Disappearing Arctic Lakes

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Arctic warming has accelerated since the 1980s, driving an array of complex physical and ecological changes in the region (*1*). Particularly puzzling has been evidence for perturbations to the terrestrial water cycle (*2*), which plays an integral role in nearly every aspect of the Arctic system. We compared satellite imagery acquired across ~515,000 km² of Siberia in the early 1970s with recent (1997 to 2004) satellite data to inventory and track ongoing changes in more than 10,000 large lakes after three decades of rising soil and air temperatures in the region (*1*, *3*, *4*). Our analysis reveals a widespread decline in lake abundance and area, despite slight precipitation increases (*4*). The spatial pattern of lake disappearance strongly suggests that thawing of permafrost is driving the observed losses.

Between 1973 and 1997–98, the total number of large lakes (those >40 ha) decreased from 10,882 to 9712, a decline of 1170 or ~11% (SOM text). Most did not disappear altogether, but instead shrank to sizes below 40 ha. Total regional lake surface area decreased by 93,000 ha, a ~6% decline. One hundred and twenty-five lakes vanished completely and are now revegetated, as indicated by sharp increases in near-infrared reflectance (Fig. 1, B and C). Subsequent monitoring of these former lakebeds (2000 to 2004) confirms that none have refilled since 1997–98. These lakes are therefore considered to be permanently drained.

The regional totals indicate a net decline in Siberian lake cover but mask an interesting spatial pattern. In continuous permafrost, total lake area increased by 13,300 ha (+12%), and lake numbers rose from 1148 in 1973 to 1197 by 1997–98 (+4%) (Fig. 1D). This trend of net lake growth in continuous permafrost stands in sharp contrast with more southerly zones of discontinuous, sporadic, and isolated permafrost, all of which experienced net declines in total lake number (–9%, –5%, and –6%, respectively) and in area (–13%, –12%, and –11%) (Fig. 1D). These declines have outpaced lake gains in the north, lending an overall loss to the region.

Numerous studies have described increased surface ponding in warming permafrost environments, driven primarily by slumping and collapsed terrain features (thermokarst) that subsequently fill with water (SOM text). Such observations are in apparent conflict with the phenomenon seen here and also near Council, Alaska, where thermokarst ponds in discontinuous permafrost are also shrinking (*5*).

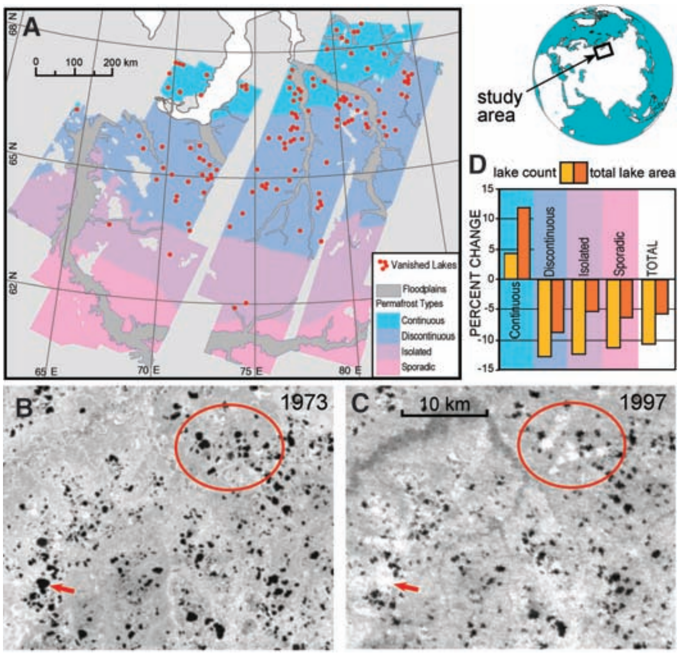

Fig. 1. (**A**) Locations of Siberian lake inventories, permafrost distribution, and vanished lakes. Total lake abundance and inundation area have declined since 1973 (**B**), including (**C**) permanent drainage and revegetation of former lakebeds (the arrow and oval show representative areas). (**D**) Net increases in lake abundance and area have occurred in continuous permafrost, suggesting an initial but transitory increase in surface ponding.

Geophysical surveys at the Alaskan site suggest that warming temperatures lead to thinning and eventual "breaching" of permafrost near lakes, greatly facilitating their drainage to the subsurface. The apparent discrepancy between these opposing sets of observations is in fact resolved if the process is understood as a continuum: Initial permafrost warming leads to development of thermokarst and lake expansion, followed by lake drainage as the permafrost degrades still further. This conceptual model is supported by the broad geographic pattern observed in Siberia (i.e., lake increases in continuous permafrost and losses where permafrost is thinner and less contiguous) and by the fact that permanently drained lakes are commonly found alongside undisturbed neighbors (suggesting a spatially patchy process, rather than a direct climatic mechanism such as increased evaporation). It also raises the possibility of a diffuse lake drainage "front" where warming permafrost first experiences widespread degradation. The fact that ~85% of the vanished lakes reported here occur within 200 km of the continuous permafrost boundary lends some support to this concept (Fig. 1A).

Clearly, other factors besides permafrost influence substrate permeability and lake drainage. In west Siberia, shallow water tables and extensive, low-permeability peatlands (*6*) ensure continued survival of many lakes, even where permafrost is absent. Overlay of our lake maps with a detailed peatland inventory (*7*) shows that, although lakes in continuous permafrost are found on all substrates, they exist only as perched systems on peatlands further south. In such regions, factors besides permafrost degradation will be important to lake persistence. However, aside from low-permeability environments and/or beneficent water balance adjustments (i.e., further increases in net precipitation), the ultimate effect of continued climate warming on high-latitude, permafrost-controlled lakes and wetlands may well be their widespread disappearance.

References and Notes

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