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Scaling Soil Carbon Stocks and Fluxes at the BOREAS Northern Study Area

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THE GLOBE AND MAIL

SCIENCE & ENVIRONMENT

DEER MOUSE

A small, delicately built rodent found from Alaska to South America; large eyes and ears; nocturnal; often used as a laboratory animal

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EMISSIONS

Where has all the carbon gone?

BY MICHAEL SMITH
Special to The Globe and Mail
Toronto

Of the billions of tonnes of carbon released into the atmosphere every year, a large chunk cannot be accounted for. A study of the boreal forest may shed light on the mystery

IF you look at Toronto from a distance, you'll notice the air seems to be thicker and browner over the downtown core. Part of the smog is dust kicked up by a few million people and vehicles; another part is carbon, emitted in the form of oxides by those fossil-fuel-using vehicles, by the furnaces of skyscrapers and homes and by steam plants and incinerators.

The main form of carbon dumped into the air by these human activities is carbon dioxide, a so-called "greenhouse gas" that many scientists believe contributes to

The Boreal Ecosystem Atmosphere Study is monitoring the carbon intake of a huge area of

However, the BOREAS data on the lost carbon are preliminary: Results from a large environmental prairie study concluded a decade ago in Kansas are still being analyzed and producing scientific papers, Dr. Hall says, and there's no reason to believe BOREAS won't take at least as long to analyze in detail. The missing sink may be lurking in reams of unstudied information.

And the study sites in Manitoba and Saskatchewan — areas featuring black spruce on the high ground and peat bogs on the lower — may not be as typical of the boreal forest as researchers had thought.

"What we've learned in the three or four years we've been here is that in black

SCALING SOIL CARBON STOCKS AND FLUXES AT THE BOREAS NORTHERN STUDY AREA

Boreal forests and wetlands are currently thought to be significant carbon sinks in global C budgets and they could become net C sources as the Earth warms. Most of the C of boreal forest ecosystems is stored in the soil and moss. Carbon budgets of several boreal forest and wetland ecosystems were studied intensively in 1994 at the plot scale during the BOReal Ecosystem-Atmosphere Study (BOREAS). The objective of our study was to estimate soil C stocks and fluxes at a larger spatial scale for the 733 km^2 BOREAS Supersite study area in northern Manitoba. We developed maps of soil C stocks and drainage class. To estimate C fluxes and the balance between input and decomposition, we developed a fire history map and applied algorithms for input and decomposition constants based on field work using radiocarbon analyses. Soil C stocks covary with soil drainage class, with the largest C stocks occurring in poorly drained sites. In the imperfectly and poorly drained sites, a large carbon pool of humic material exists at the base of the moss layer that presumably originates from charcoal and other fire residues. Calculations of net flux of C are sensitive to the estimated decomposition rates for this large pool of deep soil C. While the upper moss layers regrow and accumulate C after fires, the deep C flux in years between fire events can range from a small sink to a significant source. Using the upper bound of reasonable estimates of decomposition constants, the deep soil source is large enough to nearly counter the surface moss layer sink, resulting in an annual net C flux of nearly zero for the entire soil profile. The turnover of deep soil C in these ecosystems and its response to expected warming and altered drainage patterns deserve more attention.

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PROJECT GOALS

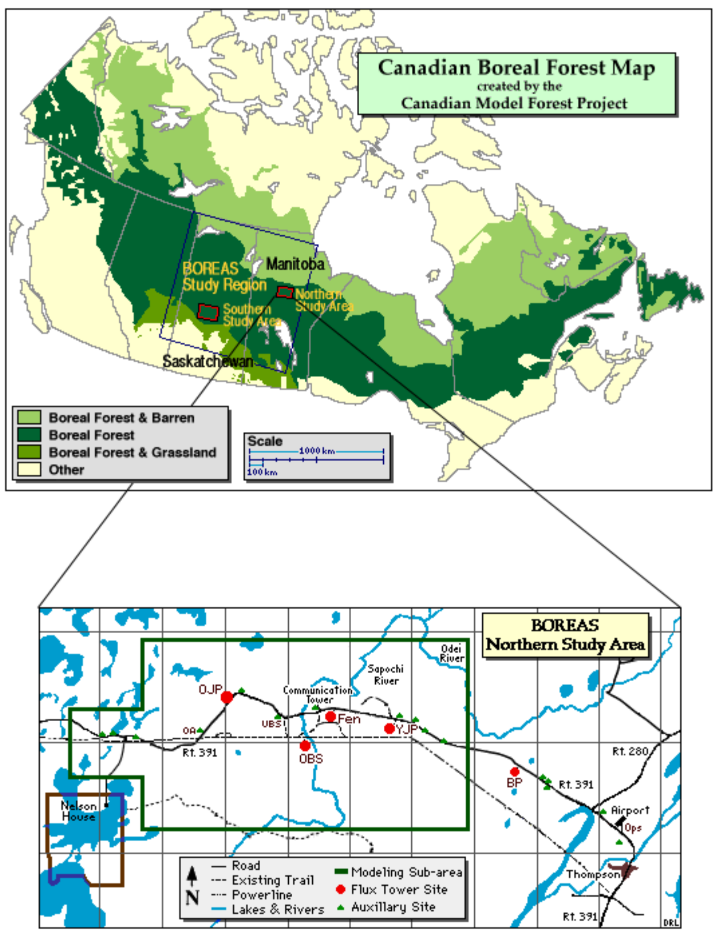
- **Estimate total carbon stocks by horizon for common soil series.**

- **Estimate soil carbon flux based on C stocks and a simple model of C turnover derived from radiocarbon studies.**

- **Generate area-weighted maps of soil carbon stock and flux.**

- **Relate patterns of carbon stock and fluxes to patterns of drainage, moss cover, and fire history.**

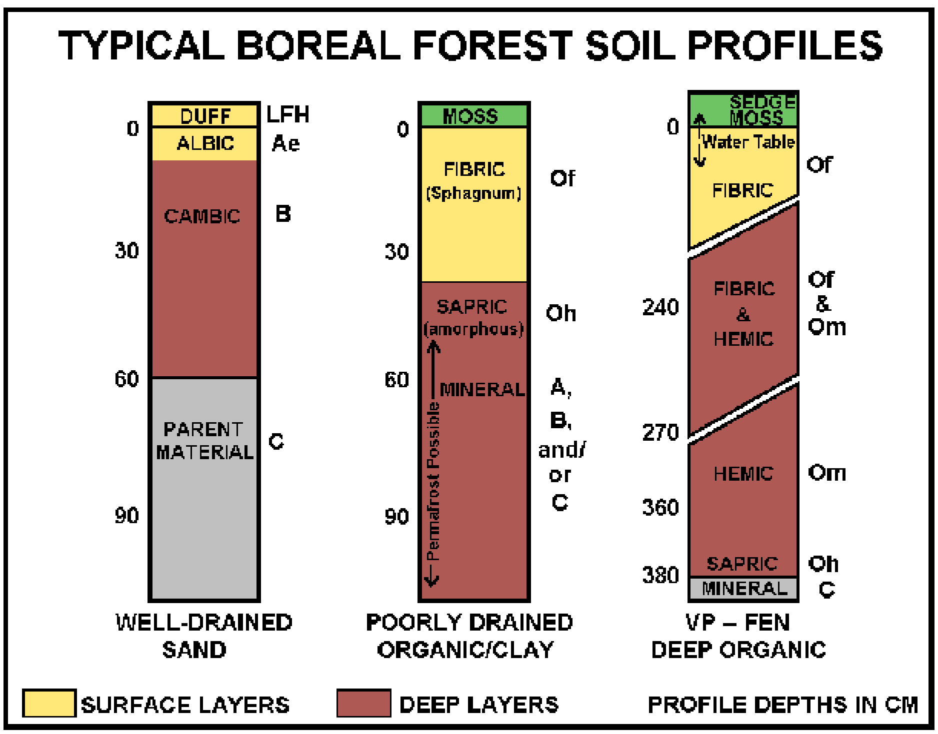
STUDY AREA



STUDY AREA -- The study area is located in northern Manitoba, close to the northern limit of the closed-crown boreal forest. The study area occupies 733 km^2, the area enclosed in the box on the lower map. (Maps courtesy of BOREAS, http://boreas.gsfc.nasa.gov/)

METHODS

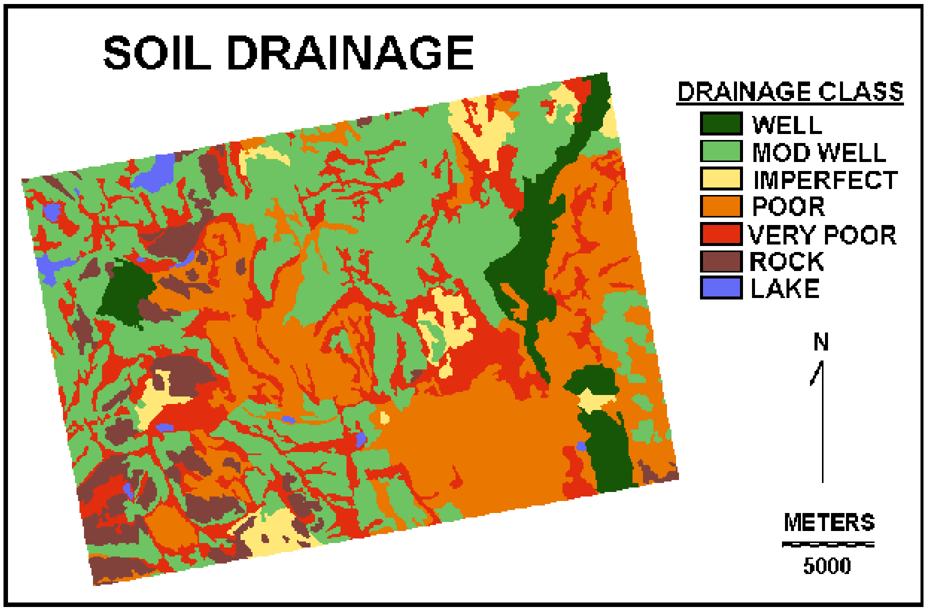
- **Stratified study area by drainage class/vegetation type.**
- **Determined time since last fire.**
- **Separated the soil profile into two broad layers -- *surface and deep* -- with distinctly different C accumulation rates.**
- **Estimated C stocks for surface layers based on a time-dependent model of moss growth after fire.**
- **Estimated deep soil C stocks from profile data and soil series map.**
- **Estimated annual C fluxes for 1994 from a simple model of input (*I*), decomposition (*k*) constants, and carbon stocks (C) based on field radiocarbon studies: Net Flux = $I - kC$.**



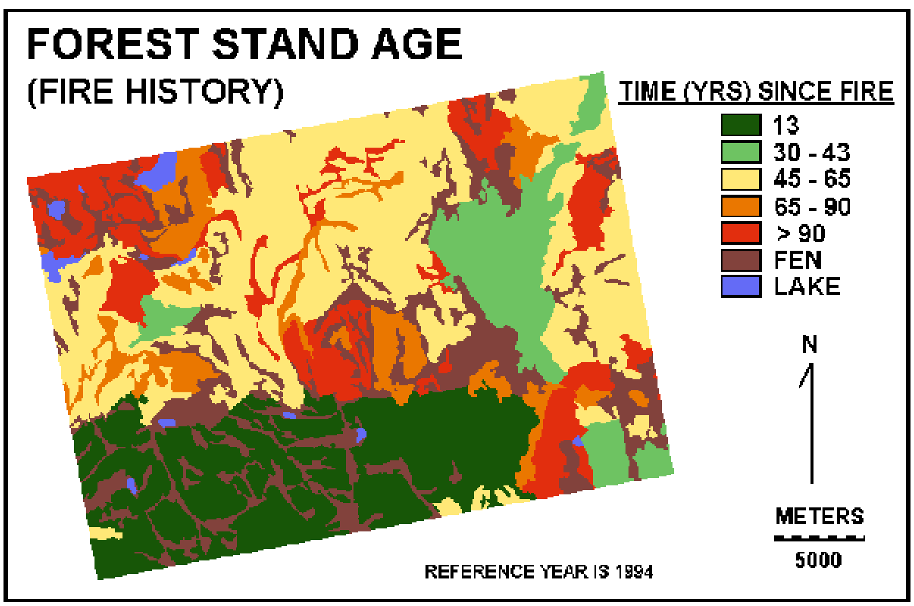
SOIL PROFILES -- Surface layers include moss and soil that is recognizable as organic material, while the deep soil layers include highly decomposed organic matter, charred material, and mineral horizons. Surface layers accumulate C between fires and turnover times are about 10 times shorter than for deep layers in which C accumulates slowly, integrating over many fire cyles.

MODEL INPUT -- VARIABLES

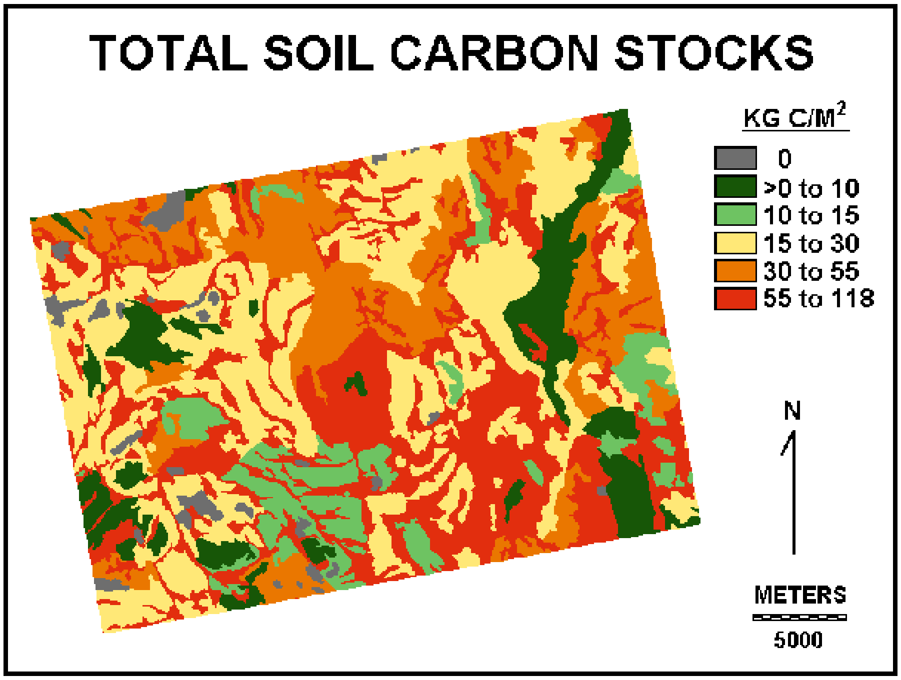
Our model has three inputs -- soil drainage, forest stand age, and carbon stocks.



SOIL DRAINAGE -- Drainage by dominant soil series of soil polygons. The five drainage classes correspond to vegetation type.



FOREST STAND AGE -- Compiled from satellite images, fire maps, forest inventory, and tree core data. Age ranges represent time since last fire. Reference year is 1994.



TOTAL C STOCKS -- Roughly correspond with drainage class and stand age. Highest stocks are in unburned, very poorly drained fen sites and lowest in recently burned upland jack pine sites.

RESULTS

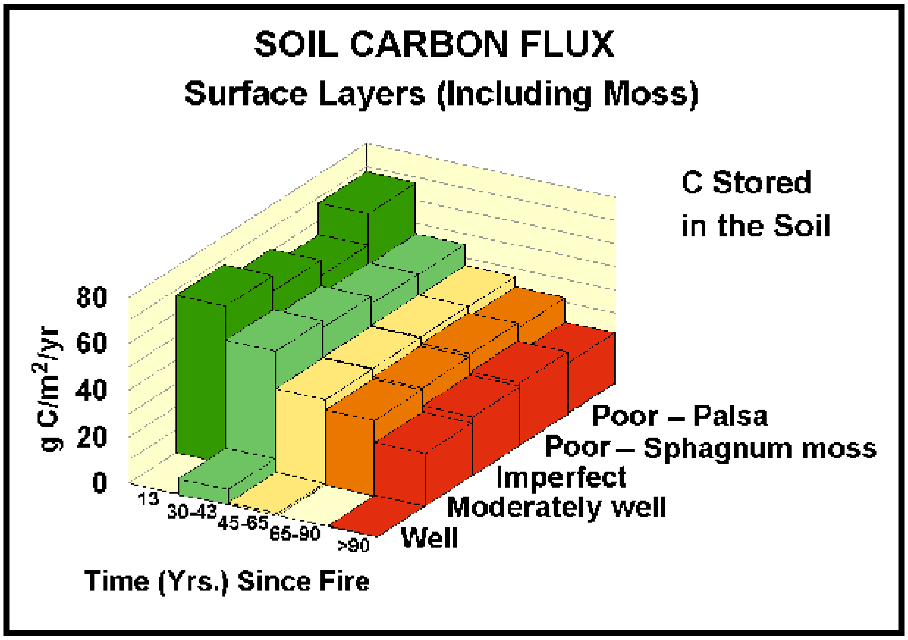
- **Soil C stocks covary with drainage class.**
- **Largest C stocks occur in poorly drained sites where humic material, presumably derived from fire residues, lies at the base of the moss layer.**
- **Calculations of net C flux are sensitive to the decomposition rate for this large pool of deep soil, which can range from a small sink to a source.**
- **Soil of the study area was a small net sink of atmospheric C in 1994, a year with no fire.**
- **Highest annual fluxes are in the most recently burned areas and the oldest, more poorly drained sites.**

PERCENT OF TOTAL STUDY AREA BY FOREST STAND AGE AND DRAINAGE CLASS/VEGETATION TYPE

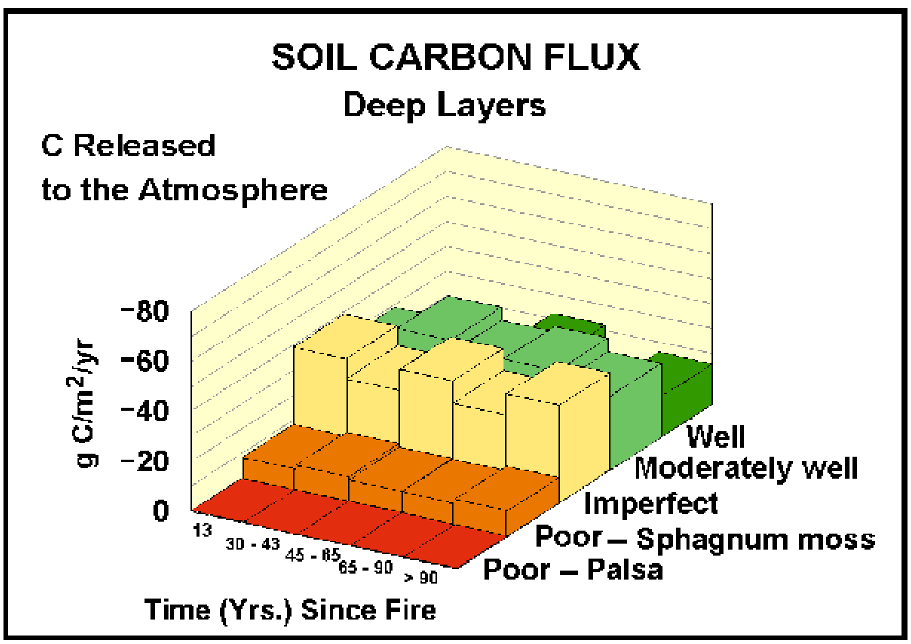
	Time Since Fire, years					
Drainage Class/*Vegetation Type*	**13**	**30-43**	**45-65**	**65-90**	**>90**	**Total**
Well						
Jack pine	0	5	< 1	0	1	6%
Moderately well						
Black spruce/Feather moss	5	2	10	2	2	21%
Imperfect						
Black spruce/Mixed mosses	3	1	6	1	1	12%
Poor						
Black spruce/Sphagnum moss	4	2	9	2	3	20%
Palsa	6	< 1	3	1	4	14%
Very poor						
Fen						18%
Collapse scar bog						1%
Other						
Rock, water, lake						8%
Total	18	10	28	6	11	100%

This table shows the distribution by vegetation type/drainage class and age range of the entire study area. The numbers are percents of the total area.

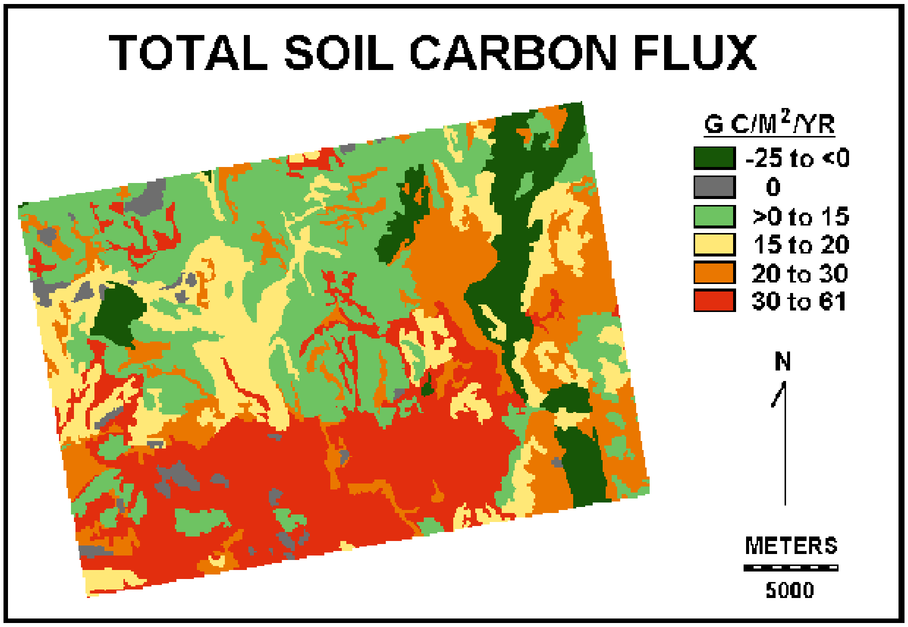
The study area is a mosaic of drainage classes and forest stand ages. The totals show that no one class occupies more than about 1/3 of the total area, and that black spruce is the dominant forest cover.



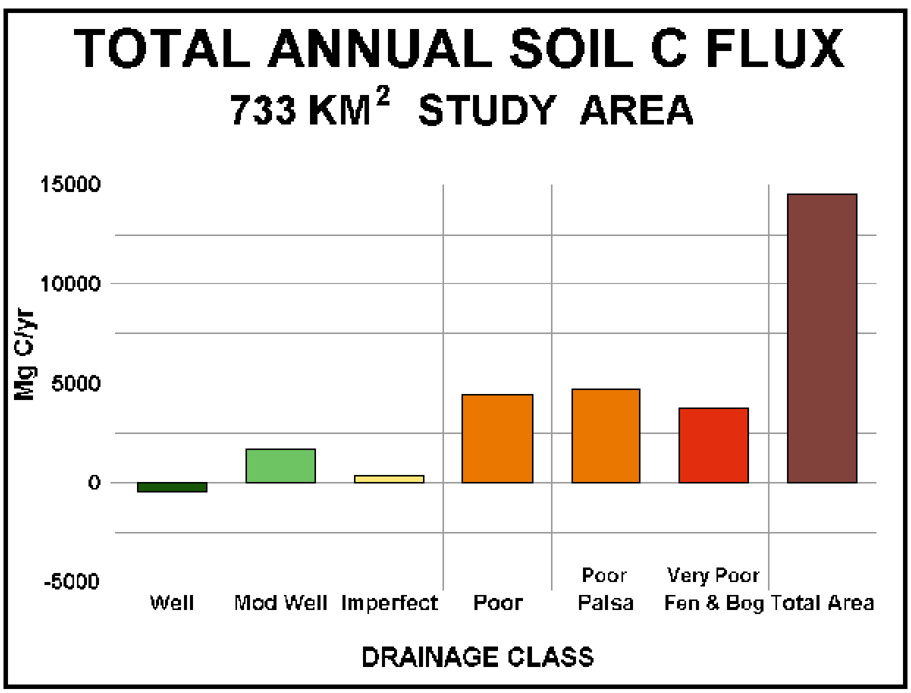
SURFACE SOIL C FLUX -- Net annual <u>uptake</u> of C by the soil (positive values). Time since fire is the important factor, with fluxes highest in the 1981 burn (13 year old stand) and progressively decreasing in older stands.



DEEP SOIL C FLUX -- Net annual <u>release</u> of C into the atmosphere (negative values). Roughly corresponds to drainage with moderately well and imperfectly drained sites losing the greatest amounts of C. Deep layers of the very poorly drained fen sites (not shown) are the exception, <u>gaining</u> C annually.



TOTAL SOIL C FLUX (surface C flux + deep C flux) -- The more poorly drained sites (orange) and the stands within the 1981 burn (red) are accumulating the greatest amount of C annually. Jack pine stands on well-drained sandy soils are showing losses to the atmosphere. Net annual flux for the entire study area is a slight gain.



TOTAL ANNUAL C FLUX -- The more poorly drained sites contribute most to the total estimate for the entire study area.

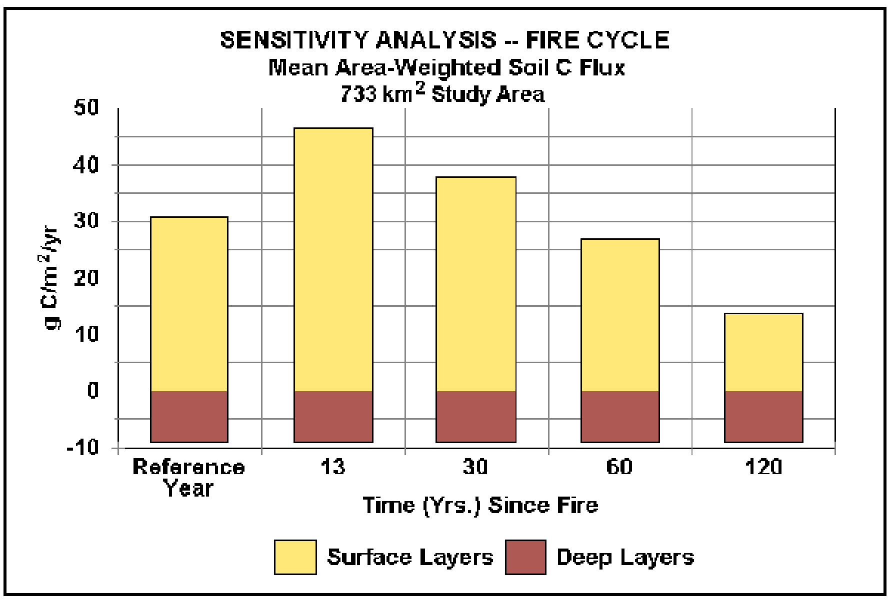
SENSITIVITY ANALYSES

We tested the sensitivity of the modeled C dynamics to two separate broad scenarios to account for the range of uncertainty of our C flux estimates and to simulate effects of changes in the fire cycle:

- *by modifying the fire cycle over 120 years.*
- *by varying decomposition rates of the deep soil based on findings of Trumbore and Harden's (1997) radiocarbon studies.*

SENSITIVITY ANALYSIS -- CHANGES IN FIRE CYCLE

To simulate conditions uniformly over the whole region, we estimated changes in annual soil C flux if the entire study area (except fens and collapse scar bogs) had burned 13, 30, 60, and 120 years ago.



Total C flux for the surface layers is highest shortly after fire, then decreases over time. Total flux for the entire profile 120 years after fire is nearly zero, with annual uptake by the surface layers nearly offset by release of C to the atmosphere by the deep layers.

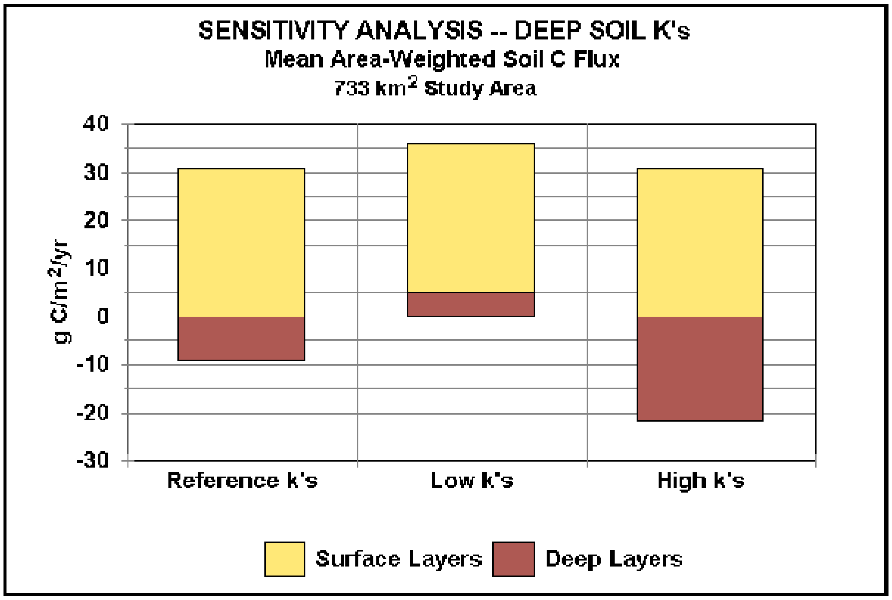
SENSITIVITY ANALYSIS -- DEEP SOIL DECOMPOSITION

Decomposition of deep soil C is a source of CO_2 to the atmosphere. The magnitude of the deep soil C source depends on the assumed decomposition (*k*) constants. As shown in the table below, rate of decomposition differs by drainage class, with fastest rates in well-drained sites and slowest in the poorly and very poorly drained sites.

	Scenario Decomposition Constants, yr^{-1}		
Drainage/*Vegetation Class*	Reference	Low	High
Well-drained sand *Jack pine*	0.01	0.007	0.012
Moderately well-drained clay *Black spruce/Feather moss*	0.003	0.0006	0.006
Imperfectly drained clay *Black spruce/Mixed mosses*	0.002	0.0006	0.003
Poorly drained *Black spruce/Sphagnum moss*	0.0007	0.0005	0.0009
Very poorly drained *Fen and collapse scar bog*	0.0004	0.0002	0.0005

From: Trumbore and Harden, 1997.

The second test compared results of changes in decomposition in the deep layers using the "reference case" of values with the low and high *k* values that Trumbore and Harden (1997) report to be consistent with their field radiocarbon data. These low and high *k* values are really the ranges of uncertainty. Using faster decomposition rates for the deep soil organic layers, individual soil series may become C sources rather than C sinks as losses of deep soil C more than offset C gains in the surface moss layers.



The deep soil can range from a small sink to a source that is large enough to almost completely counter the surface layer sink. Our results highlight the potential importance of deep soil C in the net budget of the system and our relatively poor state of knowledge about it.

MAIN MESSAGE

Deep soils are important and uncertainty is limiting our understanding of the ability of boreal ecosystems to act as present sources or sinks of carbon. The biggest uncertainty is the assumption that the deep soils are experiencing net C losses between fire events.

SUMMARY

- **The study site is a mosaic of drainage classes and forest stand ages, with no one class comprising more than about 1/3 of the total area.**
- **Soil C stocks correspond to drainage classes, with the largest stocks in poorly drained areas.**
- **Soil C fluxes depend on both drainage class and time since last fire, with the largest accumulations of soil C in fens and in the surface mosses of recently burned sites.**
- **The deep soil can range from a small sink to a source that is large enough to almost completely counter the (surface) moss layer sink. Our results highlight the potential importance of deep soil C in the net budget of the system and the importance of narrowing uncertainties in the estimates of deep soil C decomposition rates.**
- **Turnover of deep soil C in these ecosystems and its response to expected warming and altered drainage patterns deserve more attention.**

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