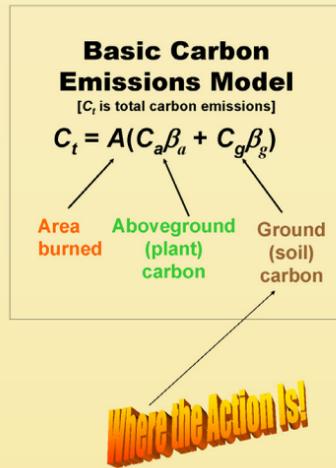


# Boreal Forest Fire Biomass Consumption for Carbon Emission Estimation: Measurement Requirements and Current Research

Nancy HF French, Altarum Institute, nancy.french@altarum.org; Timothy J Lynham, Canadian Forest Service, Great Lakes Forestry Centre; Ron J Hall, Bill de Groot, Janet Pritchard, Vernon S Peters, Canadian Forest Service, Northern Forestry Centre; Eric S Kasischke, University of Maryland, Department of Geography; Merritt R Turetsky, Michigan State University, Department of Plant Biology; Teresa N Hollingsworth, USDA Forest Service PNW Research Station; Laura L Bourgeau-Chavez, General Dynamics Advanced Information Systems

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## Why Measure Biomass Consumption?



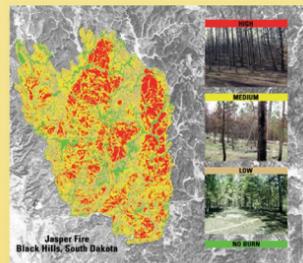
### Estimating Carbon Emissions:

The basic approach to estimating emissions from fire involves knowing the area of landscape burned and the amount of biomass carbon converted into atmospheric carbon. We divide the carbon components into aboveground (plant) and ground-layer (soil) carbon components because:

1. Burning in the ground-layer is very different from vegetation burning;
2. Aboveground fuel consumption is less variable and better quantified for many fuel types;
3. Aboveground carbon density is fairly straightforward to quantify from forest inventory data;
4. Ground-layer carbon is held in a complex soil matrix with varying densities depending on vegetation type and decomposition level;

### Why the ground layer?

Previous research has identified ground-layer carbon consumption as the main uncertainty in estimating total carbon emissions from fire (French et al 2004). Furthermore, French et al. (2004) showed that the variability in consumption is not well documented; in particular, the range of values and the shape of the uncertainty distribution have not been described well enough to properly account for the impact of consumption variation on fire emissions.



Example of Landsat-derived Normalized Burn Ratio (NBR) map (above). The NPS/USGS program has Landsat images of hundreds of fires. They have derived NBR for these fires and plan validation at many sites. The US Forest Service BAER program uses similar information from the Burned Area Reflectance Classification (BARC) product.

### Can Remote Sensing help?

To properly quantify biomass consumption across large spatial scales, it is useful to have the synoptic view provided with remote sensing. With field measurements alone we are not able to adequately cover the landscape.

Techniques have been developed to use moderate resolution satellite systems (Landsat) to map burn severity. The techniques developed by the burn severity mapping project (National Park Service & USGS) and Burned Area Emergency Rehabilitation program (US Forest Service) are being implemented across the US. The challenge is to relate burn severity, as mapped using these established techniques, to biomass consumption (see next section on terminology).

## What is Biomass Consumption?

**Words matter!**

The terminology used in fire science originates from several fields, including forest management, ecology, and carbon cycle science. It is important that terminology be properly defined when making estimates and developing protocols.

### Fuel

**available fuel**, the amount of material, held as forest biomass and carbon-based surface material (litter & duff), that could burn if ignited; this includes consideration of fuel moisture vs. **total carbon/biomass density**, the amount of material (forest, litter, duff) present regardless of vulnerability Measured as kg/m<sup>2</sup> or T/ha

### Fuel consumption

(a.k.a. biomass consumption) The amount of material consumed (oxidized) during the burn Important to quantify for carbon budgeting Relates to immediate carbon emissions from fire Indirectly related to post-fire carbon cycling due to changes in surface material

### Burn severity

(a.k.a. fire severity) An ecologically-based term centered on assessment of the impact of fire on the ecology of the site Not just fuel consumed Relationship to carbon cycling is complex: Consumption + vegetation dynamics (pre-fire & post-fire) Also used in socioeconomic terms to describe the degree of fire losses (life, property, etc.)

### Fire intensity

Energy produced (flame length, rate of spread, etc) May be related to fuel consumption or burn severity, but not yet determined

## Boreal Carbon Consumption Working Group:

**A Team Approach**

- Nancy French (Altarum) & many unfunded collaborators - NASA New Investigator Program "Assessment of Biomass Consumption Variability"
- Canadian Carbon Emissions Team (CET) is a partnership between Canadian Forest Service (CFS) teamed with Canada Centre for Remote Sensing (CCRS) - Robert Landry (CCRS), Bill de Groot (CFS), Tim Lynham (CFS), Ron Hall (CFS), many others - Development of Canadian Wildland Fire Information System - Part of Carbon Accounting Team undertaking carbon monitoring, accounting and reporting
- Eric Kasischke (UMd), Merritt Turetsky (MSU), Dave McGuire (JAF) - NASA North American Carbon Program "Wildfire Consumption of Ground-Layer Organic Matter in North American Boreal Forests and Peatlands: Implications for Atmospheric Trace Gas Emissions and Long-Term Soil Carbon Storage"
- Teresa Hollingsworth (UAF), Jill Johnstone (Carleton U.), David Verbyla (UAF), Ted Schuur, Michelle Mack, Terry Chapin (UAF) - Joint Fire Science Program "Managing fire with fire in Alaskan black spruce forests: Impacts of fire severity on successional trajectory and future forest flammability"
- Laura Bourgeau-Chavez (General Dynamics) - NASA Natural Hazards Program "Use of SAR to assess fuel moisture in Alaska"

### Collaboration Questions:

- Does burn severity, as measured through CBI/ΔNBR properly describe biomass consumption?
- Can model relationships between field and image be used in studies that quantify biomass consumption?

References:  
French, N. H. F., P. Gooverts, and E. S. Kasischke. 2004. Uncertainty in estimating carbon emissions from boreal forest fires. *Journal of Geophysical Research* 109:D14806, doi:10.1029/2003JD003635.  
Turetsky, M. R., K. Wieder, L. Halsey, and D. Vitt. 2002. Current disturbance and the diminishing peatland carbon sink. *Geophysical Research Letters* 29, doi:10.1029/2001GL014000.  
Turetsky, M. R., B. D. Amiro, E. Bosch, and J. S. Gray. 2004. Historical burn area in western Canadian peatlands and its relationship to fire weather indices. *Global Biogeochemical Cycles* 18:GB4014, doi:10.1029/2004GB002222.

## Abstract

Quantification of carbon emissions from boreal fire includes measuring both spatial extent and the biomass consumed during the fire and converted to atmospheric carbon. Based on previous research, it is hypothesized that the variability in biomass consumed during fire is the main driver of uncertainty in carbon emission from wildfires. In boreal systems, consumption of both aboveground biomass and carbon held in the forest floor and upper soil layers needs to be assessed. Current emissions models use consumption values based on a few direct measurements and some modeled estimates. For the North American boreal region these values are typically in the range of 20-25% of aboveground biomass consumed under average fire conditions. Values range from 5-40% of ground-layer carbon consumed. While these values have been used by many researchers to make emissions estimates, they have not been scrutinized, and the variability in consumption has not been fully assessed. Better measures are needed to define both the typical levels of consumption and describe the variability in consumption possible as a function of vegetation type, biomass density, ground-layer carbon depth, and burn severity.

Approaches to quantifying biomass consumption and results of measurement activities are presented in this paper. Direct, field-based measures, requiring measurement from before and after burning, are collected on a limited level. Post-fire field studies, measuring ground-layer depth within and outside of recent burn sites and determining burn depth from analysis of remaining material, have shown a high level of variability in ground-layer burning. Indirect measures include remote sensing; a technique developed to assess ecological burn severity using field data (Composite Burn Index) and pre- and post-fire Landsat images (Normalized Burn Ratio) is being assessed. The Canadian forest fire behavior prediction (FBP) system was developed to predict fire behavior at the fireline. Recently it has been used to estimate the amount of carbon released from fires. This application, while promising, is being validated to confirm whether the FBP consumption levels are correct for carbon emissions estimates.

In this paper, we present the work of several groups finding ways to better quantify biomass consumption in boreal fires. We review issues in terminology used by scientists and managers as well as problems of using measurements developed for fire management or ecological studies for the study of carbon emissions. We review how various measurement methods may or may not be useful in estimating biomass consumption and carbon emissions from boreal wildfires.

## How Do We Quantify Biomass Consumption?

**Multiple approaches**

### Field

- Composite Burn Index (CBI): developed to complement Normalized Burn Ratio (ΔNBR) by interagency burn severity mapping program
- BAER team field and aerial-based reconnaissance efforts
- Ground-layer (surface) fuel consumption (see box)
- Aboveground fuel consumption

### Remote sensing

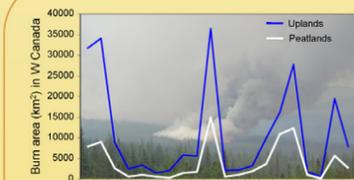
- Landsat derived burn severity (ΔNBR): uses pre & post fire images
- Active fire mapping for date stamping, fire type (flaming/smoldering) & fire intensity (FRP)
- Mapping fuel/site type to determine consumption conditions (e.g. mapping peatlands with deep organic)

Consumption of the surface organic material poses the biggest challenge. Several methods are used to determine the consumption levels in the field:

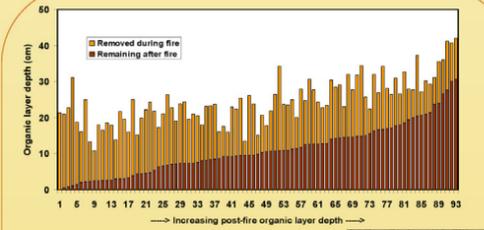
<b>1. Pin severity</b> Cm reduction * Mass <sub>s</sub>	<b>2. Carbon stock</b> Mass <sub>s</sub> - Mass <sub>o</sub>
<b>3. Tau</b> a. % loss $(1 - (\frac{\%C_c}{\%C_o} / \frac{\%S_b}{\%S_o}))^{-1}$ b. Mass loss = Tau * Mass <sub>s</sub>	<b>4. LOI</b> a. Plant Ash = (Mass <sub>s</sub> * OM Conc <sub>s</sub> ) / (Ash Conc <sub>s</sub> / OM Conc <sub>s</sub> ) b. Fire Ash = (Mass <sub>s</sub> * Ash Conc <sub>s</sub> ) - plant ash c. Combustion Ash = Fire Ash / (OM Conc <sub>s</sub> / Ash Conc <sub>s</sub> )

## Current Activity & Progress

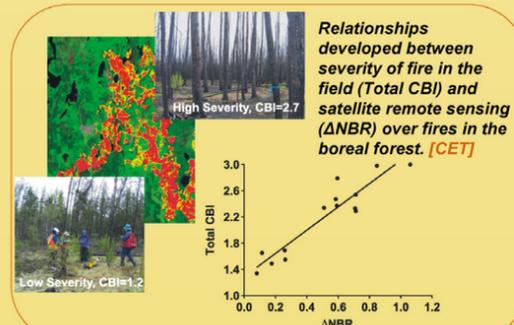
**Ongoing research by team members**



Turetsky et al. 2002, 2004; Harden et al. 2004



[Kasischke and others]



### Carbon emission range at experimental burns in jack pine stands [CET]

<b>Forest Overstory</b> Carbon storage: 34-90 t/ha Emissions rate: 3-11 t/ha (10-25%)	<b>Total C Emission: 4-27 t/ha</b>
<b>Forest Floor</b> Carbon storage: 2-28 t/ha Emissions rate: 1-14 t/ha (28-74%)	