TITLE: How does wildfire severity influence post-fire nutrient cycling in forest soil?
LOCATION: Boundary Waters Canoe Area Wilderness, Superior National Forest
DATE: 9/29/2013
DURATION: Year 1 of 2-year project **FUNDING SOURCE:** Fire Evaluation Monitoring

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PROJECT OBJECTIVES: Our overarching goal is to investigate the ecological effects of increased wildfire severity, expected to occur under future climate scenarios. We propose to evaluate wildfire effects on soil carbon (C) and nitrogen (N) pools and cycling along a gradient of fire severity in the 2011 Pagami Creek wildfire site. We will build on extensive existing data on pre- and post-fire forest characteristics, fire severity classifications, and immediate post-fire soil C and N measurements to:

1) Measure persistent effects of fire on soil C and N pools and cycling, and evaluate differences among contrasting fire severity levels
2) Evaluate the influence of wildfire-produced black C on post-fire soil C and N cycling and on inorganic N and phosphorus (P) availability

JUSTIFICATION: **a) Linkage to FHM program.** *We propose to evaluate the ecological impacts of a gradient of increasing wildfire severity. We focus on the southern boreal forest in a region likely to experience increased fire severity due to extended drought caused by regional climate change.* Regional projections of future climate conditions indicate warmer temperatures, more variable precipitation patterns, and greater moisture stress [1]. These conditions are likely to increase the occurrence of drought that in turn influences fire risk and severity [2, 3]. The 2011 FHM National Technical Report identified persistent and/or severe to extreme drought in recent years across the Laurentian mixed forests of the western Great Lakes region [4]. High-severity fires cause major losses of organic matter and nutrients from soil, with potential long-term impacts to forest health. The 2011 Pagami Creek wildfire in northern Minnesota provides a unique opportunity to evaluate the effects of a range of fire severity levels on forest soil C and N cycling over time, and to determine the influence of black carbon (BC) on these dynamics. A previous study at this site used advanced remote sensing technology and intensive field measurements to characterize pre-fire forest attributes as well as post-fire severity, aboveground forest structure and composition, and total soil C and N (Townsend and Kolka, unpublished data). This work included post-fire soil sampling in 2011 and 2012 at five FIA plots inside the fire boundary and nearby points in unburned forest. An additional 133 plots were established following FIA plot design, and augment the FIA network by providing increased characterization of soils in the area and of soil variability across fire severity categories. *The existing soil and severity data provide a strong foundation for monitoring the impacts of high- versus low-severity fire on forest soils.*

b) Significance/Impact of forest health issue. *This project will increase understanding of the environmental impacts of fire disturbance by investigating how ecological processes are affected by increases in wildfire severity.* The effects of increased fire severity may occur as immediate (i.e., greater consumption of organic matter and volatilization of N) or delayed effects (i.e., greater impacts to nutrient cycling and decreased nutrient availability for the recovering forest). Wildfires also produce BC via incomplete combustion of organic material. BC is a form of organic matter that is resistant to decomposition, and plays an important role in soils by increasing water holding capacity and nutrient availability, both of which are critical for recovering vegetation. Our preliminary data show that BC concentration increases with fire severity level, and that conifer-dominated stands show a different response than stands dominated by deciduous species. *These results suggest that high-severity fires may be most detrimental to forest types in which fire was a historically uncommon occurrence, yet these forests will experience increased likelihood of* *fire if periods of prolonged drought continue.* However, we found no consistent pattern in total C loss with fire severity level [5]. Together, these results suggest that the ecological effects of increased fire severity level are likely to be delayed, as BC influences post-fire C and N cycles. This project will provide key information for monitoring fire effects on long-term nutrient availability. Our use of remotely-sensed and ground-based severity estimates will support linkages between FIA and the national Monitoring Trends in Burn Severity project (www.mtbs.gov). We will apply our results to the broader FIA network by using statistical relationships between fire severity, pre-fire C, and post-fire BC to predict BC content in other fire-impacted FIA plots across landscapes within and beyond our focus region. Monitoring linkages between BC and soil nutrition will assist in prioritizing efforts to restore natural fire regimes as well as for predicting fire impacts on forest productivity at the landscape scale. Thus, our project will inform forest and fire management practices that ultimately influence soil quality and future forest productivity, such as the use of prescribed fire and managed wildfires. This information is particularly relevant to regional economics because the Pagami Creek fire occurred in the heavily-used Boundary Waters Canoe Area Wilderness.

c) Scientific basis. *Our proposed project will build on previous efforts by monitoring fire severity impacts on soil C, N and P in a recovering forest.* Townsend's group has conducted more than a decade of research in this region, and the Pagami Creek fire provided opportunity to investigate changes in forest attributes between pre- and post-fire periods. A network of more than 133 plots, including FIA plots, exist inside the fire boundary with an additional 35 plots located in adjacent unburned forest. Plots were sampled immediately following fire in 2011, and again in 2012 to evaluate proximate changes in soil and vegetation.

d) Cost/Economic efficiency. We leverage an NSF rapid-assessment study that characterized fire severity and aboveground forest attributes using remote sensing and field measurements, and quantified total soil C and N. The existing data enables us to investigate fire effects on soil resources beyond what would be possible in individual monitoring projects. *The cost and effort for obtaining immediate post-fire samples were completed on the NSF grant, and we contribute the majority of costs for new sampling.* We request partial specialist salary and travel support for field crew transportation from MSU to the field site, and summer support for a graduate student to perform (1) field sampling to obtain fresh soil samples to determine fire severity effects on C and N cycling and to monitor delayed fire effects on soil C, N and P, and (2) analysis of BC on fresh samples to determine its influence on post-fire C and N cycling and N and P availability.

e) Priority Issues. *Our project will provide relevant information for understanding and anticipating the ecological effects of increased fire severity in fire-prone forests nationwide.* This project will increase the understanding of the **ecological impacts of fires** by characterizing relationships among pre-fire forest attributes, wildfire severity, BC, rates of soil C and N mineralization, and N and P availability. Because sampling was stratified by fire severity, our data will help to understand potential increases in fire impacts that are likely to occur under increased drought associated with predicted **climate change** scenarios.

DESCRIPTION: a) Background: Fire is a key ecological driver in determining vegetation composition, biomass and ecosystem dynamics in coniferous forests of the Laurentian mixed forests in the Great Lakes region [6, 7]. This region (MI, MN and WI) experienced an average of 3,787 wildfire ignitions annually over the past decade (http://www.nifc.gov/fireInfo/fireInfo_statistics.html). Several large fires have occurred in the Boundary Waters Canoe Area Wilderness (northern MN) in recent years (Cavity Lake Fire, July 2006, 12,748 ha; Ham Lake Fire, May 2007, 30,351 ha), and the 38,000 ha 2011 Pagami Creek wildfire was the largest since 1918. The fire burned through diverse vegetation types including virgin pine forest and second-growth aspen-birch forest with spruce-fir understory, exhibiting behavior ranging from light surface fire to rapidly spreading crown fire. As a result, the burned area includes areas of varying fire severity across a range of forest types and prior disturbance histories. The availability of detailed spatial data on pre- and post-fire forest composition, structure, and disturbance, including unique data such as NASA hyperspectral imagery, forest plot and biogeochemical cycling data, and spruce budworm disturbance assessments assembled by Townsend's research team over the past decade provide a comprehensive framework for understanding fire impacts on forest soil [8].

Fires can both stimulate and depress forest recovery by affecting soil processes. In moisture-limited systems, such as dry coniferous forests, fire is an important mineralizing agent and can accelerate soil organic matter (SOM) breakdown and nutrient release [3]. *Severe fires, however, may cause long-term nutrient losses by consuming SOM, volatilizing nitrogen, and inhibiting microbial activity, and may consequently inhibit post-fire forest recovery.* Wildfire severity is a measure of the magnitude of a fire's impact on the environment, and is a product of fuel consumption and fire intensity and residence time that varies spatially within a fire depending on local environmental and micro-climate conditions [3]. Understanding the environmental effects of forest fire as a function of fire severity is critical for developing appropriate policies and practices for minimizing detrimental long-term effects and managing fire-prone forests for long-term resilience [9].

Incomplete combustion of biomass during fires produces black carbon (BC), a stable and highly concentrated form of C that controls soil fertility in many ecosystems [10]. BC in forests is generated by thermal decomposition of biomass during flaming or smoldering combustion [11]. The highly aromatic chemical structure of BC contributes to its resistance to decomposition and long residence time in soil [12]. Up to 40% of soil C may exist as BC in fire-disturbed forests [12]. BC has been positively correlated with soil pH, total C and N, P availability, and conifer seedling regeneration [13, 14], *indicating that BC plays a critical role in post-fire forest recovery*. However, BC quantity, characteristics and influence on soil nutrient availability depends in large part on the combustion conditions (temperature, oxygen concentration, and duration of exposure to heat) in which the BC was produced. Shifts in global and regional climate are likely to alter the range of combustion conditions in a wildfire, relative to the range of historical conditions to which the forest is adapted. ***Thus, fire severity is likely to be a key driver in soil BC content, in post-fire recovery of soil C and N pools, and in the relationships between BC and the ecological process that drive nutrient availability for plants.*** These relationships remain poorly understood, despite their importance for post-fire ecosystem recovery and soil carbon sequestration [15].

The availability of high-resolution maps of within-fire severity from LANDSAT and AVIRIS imagery, field characterization of canopy and soil fire severity, and detailed pre/post-fire measurements for the Pagami Creek wildfire provides a timely opportunity for monitoring effects of fire severity on soil C and N cycling and N and P availability, and their dependence on BC.

b) Methods: Available archived soil samples include forest floor (organic layer) and mineral (0-10 cm, 10-20 cm) soil samples taken in October-November 2011 (immediately post-fire), May 2012 and August/September 2012 (following first growing season post-fire). We have analyzed all samples for total C and N, and a subset for BC. Twenty-one Forest Inventory and Analysis (FIA) plots are within the boundary of the current fire, with permission for use granted to project Cooperator P. Townsend. Our initial post-fire sampling included measuring five of the FIA plots for coarse and fine fuel loads, and forest floor and mineral soil C and N. We will obtain fresh soil samples in Year 1 of this study (3 years post fire) to measure soil physical properties (bulk density, soil texture), chemistry (pH, total C and N, P availability, NH_4^+ and NO_3^- pools) and ecological processes (N mineralization rates via two 60-day *in situ* soil incubations, and CO_2 flux measured in the field using static chambers) [16]. We will use the benzene polycarboxylic acid (BPCA) method with standard reference materials [17, 18] to quantify BC in archived and fresh soil samples. We will calibrate the BPCA analysis with solid-state direct polarization magic angle spinning (DP MAS) ^{13}C- nuclear magnetic resonance (NMR) spectroscopy. We will use existing spatially-referenced data on pre- and post-fire aboveground forest attributes in multivariate statistical approaches to characterize direct and indirect relationships among pre-fire forest biomass, fire severity, BC and rates of soil C and N mineralization. *These relationships will enable estimation of BC content across the broader FIA plot network.*

c) Products: This work will result in 2 peer-reviewed scientific manuscripts (addressing changes soil C and N over time since fire, and structural equation modeling of relationships among pre-fire forest attributes, fire severity, BC and soil C and N dynamics), conference presentations, a research brief targeted for resource managers, and the training of a graduate student. We will work with the Lake States Fire Science Consortium (www.lakestatesfiresci.net) to develop a research brief and webinar designed for regional and national fire research and management communities. We will contribute our data to the International Soil Carbon Network (http://www.fluxdata.org/nscn/SitePages/ISCN.aspx) to facilitate data sharing and collaborations.

d) Schedule of Activities: Year 1: Conduct field sampling and laboratory analyses to characterize relationships among black C, soil CO_2 flux, inorganic N and P availability, and N mineralization rates on fresh soil samples. **Year 2:** Complete laboratory analyses. Conduct statistical analyses to characterize relationships among pre-fire forest characteristics, fire severity, and soil (BC, total C and N, and C and N fluxes). Complete data analysis; present and publish results.

e) Progress/Accomplishments: N/A; this is a new project.

f) Relevant Citations: **[1] Handler, S., et al.,** *Michigan forest ecosystem vulnerability assessment and synthesis: a report from the Northwoods Climate Change Response Framework. Gen. Tech. Rep. NRS-XX*. DRAFT, Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. **[2] Clark, J.S.,** *Effects of long-term water balances on fire regime, north-western Minnesota*. J. Ecol., 1989. 77:989-1004. **[3] Neary, D.G., K.C. Ryan, and L.F. DeBano,** *(Revised 2008). Wildland fire in ecosystems: Effects of fire on soils and water. General Technical Report RMRS-GTR-42-vol.4*. 2005, Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. 250 pp. **[4] Potter, K.M. and B.L. Conkling,** *DRAFT Forest Health Monitoring 2011 National Technical Report*. 2012, Washington, D.C.: U.S. Department of Agriculture, Forest Service. 123 pp. **[5] Kolka, R., et al.,** *Forest Floor and Upper Mineral Soil Carbon, Nitrogen and Mercury Pools Shortly After Fire and Comparisons Utilizing Fire Severity Indices* Soil Sci. Soc. Am. J., In Review. **[6] Frelich, L.E.,** *Old forest in the Lake States today and before European settlement.* Nat. Areas J., 1995. 15:157-167. **[7] Cleland, D.T., et al.,** *Characterizing historical and modern fire regimes in Michigan (USA): A landscape ecosystem approach.* Landscape Ecol., 2004. 19:311-325. **[8] Wolter, P.T. and P.A. Townsend**, *Multi-sensor data fusion for estimating forest species composition and abundance in northern Minnesota.* Remote Sens. Environ., 2011. 115:671-691. **[9] Karau, E.C. and R.E. Keane**, *Burn severity mapping using simulation modelling and satellite imagery.* Int. J. Wildland Fire, 2010. 19:710-724. **[10] Shrestha, G., S.J. Traina, and C.W. Swanston,** *Black carbon's properties and role in the environment: A comprehensive review.* Sustainability, 2010. 2:294-320. **[11] Masiello, C.A.,** *New directions in black carbon organic geochemistry.* Marine Chem., 2004. 92:201-213. **[12] Preston, C.M. and M.W.I. Schmidt,** *Black (pyrogenic) carbon: a synthesis of current knowledge and uncertainties with special consideration of boreal regions.* Biogeosci., 2006. 3:397-420. **[13] MacKenzie, M.D., et al.,** *Charcoal distribution affects carbon and nitrogen contents in forest soils of California.* Soil Sci. Soc. Am. J., 2008. 72:1774-1785. **[14] Makoto, K., et al.,** *Effects of fire-derived charcoal on soil properties and seedling regeneration in a recently burned Larix gmelinii/Pinus sylvestris forest.* J. Soil Sediments, 2011. 11:1317-1322. **[15] Gonzalez-Perez, J.A., et al.,** *The effect of fire on soil organic matter - a review*. Environ. Int., 2004. 30:855-870. **[16] Robertson, G.P., et al.,** *Standard Soil Methods for Long-Term Ecological Research*. 1999, New York: Oxford University Press. 480. **[17] Brodowski, S., et al.,** *Revised black carbon assessment using benzene polycarboxylic acids.* Organic Geochem., 2005. 36: 1299-1310. **[18] Wiedemeier, D.B., et al.,** *Improved assessment of pyrogenic carbon quantity and quality in environmental samples by high-performance liquid chromatography.* J. Chromatog. A, 2013. 1304:246-250.

COSTS: ***We contribute the majority of total project costs.*** We request summer support (Yr 1 and 2) for one graduate student responsible for field sampling and laboratory analyses, two weeks/yr support for a remote sensing specialist, partial support for field personnel airfare (3 trips x 3 people) for field work in Year 1, and conference travel to present project results in Year 2. We contribute academic year student support and 10% Miesel time in both years, the majority of travel costs in Year 1, and all analysis costs.

	Item	Requested FHM EM funding	Other-Source Funding	Source
YEAR 1				
Administration	Salary	$ 12,422	*$ 37,474*	*Miesel –MSU*
	Overhead	$ 8,594		
	Travel	$ 2,000	*$ 3,500*	*Miesel --MSU*
Procurements	Supplies	$ -	*$ 4,500*	*Miesel --MSU*
Total Year 1		**$ 23,016**	***$ 45,474***	
YEAR 2				
Administration	Salary	$ 11,671	*$ 38,677*	*Miesel --MSU*
	Overhead	$ 9,356		
	Travel	$ 1,500		
Procurements	Supplies	$ -	$ 1,300	*Miesel --MSU*
Total Year 2		**$ 22,527**	***$ 39,977***	
GRAND TOTAL		**$ 45,543**	***$ 85,451***	***Contributed: 65% of total***