Fire effects on temperate forest soil carbon and nitrogen storage

Lucas Nave, Eric Vance, Christopher Swanston, Peter Curtis

University of Michigan BIOLOGICAL STATION

ncasi National Council for Air and Stream Improvement, Inc.

NIACS Northern Institute of Applied Climate Science

THE OHIO STATE UNIVERSITY DEPARTMENT OF EVOLUTION, ECOLOGY, AND ORGANISMAL BIOLOGY

ASA/CSSA/SSSA Annual Meetings

S07: Management Effects in Forest Range and Wildland Soils
17 October 2011

Supported by:
Northern Global Change Research Program

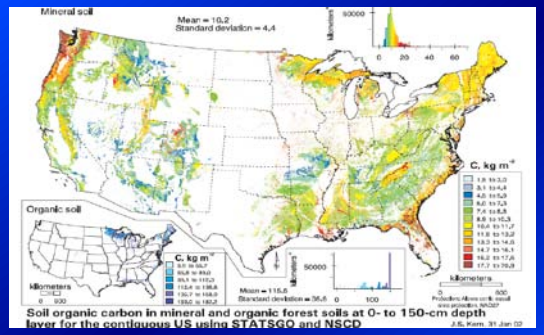
-and-

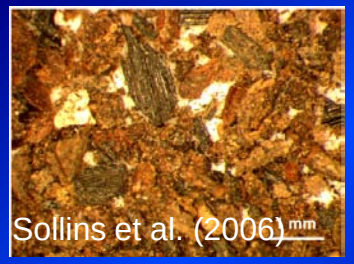
THANK YOU!

Helpful information and conversations: John Clark, Alex Friend, Bruce Leach, Jim Le Moine, Buck Sanford

Temperate forests: soil carbon and nitrogen

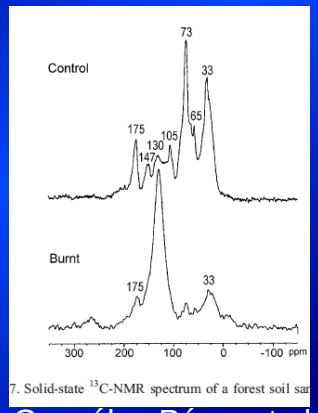
- Forests of the temperate zone are a globally important carbon (C) sink
  - most temperate forest carbon is stored in soils
- Soil C storage is **dynamic**. Variability is driven by the balance between several interrelated factors:
  - \+ detritus inputs and stabilization processes
  - \- destabilization processes and oxidation
- Nitrogen (N) biogeochemistry mediates all the above factors (+ and –)
- **Management** (or disturbance) can act directly on a soil's C and N stocks, and indirectly (*e.g.*, by affecting detritus inputs)
- C and N storage in forest soils has critical linkages to forest productivity, water and nutrient retention, and the climate





Direct and indirect effects of fire on soil C and N

- Fire pyrolizes and volatilizes C and N from litter and soil organic matter (SOM)
  - direct effects on C&N stocks
- Litter and SOM losses have hydrologic impacts
  - decreased soil water holding capacity, increased runoff and erosion
  - indirect effects on C&N cycling rates and transport processes
- Remaining litter and SOM have altered molecular composition and structure
  - indirect effects on C&N cycling, feedbacks to plant productivity



González-Pérez et al. (2004)

Approaches to studying fire effects on soils: Individual studies vs. synthesis

- Within and between individual studies, fire effects on soil C&N are often quite variable
  - Reflects variability of fires, soils, sites
  - Variability can be useful for elucidating mechanisms at a site, but hinders understanding broader impacts
- Synthesis using meta-analysis can quantify broader impacts, if they exist
  - Not conclusive for mechanisms, but can identify drivers of variation
- Publication and data-sharing are rapidly increasing data availability for synthesis work, including meta-analysis

Research questions and scope

1) In synthesis, what are the magnitude and variability of fire effects on temperate forest soil C and N storage?

2) What factors drive variation in fire effects on soil C and N storage, and what are some plausible mechanisms by which these factors may work?

Population: Global temperate forest soils

Sample: 57 publications from 1975-2008

Methods follow previous S7 presentations, detailed in:

Nave *et al*., 2011. Fire effects on temperate forest soil C and N storage. *Ecological Applications* 21: 1189-1201.

Meta-analysis in brief

- Response data: the response ratio (*R*) is calculated as a metric of experimental effects

  R = TRT mean / CTRL mean

  *usually ln-transformed

- Often several *R* values in each paper (*e.g.*, multiple sites, horizons, or treatments); unweighted *R* used in this analysis (k=468)

- Bootstrapping permutes and resamples the assembled distribution of *R* values to quantify the mean effect size and confidence interval

- Meta-data: predictor variables, can be categorical or continuous

- Statistical methods partition variation (heterogeneity) into attributable (metadata) vs. unknown sources, much like ANOVA/GLM

RESULTS

Generalized effects of fire on soil C&N

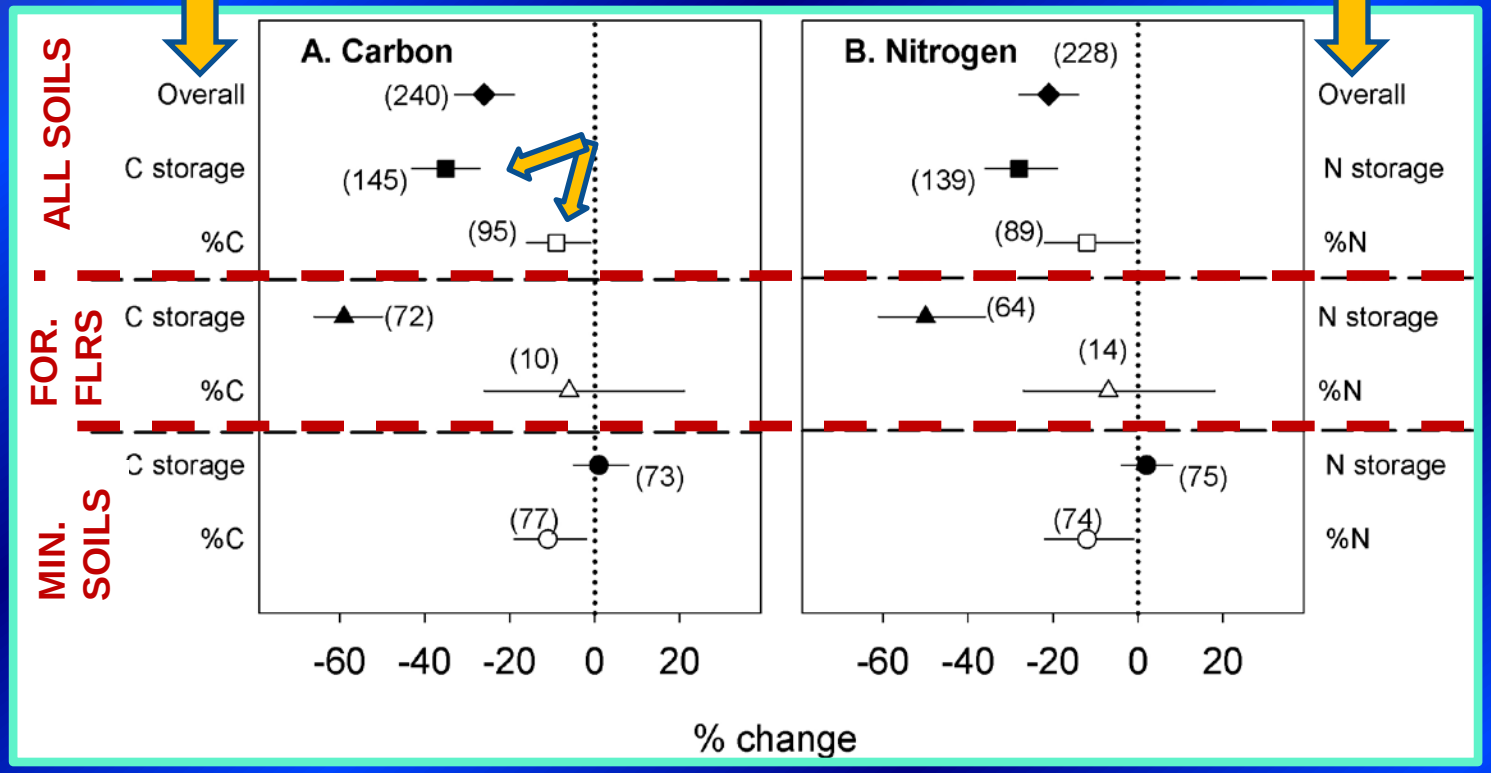


Figure 1. Effects of fire on soil C&N, overall and by soil layer. Points are means with 95% CIs and the number of response ratios (*k*) in parentheses. Filled diamond at top is the overall effect, other filled symbols are pool sizes, and open symbols are C&N concentrations.

- Overall, fire decreased soil C by 26±6%, soil N by 22±6%
  - Pool sizes more affected than concentrations (C pool -35%, N pool -28%)
- Soil layers showed very different responses:
  - Forest floors lost C&N stocks, but no significant change in concentrations
  - Mineral soils had no apparent change in pool size, but lower C&N concentrations
- Forest floor vulnerability: smaller C&N pool size, more exposed position

Forest floor C and N: underlying variation

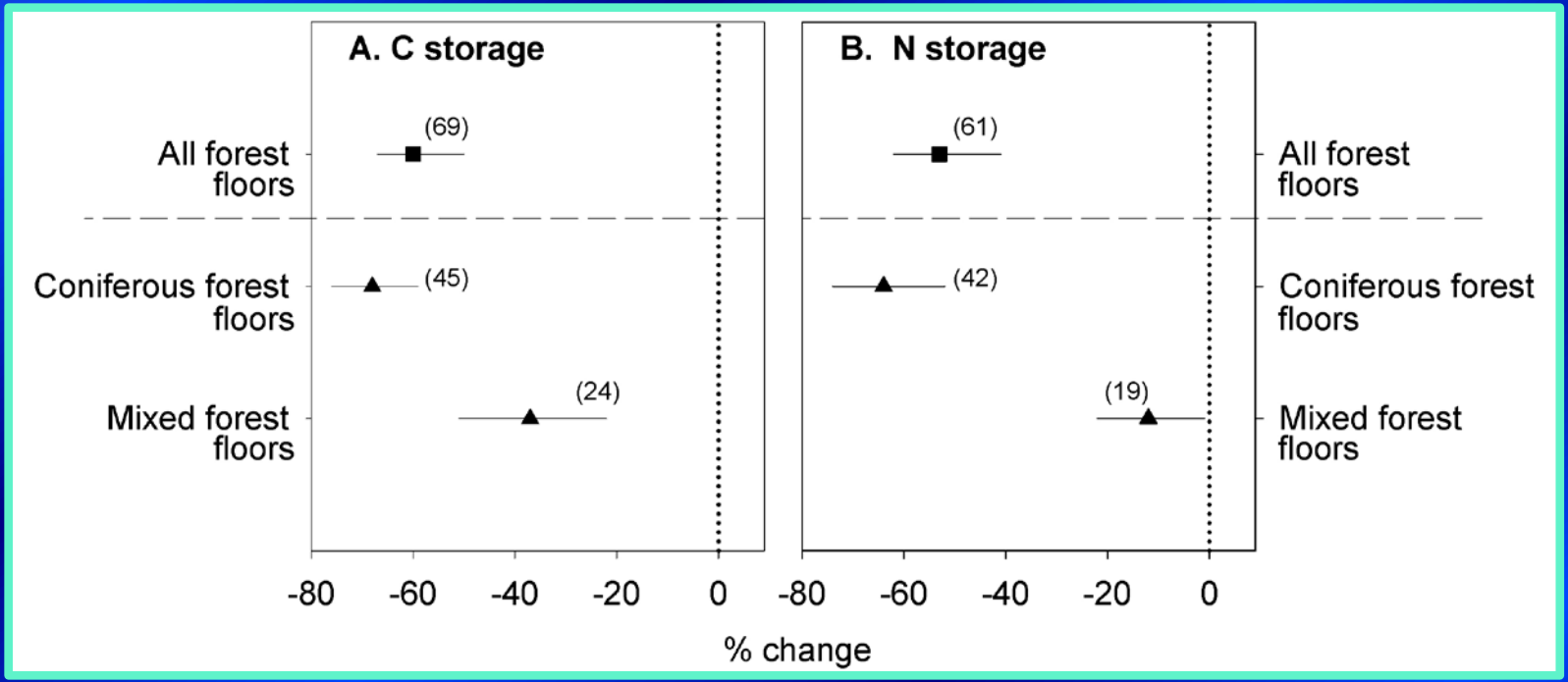


Figure 2. Fire effects on forest floor C&N storage, by species composition groups.

- Fire-induced decreases in forest floor C (-59%) and N storage (-50%) were large and fairly consistent
- Pure conifer forests lost more forest floor C and N stocks than mixed hardwood/conifer forests
- Conifer detritus less decomposable/more flammable

Variation within forest floors, cont'd.

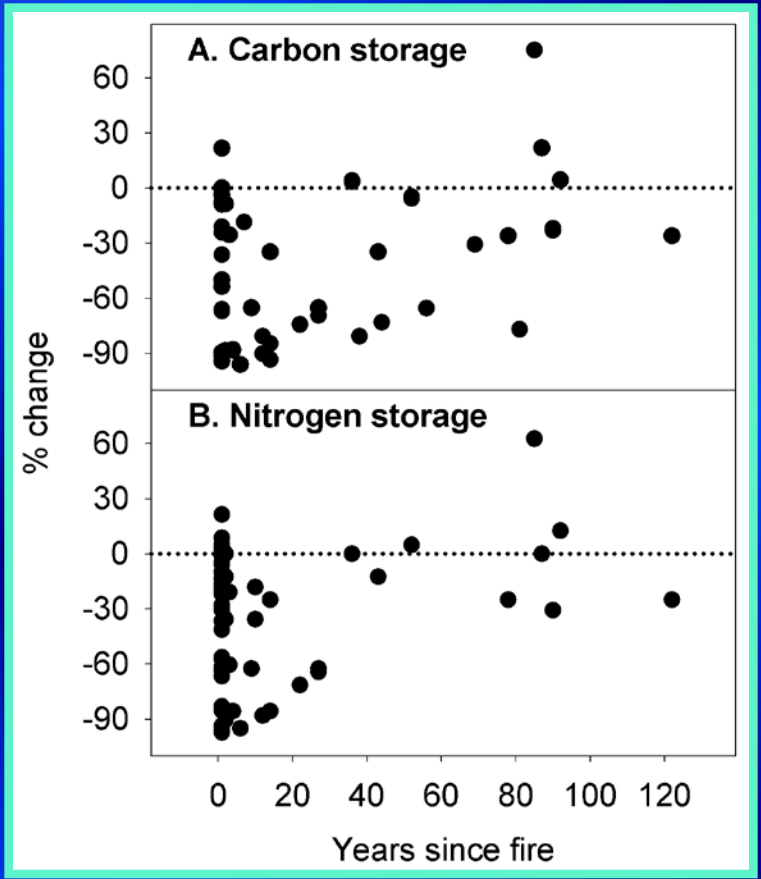


Figure 3. Net changes in forest floor C and N storage as a function of time since fire. Each point represents one response ratio.

- In general, burned forest floor C&N pool sizes eventually recover to unburned levels
- Mean recovery times for C (128 yr) and N stocks (103 yr) are similar
- If any components of forest floor OM (*e.g.*, C, N, water) limit plant growth and cannot be compensated by mineral soil sources, forest productivity may be lower during this this recovery period

The importance of fire type

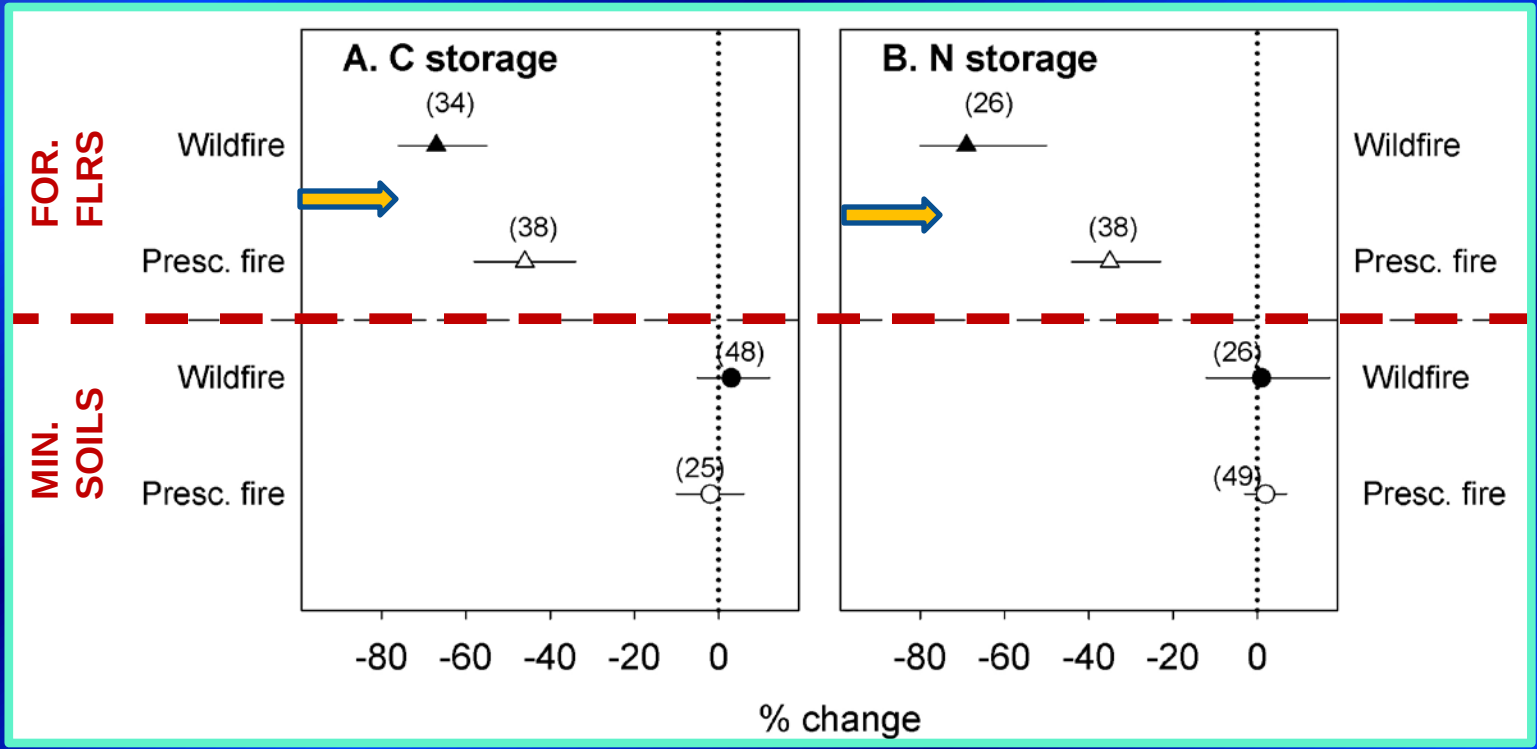


Figure 4. Net changes in forest floor or mineral soil C and N storage as a function fire type. Each point represents one response ratio.

- Forest floor C&N storage declines were significantly higher following wildfires than prescribed fires
- No detectable change in mineral soil C or N storage for either fire type
- Wildfires have become more frequent. From a C-centric perspective, prudent prescribed burns (or other management) may be necessary to mitigate anticipated C losses in wildfire-prone forests

Underlying complexity in mineral soils

Response parameter and fire type	k	Change (%) Mean	Change (%) 95% CL
Mineral soil %C			
Prescribed burn	21	4	−11, 22
Wildfire	55	−17	−26, −8
Mineral soil %N			
Prescribed burn	21	−1	−12, 11
Wildfire	52	−18	−31, −3

Table 1. Net changes in mineral soil C and N concentrations as a function of fire type.

- Apparent lack of change in mineral soil C or N storage after wildfire is belied by significant decreases in %C and %N
  - Suggests compensating increase in bulk density (~10%)
    - Loss of surface soil after wildfires?
    - Degradation of soil structure?
- Regardless, there likely are microbial and biogeochemical impacts from these changes in soil chemistry

Soil C&N Budgets

Parameter and soil layer†	k	Control (Mg/ha) Mean	Control (Mg/ha) 95% CL	Burned (Mg/ha) Mean	Burned (Mg/ha) 95% CL
C storage					
Forest floor	72	18	13, 23	7	6, 9
Mineral soil	73	37	25, 49	37	35, 40
Sum		55	38, 72	46	43, 49
N storage					
Forest floor	64	0.5	0.4, 0.6	0.2	0.2, 0.3
Mineral soil	75	1.1	0.9, 1.3	1.1	1.1, 1.2
Sum		1.6	1.3, 1.9	1.3	1.2, 1.5

Table 2. C and N budgets for unburned and burned soils. Burned values are the product of unburned means and the *R* and 95%CL values from meta-analysis.

- Forest floors: large relative losses, small C and N pool sizes
- Mineral soils: no net change, large C and N pool sizes
  - Absolute effect of fire on total profile C&N storage mitigated because the bulk of the C stocks are located in a more protected part of the profile
  - But indirect effects of forest floor losses may still be important at the profile or ecosystem level (feedbacks to productivity, hydrology)
- If fire causes tree mortality, this may replenish forest floor with OM stocks not explicitly included in this analysis (woody debris)
  - Potential C/N effects on subsequent forest floor nutrient cycling

Conclusions

- The general effect of fire is to decrease soil C and N storage
  - This effect is driven by large decreases in forest floor C&N storage (-59%, -50%, respectively)
  - Mineral soils showed no net change in C or N storage, but significant decreases in C&N concentrations (-11% and -12%)
- Wildfires have greater impacts than prescribed fires
  - Greater declines in forest floor C&N storage following WF
  - Mineral soil %C, %N unchanged by PF, decreased by WF
- Forest floors in pure conifer forests are more vulnerable to C&N losses than in forests with hardwoods
- Net recovery of lost forest floor C&N within 100-130 years of fire