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BIOGEOCHEMISTRY

Long-term effects of permafrost thaw

Carbon emissions from the Arctic tundra could increase drastically as global warming thaws permafrost. Clues now obtained about the long-term effects of such thawing on carbon dioxide emissions highlight the need for more data.

DONATELLA ZONA

Global warming is causing tundra ecosystems to undergo hydrological changes as a result of thawing of the underlying permafrost[1] — the permanently frozen soil layer that acts as a barrier to soil drainage. Thawing of permafrost can cause a reduction in soil moisture through increased soil drainage. The effect of these changes on the fluxes of greenhouse gases (carbon dioxide and methane) released from the Arctic is of great concern, because a vast amount of carbon is stored in this permafrost-dominated region. But our understanding of how hydrological changes in the Arctic affect net greenhouse-gas emissions has been limited by the short-term nature of previous experiments and available observations. Writing in *Biogeosciences*, Kwon *et al.*[2] report the long-term effect of drainage on vegetation and CO_2 flux by returning, after a decade, to a site in the Russian Arctic that was experimentally drained (Fig. 1).

Soil moisture is a dominant control on the carbon balance of tundra ecosystems — the amount of carbon released to the atmosphere through respiration versus the amount stored in vegetation through photosynthesis. This is because soil moisture tightly controls the growth and metabolism of microbes that degrade organic carbon in soil, and which thus produce CO_2 and methane. Several experiments have tested the impact of either flooding or draining on greenhouse-gas fluxes from Arctic tundra, a few of which were performed on a large ecosystem scale[3,4], but only over the course of a few years. Kwon and colleagues' study is the only large-scale drainage experiment performed in the Russian Arctic, and the only large-scale study to look at the effect of drainage after more than just a few years.

The authors report that drainage has increased the temperature in near-surface soils, whereas the temperature of the deeper soils has fallen. Drier soils conduct heat less effectively than wetter ones, and the upper soil layers have therefore accumulated heat, warming more than deeper soils. The warming of near-surface soil layers is expected to have a strong effect on soil respiration, because these layers are the richest in easily decomposable organic matter. Sure enough, the authors found that surface warming has stimulated decomposition and CO_2 loss.

Kwon *et al*. also noted that drying of the soil increased the abundance of shrubs and *Carex* sedges, which do well in dry environments, and decreased the abundance of cottongrass (*Eriophorum angustifolium*), which flourishes in wetter soils. This 'shrubification' is consistent with that previously reported in Alaska[5] and across the Arctic in general[6]. Such increases in shrub abundance might boost the productivity and CO_2 uptake of tundra ecosystems. However, the authors report that the net effect of drainage in their study is an increase in the amount of CO_2 emitted to the atmosphere, which will ultimately magnify climate change.

Importantly, Kwon and colleagues show that the increase is highest during the cold season, a notoriously under-studied part of the year in tundra ecosystems. Cold-season emissions are seldom measured in the Arctic because of the logistical difficulties in collecting such measurements, but they can be a dominant component of the overall carbon balance[7–9].

The authors compared the drained site with a nearby undrained site, an approach that adds greatly to our understanding of the long-term implications of hydrological changes on tundra ecosystems. Ideally, the two sites would have been measured and compared before one of the sites was manipulated. Unfortunately, these baseline data are missing, and so there is no information about differences between the sites that might be due to factors other than drainage. Tundra ecosystems can show substantial differences in vegetation and ***[the depth of?]*** water table, for example, over distances of a metre or less. However, the area studied by Kwon *et al*. is more homogeneous than many tundra sites, which probably limits the effect of such spatial variability.

The study would also have benefited from the inclusion of measurements of methane flux from the tundra, because methane might be a crucial component of the carbon balance of tundra ecosystems. The original drainage experiment[3] a decade earlier did indeed examine the impact of drainage on both CO_2 and methane fluxes. A follow-up study would be useful to fill the gap in the current findings.

Kwon and co-workers' results illustrate the value of long-term studies in the Arctic, but they also highlight the paucity of long-term data, which limits our ability to predict the effect of environmental change on greenhouse-gas fluxes in tundra ecosystems. Observations and manipulations over decades and across a variety of sites in the Arctic are required to understand and predict the long-term effects of climate change on ecosystem functions more fully. Such studies would enable a better assessment of the applicability of research results such as those of Kwon and colleagues.

Unfortunately, given the costs of doing research in this region, funding agencies tend to support only short-term projects of

3–5 years — hardly long enough to provide even a first glimpse of the impact of climatic change. Long-term studies would be possible only through a collaboration of research groups, with several funding agencies sharing the financial burden. Maintaining long-term research across the Arctic should be a priority.

Large-scale collaborative projects could be the way forward. For example, in the European Union-funded INTAROS project, various research groups are joining forces to develop an integrated Arctic observation system that extends, improves and unifies existing systems in different regions of the Arctic. It is to be hoped that this effort will be followed by increased collaboration of other funding agencies and research groups across the area. ■

Donatella Zona *is in the Department of Biology, San Diego State University, San Diego, California 92182-4614, USA, and in the Department of Animal and Plant Sciences, University of Sheffield, UK.*
e-mail: dzona@mail.sdsu.edu ***[Contact details OK?]***

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Figure 1 | Drainage site in the Arctic tundra. Kwon *et al.*[2] investigated the effect of drainage on vegetation and carbon dioxide flux at a site in the Russian Arctic (pictured). The boardwalk was used to minimize ecosystem disturbance caused by researchers walking across the site. The tripods supported electric cables used to power instruments in the study.