Satellite-based method measures carbon in peat bogs

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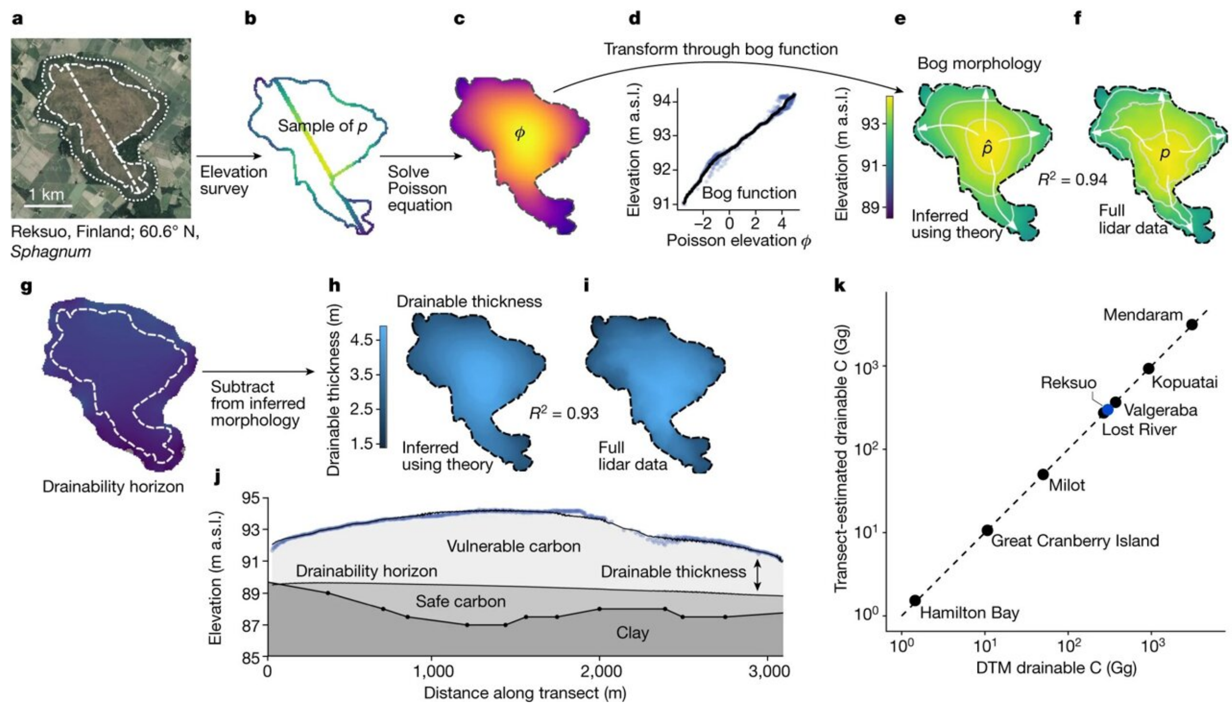

Estimating whole-bog morphology and irrecoverable carbon stocks from a single elevation transect. **a**, Reksuo, a raised bog in Finland. Satellite image: Google, Landsat/Copernicus. **b**, Lidar-derived elevations from the bog boundary and a transect provide a sample of the bog function describing the relationship between the solution to Poisson's equation $\phi(x, y)$ and surface elevations p. By transforming the solution to Poisson's equation (**c**) using this approximate relationship (**d**), the bog morphology can be estimated with high accuracy in unsurveyed parts of the bog (**e** versus **f**; root-mean-squared error 18.5 cm, bias −0.81 cm). Subtracting a horizon that represents the limit of drainability using a grid of ditches (**g**; see Methods) from the inferred morphology yields a map of the drainable thickness of peat (**h**), which closely matches estimates based on the complete surface morphology from lidar (**i**). **j**, Cross-section along transect in **a**, showing peat surface from the lidar transect (**b**, blue dots), approximate surface from bog function (**d**, black line), drainability horizon (**g**) and the underlying clay substrate[57]. **k**, Vulnerable carbon stock in gigagrams (Gg) of each bog shown in Figs. 1 and 4 and Extended Data Fig. 1 based on its shape inferred from an elevation transect (**a–i**) versus vulnerable carbon stock computed from its lidar-measured volume. Credit: *Nature* (2023). DOI: 10.1038/s41586-023-06807-w

Peat bogs in the tropics store vast amounts of carbon, but logging, plantations, road building, and other activities have destroyed large swaths of these ecosystems in places like Indonesia and Malaysia. Peat formations are essentially permanently flooded forestlands, where dead leaves and branches accumulate because the water table prevents their decomposition.

The pileup of organic material gives these formations a distinctive domed shape, somewhat raised in the center and tapering toward the edges. Determining how much carbon is contained in each formation has required laborious on-the-ground sampling and so has been limited in its coverage.

Now, researchers from MIT and Singapore have developed a mathematical analysis of how peat formations build and develop that makes it possible to evaluate their carbon content and dynamics mostly from simple elevation measurements. These can be carried out by satellites without requiring ground-based sampling. This analysis, the team says, should make it possible to make more precise and accurate assessments of the amount of carbon that would be released by any proposed draining of peatlands—and, inversely, how much carbon emissions could be avoided by protecting them.

The research is being reported today in the journal *Nature* in a paper by Alexander Cobb, a postdoc with the Singapore-MIT Alliance for Research and Technology (SMART); Charles Harvey, an MIT professor of civil and environmental engineering; and six others.

Although it is the tropical peatlands that are at greatest risk—because they are the ones most often drained for timber harvesting or the creation of plantations for palm oil, acacia, and other crops—the new formulas the team derived apply to peatlands all over the globe, from Siberia to New Zealand. The formula requires just two inputs.

The first is elevation data from a single transect of a given peat dome—that is, a series of elevation measurements along an arbitrary straight line cutting across from one edge of the formation to the other. The second input is a site-specific factor the team devised that relates to the type of peat bog involved and the internal structure of the formation, which together determine how much of the carbon within remains safely submerged in water, where it can't be oxidized.

"The saturation by water prevents oxygen from getting in, and if oxygen gets in, microbes breathe it and eat the peat and turn it into carbon dioxide," Harvey explains.

"There is an internal surface inside the peat dome below which the carbon is safe because it can't be drained because the bounding rivers and water bodies are such that it will keep saturated up to that level even if you cut canals and try to drain it," he adds.

In between the visible surface of the bog and this internal layer is the "vulnerable zone" of peat that can rapidly decompose and release its carbon compounds or become dry enough to promote fires that also release the carbon and pollute the air.

Through years of on-the-ground sampling and testing and detailed analysis comparing the ground data with satellite lidar data on surface elevations, the team was able to figure out a kind of universal mathematical formula that describes the structure of peat domes of all kinds and in all locations. They tested it by comparing their predicted results with field measurements from several widely distributed locations, including Alaska, Maine, Quebec, Estonia, Finland, Brunei, and New Zealand.

These bogs contain carbon that has, in many cases, accumulated over thousands of years but can be released in just a few years when the bogs are drained. "If we could have policies to preserve these, it is a tremendous opportunity to reduce carbon fluxes to the atmosphere. This framework or model gives us the understanding, the intellectual framework, to figure out how to do that," Harvey says.

Many people assume that the biggest greenhouse gas emissions from cutting down these forested lands are from the decomposition of the trees themselves. "The misconception is that that's the carbon that goes to the atmosphere," Harvey says. "It's actually a small amount because the real fluxes to the atmosphere come from draining" the peat bogs. "Then, the much larger pool of carbon, which is underground beneath the forest, oxidizes and goes to the air or catches fire and burns."

But there is hope, he says, that much of this drained peatland can still be restored before the stored carbon all gets released. First of all, he says, "you've got to stop draining it." That can be accomplished by damming up the drainage canals.

"That's what's good about this mathematical framework: You need to figure out how to do that, where to put your dams. There are all sorts of interesting complexities. If you just dam up the canal, the water may flow around it. So, it's a neat geometric and engineering project to figure out how to do this."

While much of the peatland in Southeast Asia has already been drained, the new analysis should make it possible to make much more accurate assessments of less-well-studied peatlands in places like the Amazon basin, New Guinea, and the Congo basin, which are also threatened by development.

The new formulation should also help to make some carbon offset programs more reliable, since it is now possible to calculate accurately the carbon content of a given peatland.

"It's quantifiable because the peat is 100 percent organic carbon. So, if you just measure the change in the surface going up or down, you can say with pretty good certainty how much carbon has been accumulated or lost, whereas if you go to a rainforest, it's virtually impossible to calculate the amount of underground carbon, and it's pretty hard to calculate what's above ground too," Harvey says. "But this is relatively easy to calculate with satellite measurements of elevation."

"We can turn the knob," he says, "because we have this mathematical framework for how the hydrology, the water table position, affects the growth and loss of peat. We can design a scheme that will change emissions by X amount for Y dollars."

More information: Alexander Cobb, A unified explanation for the morphology of raised peatlands, *Nature* (2023). DOI: 10.1038/s41586-023-06807-w. www.nature.com/articles/s41586-023-06807-w

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