IMPACT OF FIRE ON THE GEOCHEMISTRY OF THE FOREST FLOOR AND MINERAL SOILS, NORTH-CENTRAL U.S.

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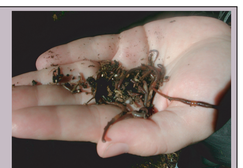
LANDSCAPE GEOCHEMISTRY AND FOREST FIRE

By the summer of 1936, three drought years had created extreme fire hazards across much of the Upper Midwest. In midsummer, fires broke out in areas now within Isle Royale and Voyageurs National Parks. The fires burned out of control for weeks, eventually devastating more than 105 km^2 on Isle Royale and 180 km^2 on the Kabetogema Peninsula in Voyageurs. In many places, the fires burned so hot that entire stands of trees were killed and bare rock exposed.

Our research in the two National Parks shows that the very severe fires of 1936 had a profound impact on the geochemistry of soils that is still apparent today. Within the 1936 burn areas, organic soils (O-horizon) are thin or absent and mineral topsoils have notably lower C and Hg contents compared to soils outside the burn areas. Carbon losses from soils result from direct volatilization during severe fire and less immediately from decreased litter input and from increased decomposition because of exposure and warming of topsoils following the loss of the forest canopy and insulating organic mat. Low mercury contents can be directly tied to lowered carbon contents.

Birch in 1936 burn area, Isle Royale

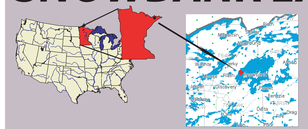
EARTHWORM WILDCARD!



In northern forests, nutrient availability following fire is of great concern. Nutrients are concentrated in the forest floor and the upper mineral soil. The presence of an O-horizon protects the mineral soil from erosion and degradation. Severe fire can remove much of the organic matter from a forest, but natural regeneration will restore much of the original forest floor, mitigating fire effects. In fact, as shown by the geochemical changes in the O- and A-horizons at Snowbank Lake, fire releases many essential nutrients and can be highly beneficial to forests.

However, a recently recognized complication in the nutrient cycle of northern hardwood forests in the Upper Midwest is the introduction and proliferation of European earthworms. Researchers at the University of Minnesota have found that when worms move into an area they quickly consume and process organic material, typically destroying the O-horizon. In areas of high infestation, worm activity exposes bare mineral soil, which results in the same type of erosion and degradation that may immediately follow severe fire. However, in contrast to fire, the persistence of worms inhibits restoration of the protective organic layer as they consume all litter as it falls. Long term effects may lead to shifts in soil structure and productivity, plant communities and, ultimately, forest ecosystems. We are taking advantage of our on-going Snowbank study site to investigate the complex interplay of fire, worms, and forest geochemistry.

SNOWBANK LAKE BURN, MINNESOTA



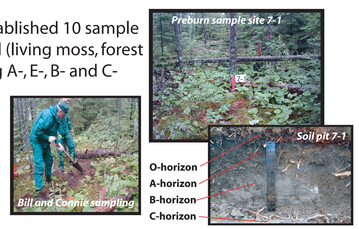
A major blowdown event in July 1999 knocked down more than 1 million trees in a 1550 km^2 area in northern Minnesota and Canada. The devastation resulted in a five- to ten-fold increase in fuel loads at the surface. The U.S. Forest Service and the Ontario Ministry of Natural Resources are conducting a series of prescribed burns for fuel reduction in the blowdown area. At a burn site on Snowbank Lake, MN we are conducting an on-going study of the impact of fire on the forest floor. We have collected a chronological series of forest soils before and periodically after the burn on October 2000.

PROJECT DESCRIPTION

Blowdown at Snowbank

Prior to the blowdown the area around Snowbank Lake was an older-aged mixed stand of balsam fir, spruce, aspen, red pine, and jackpine. Most trees affected by the blowdown were mature balsam and spruce, leaving an overstory of mostly aspen. The fuel loads at the surface included 1-6 cm of organic material on the forest floor in addition to small woody fuel and dead foliage.

In July, 2000, prior to the prescribed burn, we established 10 sample sites. At each site we collected forest floor material (living moss, forest litter and duff) and mineral soil horizons (including A-, E-, B- and C-horizons, where present) for geochemical analysis.



Bill and Connie sampling

The U.S. Forest Service conducted a burn on 97 acres in the blowdown area on October 11, 2000. The fire was ignited by dropping a volatile combination of gasoline and napalm from a 55-gallon drum suspended from a helicopter.

Snowbank Lake burn October 10, 2000

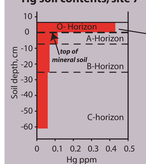
Photo credits: Minnesota Public Radio, Bob Kellaher

On October 13 we were able to begin our soil sampling prior to any post-fire rainfall. The fuel load at the surface, slope, and the soil moisture content controlled the impact of the fire on the forest floor. Fire severity, estimated by the extent of removal of the forest floor, was high at 4 sites, moderate at 1 site, and low at 4 sites. One site near the fire control line was unburned. We returned to Snowbank Lake in May 2001 and May 2002 to resample. During each sampling trip efforts were made to duplicate samples as closely as possible. All samples were handled and analyzed by identical protocols and methods.

Site 7-1	Site 7-3	Site 6-1
High fire severity 100% organic material consumed, mineral soil exposed	*Moderate fire severity ~50% organic material consumed, mineral soil not exposed*	*Low fire severity organic layer charred on surface, mineral soil not exposed*

MERCURY EMISSIONS FROM FIRE

For the Snowbank samples a number of elements, including C, N, S, Hg, Ca, Cu, Mn, Ni, and Zn, are concentrated in the organic material overlying mineral soil. During fire, combustion of this organic layer can release these elements either as a gas or as particulates. Emission of Hg from fire is of special concern because of potential human and wildlife health risks. At high fire severity sites, temperatures often are high enough to release most of the Hg contained in the organic layer (vaporization T = 357°C). Using the measured thickness of the organic layers and estimates of fire severity at each site in the Snowbank Lake burn , we calculate that **average** mercury emissions from **high fire severity** sites is about **0.2 kg/km^2** or about **2 g/ha**.



O-horizon at Snowbank sites

Site	Thickness	Hg (ppm)	Fire Severity
7-1	5.6 cm	0.43	**high**
7-2	1.3 cm	0.44	**high**
7-3	3.8 cm	0.33	**high**
7-4	1.3 cm	0.13	**high**
7-5	3.0 cm	0.31	moderate
6-1	3.0 cm	0.60	low
6-2	5.6 cm	0.38	low
6-3	3.0 cm	0.36	low
6-4	8.1 cm	0.50	low

thickness x density x Hg content = Hg emission

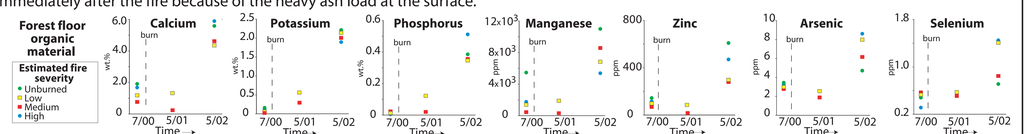
$5.6\ cm * 0.01\ g/cm2 * 0.43\ ppm/1 \times 10^{6} = 2.41 \times 10^{-8}\ g/cm^2$

$2.41 \times 10^{-8}\ g/cm^2 * 1 \times 10^{-3}\ kg/g * 1 \times 10^{10}\ cm^2/km^2 =$ **$0.241\ kg/km^2$**

This estimate of Hg emission is highly approximate. It may underestimate emissions as it does not include volatilization of mercury by the burning of vegetation above the forest floor, a potentially significant source. It may overestimate mercury emissions as it assumes total combustion of the organic layer and that all mercury in the burned organic layer is emitted, when, in fact, some mercury may be retained in the ash. In either case, it is apparent that substantial quantities of mercury can be released and translocated by forest fires.

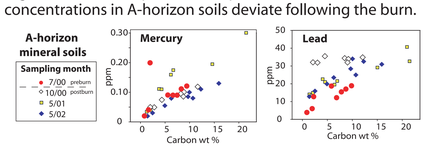
POST-FIRE CHANGES IN ORGANIC AND MINERAL SOILS

The plots below show changes in the organic O-horizon. Samples were collected pre-fire in July 2000 and post-fire in May 2001 and 2002, but not immediately after the fire because of the heavy ash load at the surface.



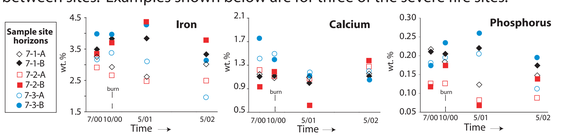
These changes observed in the O-horizon, with marked enrichment in a number of elements more than a year after the burn, probably result from leaching from ash into residual forest floor. Many of the constituents are essential nutrients for plant growth, and fire has the beneficial effect of increasing their availability. However, release of metals, such as As and Se, as well as Hg, may be of some environmental concern if they move into aquatic systems, either by ashfall during fire, by physical erosion of ash and loose soil following fire or by increased solubility in the burned soils.

Mercury and Pb in A-horizon soils show strong correlations with C, as both elements have an atmospheric source and bind to organic carbon compounds. Despite these similarities, their concentrations in A-horizon soils deviate following the burn.



Mercury contents increased in May 2001 without similar increases in carbon. This increase is probably the result of leaching from overlying ash into the mineral soils. Lead values increased immediately following the burn in October. This may reflect concentration of residual Pb from burning of the forest vegetation. For both elements, current values seem to be approaching preburn levels.

A- and B- horizon soils show variable patterns of losses and gains, apparently dependent on relative solubilities of different elements and varying soil characteristics between sites. Examples shown below are for three of the severe fire sites.



Changes in Fe contents at different sites suggest that 10 months after the burn Fe leached from the A-horizon was redeposited into the B-horizon, with leaching from both horizons one year later. Ca contents suggest consistent leaching from both horizons for about a year following the fire; increases in Ca suggest contributions from ash leachate. Samples from both soil horizons have similar P contents prior to the burn. Following the burn, some sites show P loss and some P gain, with no consistency between horizons. These changes may be related to varying site characteristics.