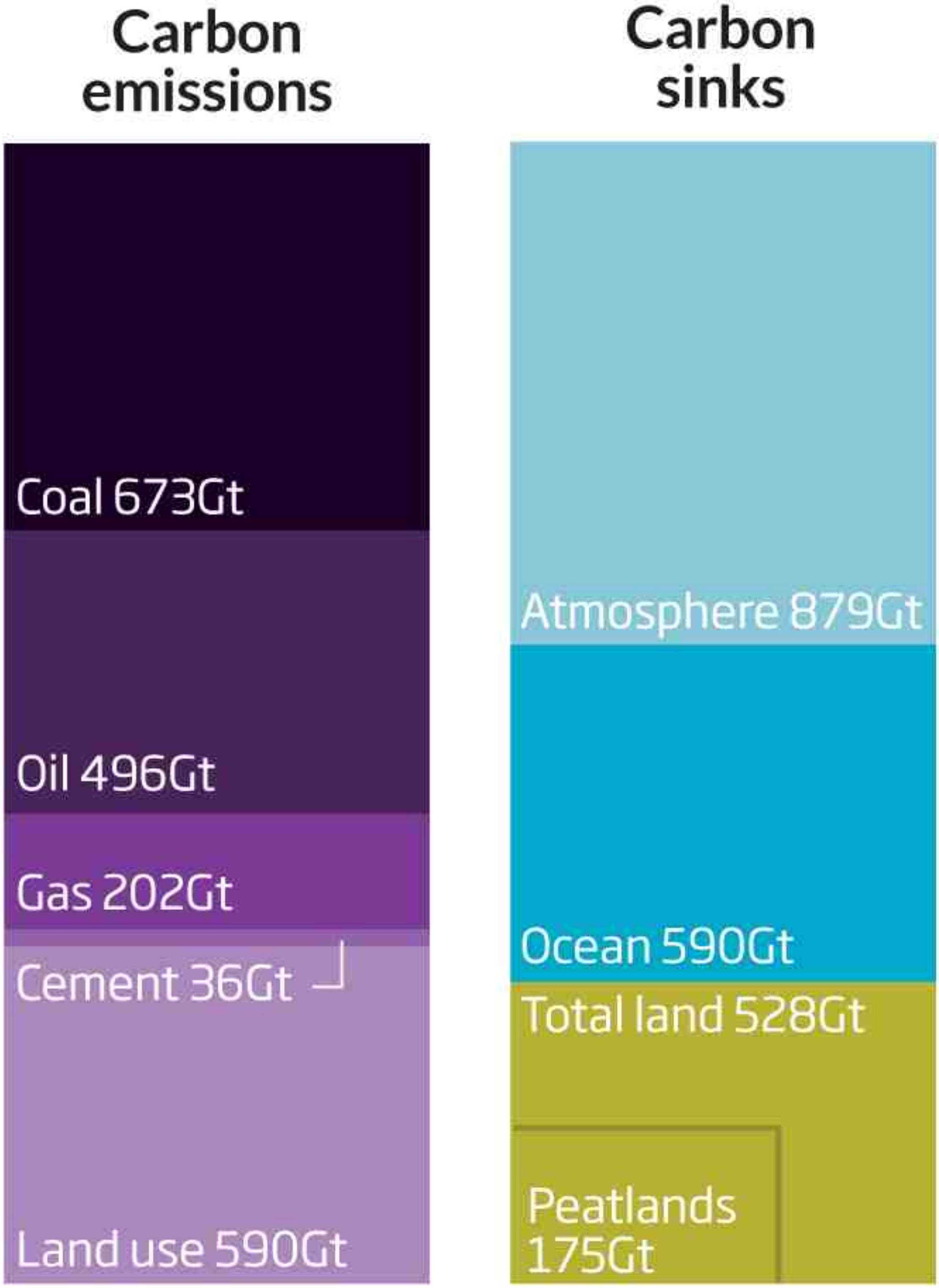
Saved by the sinks

Of all the carbon produced by human activity since 1750 – nearly 2000 gigatonnes – about a quarter has been absorbed by the land



SOURCE: IPCC (2007) WG1, GLOBAL CARBON PROJECT, CIAC, NOAA

They may lack the glamour of rainforests, but in the fight against global warming peat bogs could be our best ally... or our complete undoing

COLLEEN IVERSEN is talking to a tube. "Oh, you'll go in," she tells it. Dressed in a neon orange vest, khaki trousers and rubber boots that are ankle-deep in squelchy muck, she is pushing a wire mesh cylinder into a bog. Ignoring the mosquitoes that swarm around her face, Iversen leans her weight against the tube and gives it one more shove. Shlump! It is swallowed up, and there it will remain for the growing season until Iversen returns to collect a sample of new-grown roots and sludge.

This is not your average bog. Nestled in a crook of the Mississippi River in northern Minnesota, the watery landscape pierced with black spruce trees has been divided into 17 octagonal plots, each covering about 12 square metres and linked by aluminium boardwalks that can support a jeep. Workers are constructing glass chambers around each plot, creating a system of open greenhouses as part of a grand experiment. Its aim? To find out how climate change will effect one of the most precious and vulnerable ecosystems on Earth: the humble peat bog.

There is more to these waterscapes than meets the eye. Since they began forming 12,000 years ago in glacial hollows carved out during the last ice age, peat bogs have been squirrelling away carbon that would otherwise leak into the atmosphere. Although they cover just 3 per cent of the Earth's land, they harbour a third of its in-ground carbon (see diagram). For a given area, they are five times as carbon-dense as rainforests, which makes them our secret allies in the war against climate change. But as temperatures rise, peat bogs could be poised to make a drastic switch. The fear is that they are reaching a tipping point beyond which their stored carbon will be released, triggering a positive feedback that will warm the Earth further. However, at present we cannot say for sure what will happen. The experiment in Minnesota should end that ignorance.

Leonardo da Vinci put it rather poetically: "We know more about the movement of celestial bodies than the soil underfoot." Little has changed in the five centuries since. To ecologists, bogs are a mysterious black box: almost all their carbon storage and chemical processing takes place out of sight, within the mushy layers of peat. "We walk on the largest reservoir of terrestrial carbon every day and only have a rudimentary understanding of how important the inherent processes are to the Earth's climate system," says Dan Stover, who manages terrestrial ecosystem sciences at the US Department of Energy (DOE).

In 2008, the DOE identified peatlands as a critically vulnerable ecosystem and a gaping hole in our knowledge of the global carbon cycle. Now it is funnelling $80 million into filling that hole. Iversen, an ecosystems biologist at the DOE's Oak Ridge Laboratory in Tennessee, is one of more than 40 researchers preparing to heat up one of these ecosystems for a decade. As part of the most extensive climate-change simulation ever attempted, in spring 2014 they will switch on giant glass heating chambers that can warm the plots by up to 9 °C, while exposing them to the high levels of carbon dioxide predicted for the next century. SPRUCE, as the experiment is called, will give us the data we need to incorporate these endangered wetlands into global climate models. Essentially, SPRUCE is cooking one bog in the hope of saving the rest.

"These little guys are tough," says Rich Norby, leaping off the boardwalk around one experimental plot and into the bog. His feet sink in with a "plop-plop" sound as he plucks a plant to demonstrate. Meet *Sphagnum*, the genus of moss that carpets wetlands across the Northern hemisphere. Here it hugs the side of every minute hill and valley, looking like a thick blanket of tiny, lime-green starfish. Interlacing their star-shaped crowns like fingers, the mosses work together to wick up water. "But they're also really easy to kill," says Norby, SPRUCE's resident sphagnum researcher. With no vascular system to pump water and nutrients around, sphagnums cannot grow tall, which could be their downfall when things start to heat up. If higher CO_2 levels boost the growth of other bog plants such as sedges, they will overshadow the ground-hugging, rootless mosses, blocking out their source of energy. In a warmer, drier world, these mosses are likely to shrivel and die.

That is bad news, not just for sphagnum: it would have profound consequences for the entire peat bog ecosystem. Sphagnum mosses help to create the harsh, surreal landscape of a bog, by exuding chemicals that keep their waterlogged surroundings at around pH 3.5 – acidic enough to pickle vegetables. At the same time, the cold, wet environment kills off microbes that would otherwise decompose matter, allowing dead and dying moss to pile up. This build-up of organic matter is what makes bogs so important: they are huge carbon sponges.

Although sphagnum mosses thrive only in the world's wettest spots, they probably harbour more biomass than any other single genus in the world. The amount of carbon stored by 1 hectare of bog is equivalent to that emitted by 325 Humvees over a year. "The sphagnum, more than anything, is shaping the ecosystem," says Norby. How it responds when SPRUCE turns up the heat next spring remains to be seen.

The ecosystem that sphagnum mosses create can extend several metres into the ground. It is this subterranean world that intrigues Iversen. Below each square metre of the bog where she is standing is, on average, about 30 kilometres of roots, tangled as prodigiously as your guts. Roots are critical players in a warming ecosystem, as Iversen discovered when she started working at Oak Ridge in 2004, on an experiment to test how forests will respond to the higher atmospheric CO_2 levels of the future. The researchers knew that trees would, initially at least, use the gas to photosynthesise and grow. What surprised them was that the trees used almost all of the additional carbon to make not leaves, but new roots. Fine, deep and ephemeral, those roots were mining the soil for nitrogen and adding to the Earth's carbon stores in the process.

Going underground

On the face of it, that sounds like good news; deep-rooted plants may even help feed the world as the human population grows (see "Roots to the rescue"). But in a bog things get a little more complicated. When the SPRUCE simulation begins, plants will probably stretch their roots further down into the peat. But it is what happens next that will be critical. Fine roots do not just take up nutrients; they also exude easy-to-digest sugars. These nourish microbes, giving them the energy to break down more complex organic compounds bound up in deeper layers of peat. This means more decomposition as soils warm, releasing carbon that has been locked up for millennia. Depending on the microbes present, it enters the atmosphere as either CO_2 or methane – which has about 20 times the greenhouse potential of CO_2(though it is shorter-lived in the atmosphere). That's why researchers at SPRUCE are homing in on these little-known soil-dwellers, especially in a critical zone around the root called the rhizosphere – a bustling hub of microbial and root activity.

In a teaspoon of peat, there are tens of thousands of microbe species, says Chris Schadt, who leads the microbial ecology group at Oak Ridge. His team will analyse DNA extracted from peat to find out which kinds are most abundant, and what gases they produce. The researchers will also be looking for microbes that consume greenhouse gases. "In the upper levels of peat where there's oxygen, methane gets consumed by bacteria," says Schadt. So although warming may increase methane released, how much of this reaches the atmosphere will depend on these methane consumers.

Iversen's focus is on the roots themselves. She is interested in how they exchange gases and nutrients with their surroundings as they grow. "They respire the same way that you and I do," she says. To see the full effect, she is teasing out exactly how much of a normal bog is made up of roots, and how this will change as global warming sets in.

Rootling around

In her laboratory, Iversen straps on a binocular headband of the kind used by jewellers to peer at gemstones. She is focusing on the roots of shrubs and grasses, no wider than a human hair. Leaning in, she separates the spindly frizzes from clumps of bog peat with silver tweezers. The fine roots glow ghostly white under the magnifying lens, delicate and vulnerable. This 2-cubic-centimetre clump of dirt will take Iversen and three colleagues 8 hours to process. Welcome to "root-picking Thursdays".

Each sample is taken from a tube like the one she buried in the bog, which she has removed after four months to assess root growth. Once Iversen has separated out all the tiny roots, she will measure their biomass by weighing them. Then she will pour the roots into a petri dish and scan them into a computer to identify the plants they come from. As the SPRUCE simulation proceeds, she will be able to record any changes in biomass and species abundance as both temperature and CO_2 levels rise in the various plots.

Iversen's enthusiasm for root-picking – an exercise in patience – is boundless. But as a scientific technique, it has its drawbacks, not least its reliance on extracting soil cores, which damages plants. Happily, a new technology is giving her a non-invasive window on the world of roots.

At first glance, the photo taped to Iversen's filing cabinet looks like a spurt of molten lava, white-hot against a deep red background. Actually, it was taken underground in the bog. White is the colour of new roots before they grow their protective casing and darken. In the picture, one root has wrapped its sinewy length tightly around what looks to be another root, although it is really a fungus called a rhizomorph. Caught on camera, the two are enjoying a symbiotic exchange of nutrients. Until recently, these kinds of relationships – key to nutrient cycling in a bog – have been hidden from view. Not any more.

Iversen has planted 12 automated cameras in the peat. She controls these "soil ecosystem observatories" from her computer in Tennessee, moving them up and down in their plastic sheathings to capture the lives and deaths of roots in real time. The 30,000 daily snapshots they take have enough resolution to record once-invisible interactions, like those between roots and individual fungal strands a single cell wide. "These are the things that are still sort of magical to people, the things that we don't understand very well," says Iversen.

To her team's chagrin, automated cameras don't mean the root-picking will end. But together, tried-and-tested techniques and new technologies are shedding light on the inner workings of this vulnerable and little-known ecosystem. That's why Iversen doesn't mind delving into the earth, exposing its hidden layers to the light of day, and spending long days teasing apart the soggy peat to reveal her delicate subjects. "They're this mystery to be discovered," she says.

This article appeared in print under the headline "Deep, and dank mysterious"

Roots to the rescue

In 2007, Indian and Australian researchers met in Delhi to attend a workshop on agriculture and food security. The ideas they came up with have germinated into a four-year collaboration to create wheat with deeper roots.

At first, the Indian plant-breeders thought the idea of focusing on what happens beneath the ground sounded crazy, says root biologist Michelle Watt of Australia's Commonwealth Scientific and Industrial Research Organisation, who leads the Australian side of the project. But work at CSIRO showed that even in the driest deserts of West Africa, plants with longer roots that manage to reach an extra centimetre of water deep in the soil can yield half a tonne more grain per hectare.

The hunt for super-rooters is now on, with lab researchers scrutinising soil cores from hundreds of wheat plots in Australia and central India. Their aim is to find the genes that help plants build the most prolific root systems. "Most people don't realise that root systems are just as sophisticated and complex as the tops of plants," says Watt.

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