



Influence of Forest Fires on Levels of Mercury in Forest Soils, Lake Superior Region

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Synopsis

In the Lake Superior region, mercury (Hg) in forest soils, largely a legacy of more than a century of anthropogenically enhanced atmospheric deposition, constitutes a large pool of potentially available contaminant to local ecosystems.

Our recent work determined the concentration and mass of Hg in forest floor layers and underlying mineral soils in southern boreal forests of northern Minnesota. Most available Hg is contained within mineral soils. Within our study area forest floor layers (O-horizon) contain on average 0.22 mg/m² Hg and organic-rich mineral soils (A-horizon) contain on average 1.20 mg/m² Hg.

Because most Hg is sequestered in forest topsoils, we examined the influence of fire on Hg. A wildfire in 2004 caused an immediate release of Hg by burning of the forest floor and by mobilization of Hg from near-surface mineral soils. The amount of Hg released from mineral soils was highly dependent on fire severity and varied from insignificant at low to moderate severity areas to near total loss from severely burned areas.

We also document that severe forest fires can have a long-lasting effect on Hg contents of forest soils. A large region of our study area experienced severe wildfires in 1936, 65 years prior to our recent study. Mercury contents of soils in the 1936 burned areas are still significantly lower than in adjacent areas that did not burn.

Section 33 Wildfire

The Section 33 wildfire burned from July 8 until August 5, 2004, covering more than 580 hectares. The patchy mosaic of the burn created areas of varying fire severity, ranging from high severity (forest floor organic layer totally consumed, exposing mineral soil), through low to moderate severity (partial consumption of the forest floor), to unburned. We collected soils on August 24 and 25, 2004 prior to any major precipitation in the region.

Soil samples were taken along 10 transects each consisting of a severely burned, moderately burned, and unburned site. To minimize pre-fire soil variability, transects were located so that all three burn severity sites were in similar pre-fire vegetation types and landscape position. At each site samples of the O-horizon (where present), the A-horizon, and the upper 5 cm of the B-horizon were collected. Samples were analyzed for Hg, organic carbon (C) and a suite of other elements. Each site was resampled in May of 2005 and 2006. Geochemical data from soils collected in 2004, shortly following the fire, are presented here.



Severe Burn Site



Low - Moderate Burn Site



Unburned Site



Section 33 wildfire, July 29, 2004
Photo by Lee Grimm, National Park Service.



Section 33 wildfire, August 24, 2004
Photo by Bill Cannon, USGS

Research Area -- Voyageurs National Park, Minnesota

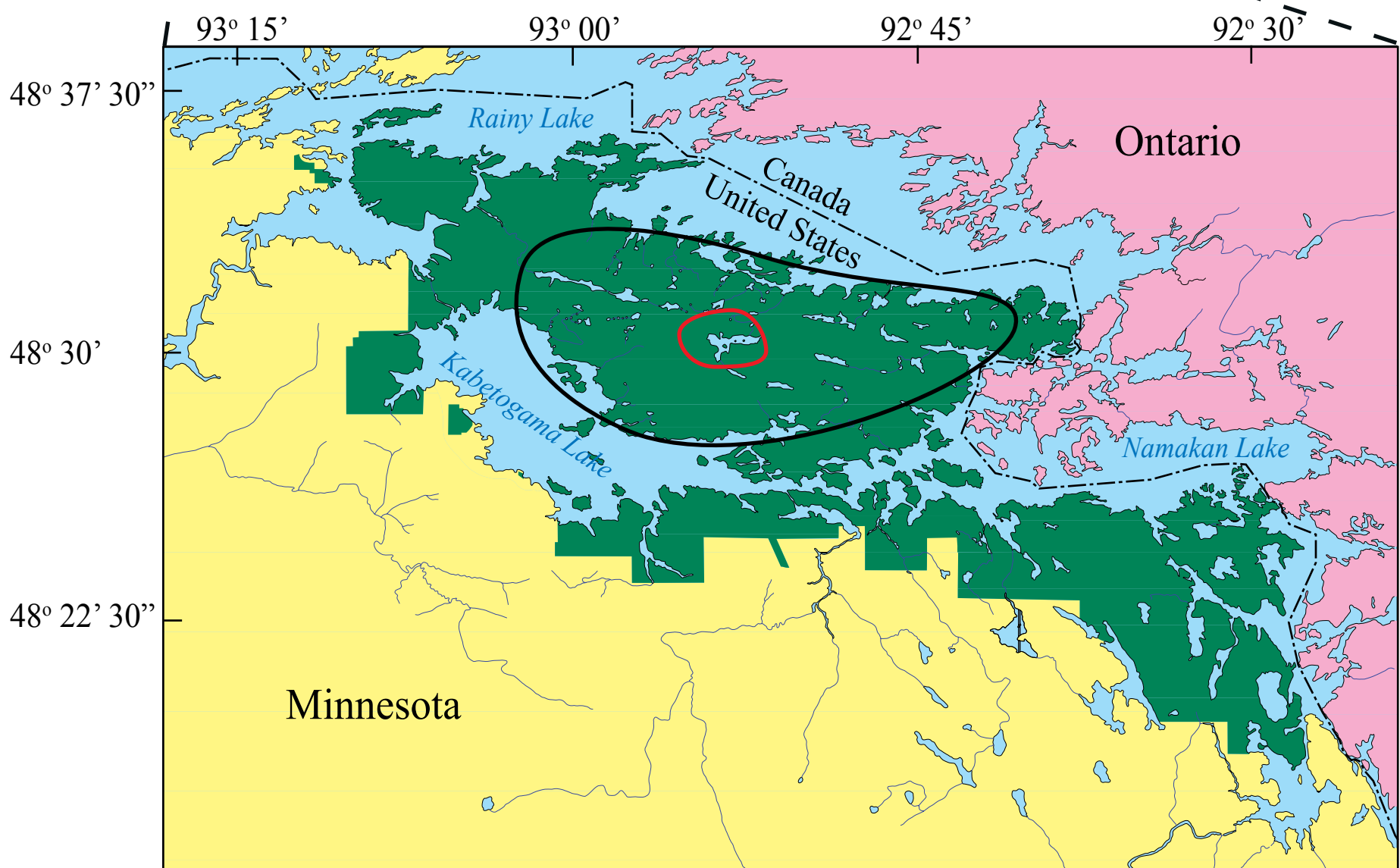
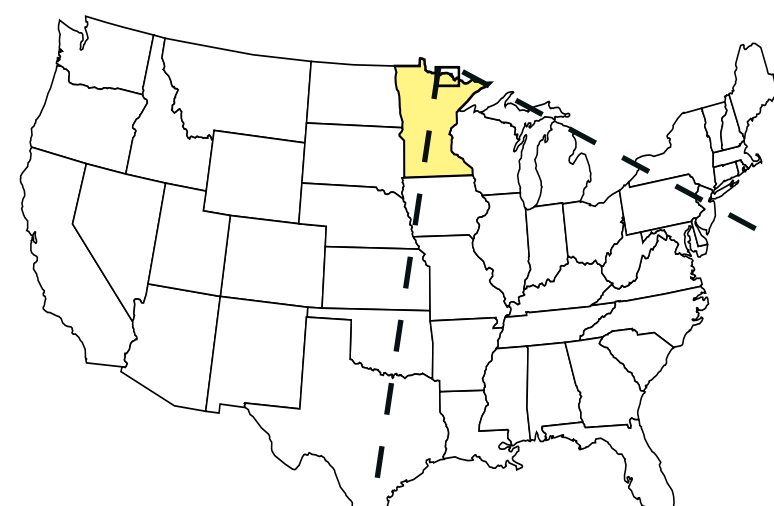


Voyageurs National Park (the Park) contains a steep, hilly landscape of Precambrian bedrock incompletely mantled by a veneer of Pleistocene glacial deposits. Nearly pristine southern boreal-Laurentian mixed hardwood forests form a mosaic of stand types and ages within this largely wilderness area. Soils are thin, loamy, and well-drained at all of our sample sites.

In spite of its remote location, Hg contamination is a significant management issue in the Park. Mercury levels in fish and piscivorous birds and mammals are among the highest in the central US and fish consumption advisories for humans are in effect throughout the Park and surrounding region.



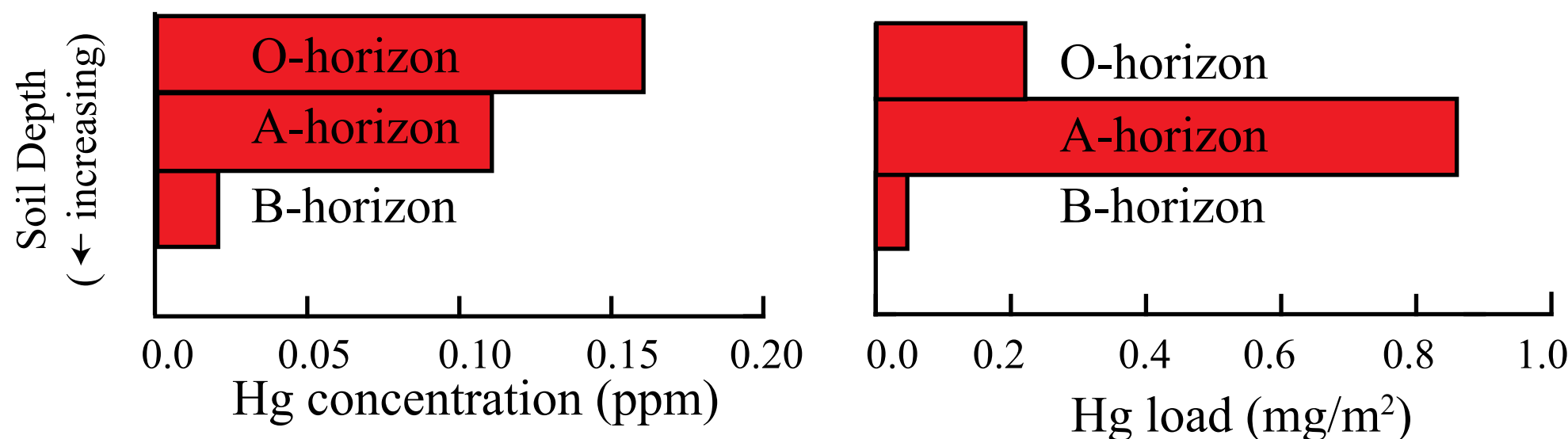
Large wildfires broke out in the Park in 1936. The 1936 fires were severe, stand-killing fires that eventually burned more than 14,000 hectares on the Kabetogama Peninsula, often consuming all vegetation and soil down to bedrock. Since 1936, aggressive fire suppression has inhibited the spread of wildfires within the Park. However, in 2004 a lightning-ignited wildfire was allowed to burn more than 580 hectares in the Section 33 wildfire. We report here on the effects of fire on forest soils from these two areas of the Park.



EXPLANATION
 Voyageurs National Park
 1936 Wildfires Study Area
 Section 33 Wildfire Area

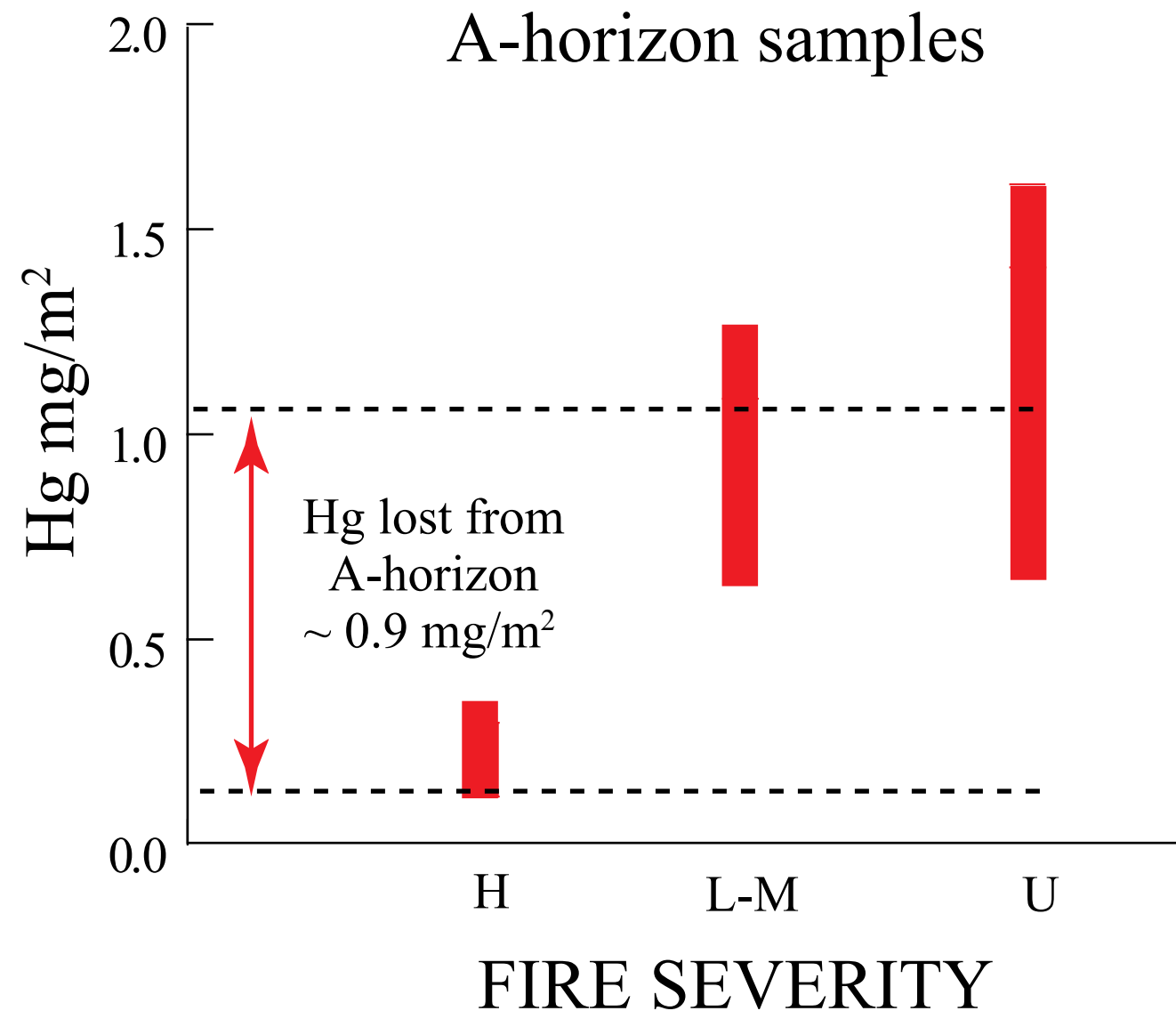
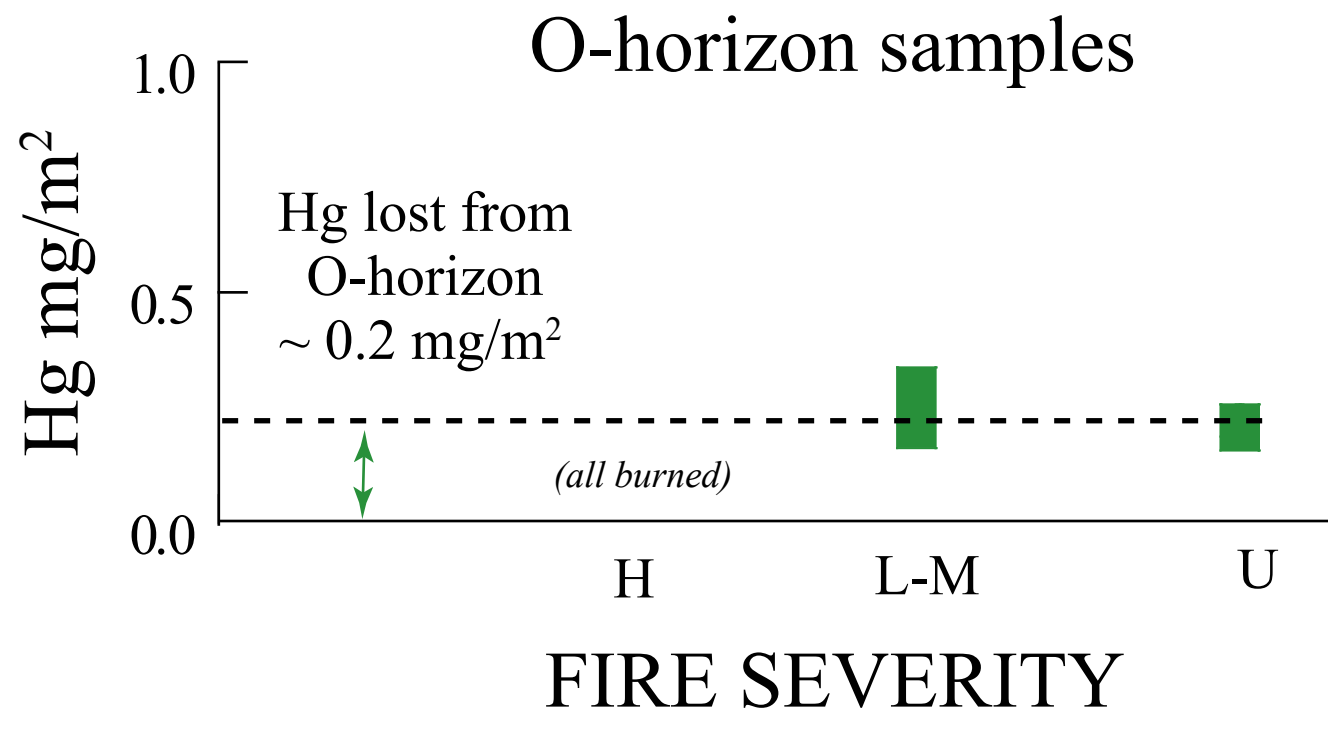
Mercury Distribution in Park Soils

Within the Park, Hg is largely sequestered with soil organic matter in O- and A-horizon soils. Although O-horizon soils typically have higher concentrations of Hg, A-horizon soils contain the larger mass of Hg. The plots below show typical average distributions of Hg in forest soils in the Park. Because of this relative enrichment of Hg in topsoils, forest disturbances, such as logging or wildfire, can have a profound impact on mercury cycling.



Short-Term Effects of Fire -- Mercury Losses from the Section 33 Wildfire

At severe sites, it is assumed that all Hg originally in the O-horizon, ~ 0.2 mg/m², is lost either by volatilization or as particulate matter in smoke. (Green rectangles represent the midrange of the data)



Mineral topsoils at severe fire sites are depleted in Hg by an average of ~ 0.9 mg/m² Hg, more than four times the losses measured for O-horizon samples. (Red rectangles represent the midrange of the data)



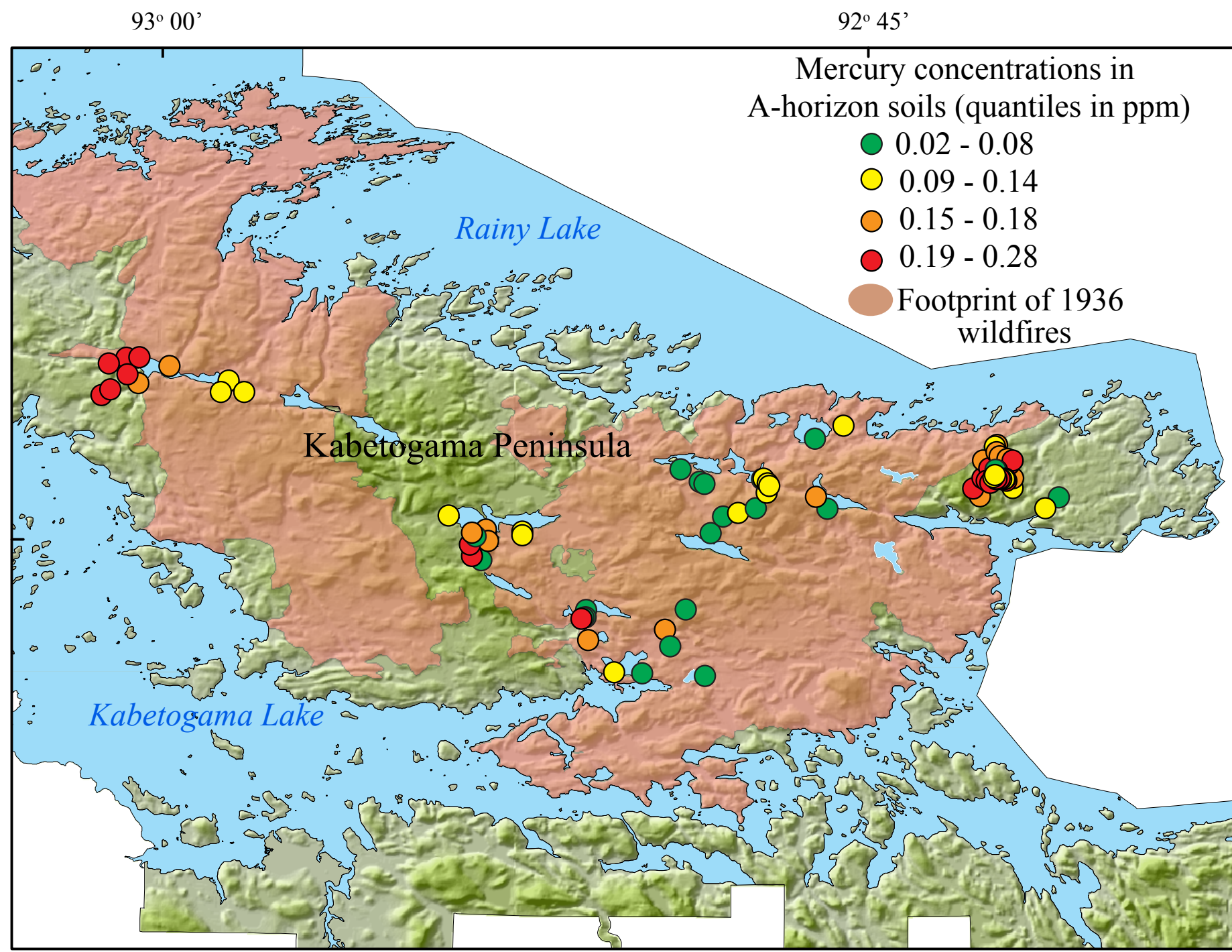
The mechanism for Hg loss in mineral soils is uncertain. Some severely burned sites exhibit regeneration of forbs just weeks after the fire. This suggests that during the fire, temperatures in the mineral soil at the depth of root systems did not exceed 100° C. Yet Hg and organic C are both reduced in these soils.

Our data show that there can be an immediate loss of soil Hg following wildfire. Where fire severity is high, Hg can be lost by combustion of forest floor organic layers, as well as by mobilization of Hg from underlying mineral soils. For the Section 33 wildfire, total Hg losses from severe sites were ~ 1.1 mg/m². Because the largest pool of soil Hg is in organic-rich upper mineral soils, understanding the impact of fire on Hg in this layer is crucial to interpreting short-term effects of wildfire on Hg.

Long-Term Effects of Fire on Mercury in Forest Soils -- Kabetogama Peninsula

Prior to our study of the Section 33 wildfire, we had collected soils from about 100 sites on the Kabetogama Peninsula.

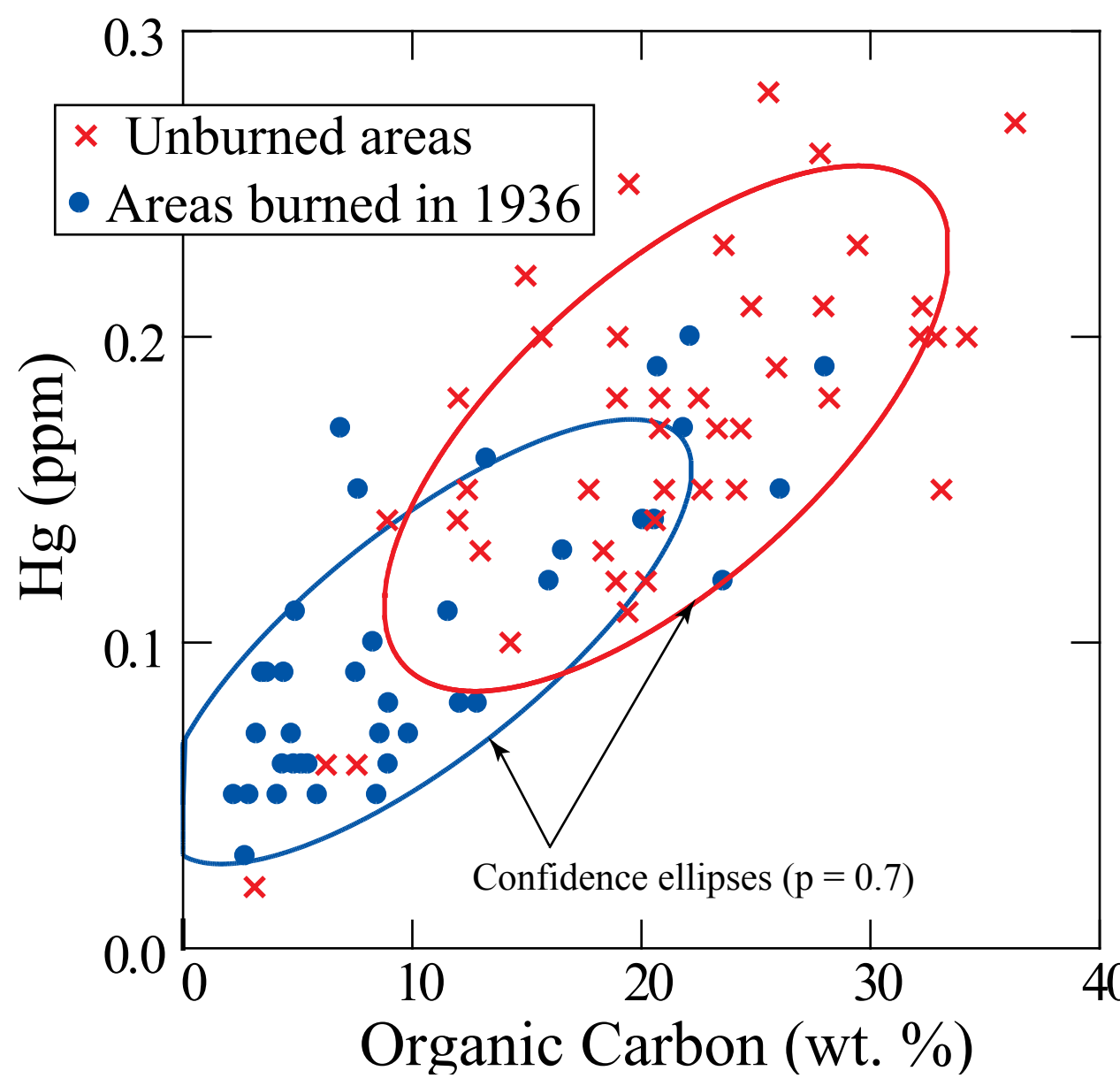
Our data show that Hg is present in very low concentrations in both bedrock (<0.02 ppm) and glacial materials (0.06 ppm) in the Park. This is taken as evidence that the higher average concentrations of Hg in O-horizon (0.23 ppm) and A-horizon soils (0.11 ppm) are the result of atmospheric deposition.



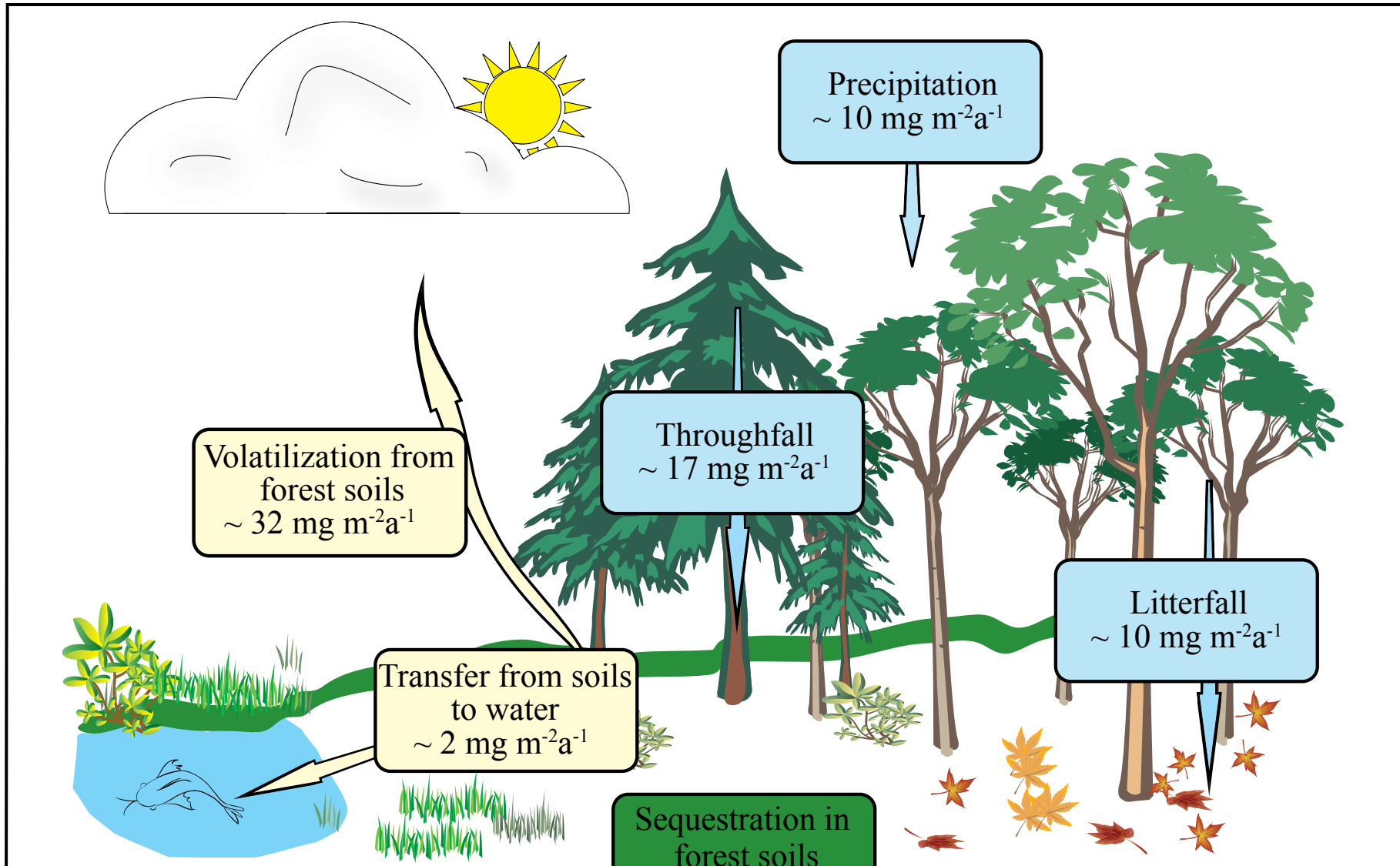
The spatial distributions of Hg (shown above) and organic C in A-horizon soils across the Kabetogama Peninsula suggest that the historic fires of 1936 continue to influence landscape chemistry today. Outside the areas burned in the severe fires of 1936 the mean concentrations of Hg and organic C are 0.17 ppm and 21.1 weight %, respectively (n = 42); within the areas burned in 1936 the mean concentrations of Hg and organic C are 0.10 ppm and 10.61 weight %, respectively (n = 38).

Severe wildfires can produce lasting effects in Hg and organic C contents of A-horizon soils. Deficiencies of these elements may reflect, in part, a long-lasting residual effect of immediate loss as documented by the Section 33 wildfire. We also suggest that an initial Hg loss may be augmented by changes in long-term Hg cycling in forested ecosystems resulting from stand-killing wildfires.

A scatter plot (right) of organic C vs. Hg in A-horizon soils from the Kabetogama Peninsula shows a strong correlation for these two elements. There also is a statistically significant differences (p < 0.000) of the concentration of both elements between areas burned in 1936 and unburned areas.



The nature of the forest canopy is known to have a strong influence on Hg deposition to the forest floor. Under a full forest canopy Hg delivery can be roughly 2.5 times greater than in unforested areas (see below). When severe wildfire destroys the forest canopy, this additional Hg input is interrupted until the canopy is restored over succeeding years or decades. Because the forest floor re-emits most deposited Hg, it is possible that A-horizon soils could become net Hg emitters for some time following fires while atmospheric Hg deposition and potential sequestration in soils are low because of canopy destruction.



Mature forests are nearly in balance between Hg inputs from the atmosphere by precipitation, throughfall, and litterfall (blue boxes) and outputs from volatilization and movement of Hg into streams and lakes (yellow boxes). Over time gains exceed losses, and a small amount of Hg is sequestered in forest floor soils (green box), mainly bound to organic carbon (modified from Grigal 2002, Environ Rev; 10:1-39).