Boreal Peatland C Storage and Emissions from Extreme Wildfire

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Background

Peatlands play a significant role in both sequestering and releasing large amounts of carbon. In the boreal zone, peatlands are estimated to represent 30% of the global organic soil C stores and are widely affected by wildfire. Climate change and resulting increases in fire frequency, extent and severity in the boreal zone have the capacity to alter the hydrology and ecology of the landscape with long term consequences to peatland ecosystems and their traditional role as C sinks.

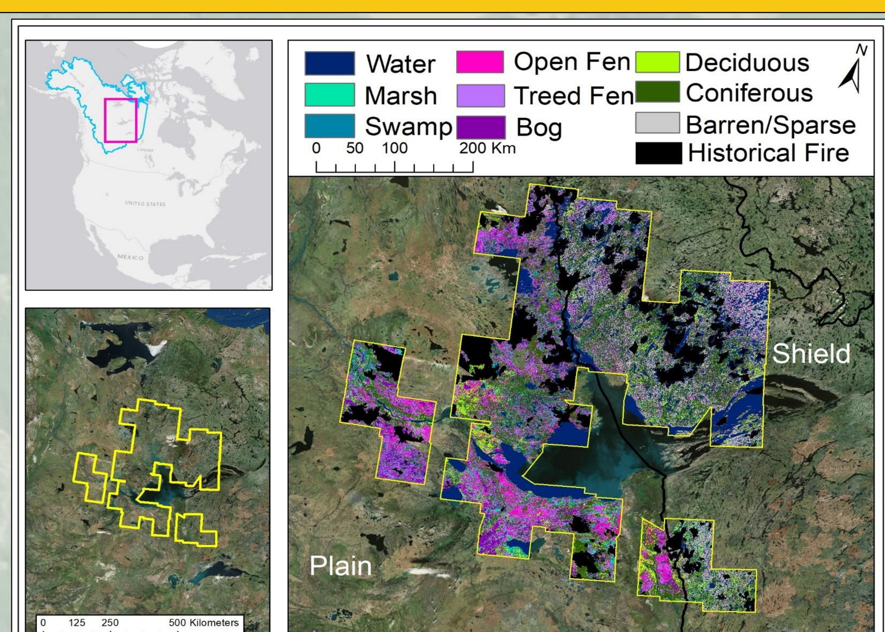
Objective: Improve the characterization, quantification and understanding of boreal peatlands in global C cycling.

Research Questions

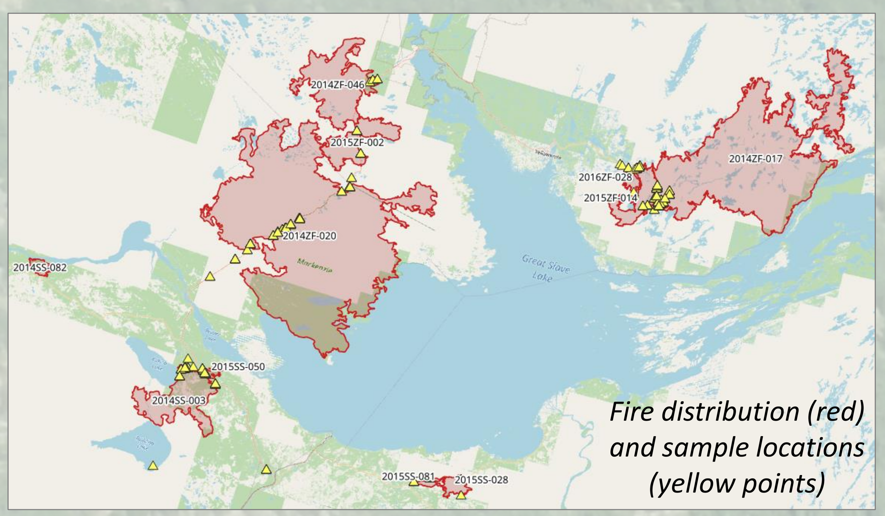
1. How much C is stored in this peat-rich study area? How does this compare to other estimates?
2. How much C is lost in emissions during wildfire from boreal peatlands vs. uplands under extreme drought conditions when peat soils are most susceptible to burning?

Study Area

- A 4.6 million ha peat-rich area around the Great Slave Lake of southern NWT and northern AB that experienced more than 136 wildfires in 2014-15
- Multi-sensor ecosystem type map with spatial distribution of peatland types (93% accuracy)
- Post-fire biophysical field data collected 2015-1019 included:
  - Multiple layers of soil depth (duff upper/lower, moss, top thickness) for fuel loading parameters
  - % Cover of woody debris, grasses, herbaceous
  - Distribution and biomass by lifeform (shrub/tree and species) for carbon estimates and fuel loading parameters
  - Peat "brownie" sampling and peat depths for carbon estimates



Bourgeau-Chavez et al. 2019. https://doi.org/10.3334/ORNLDAAC/1695



Fire distribution (red) and sample locations (yellow points)

Data Analysis 1. How much C is stored?

Carbon Equation:

$$CP = \sum_{p=1}^{P_v} \frac{D_p \rho_p C_p A_p}{10^{12}} + \frac{AGC_p A_p}{10^{12}}$$

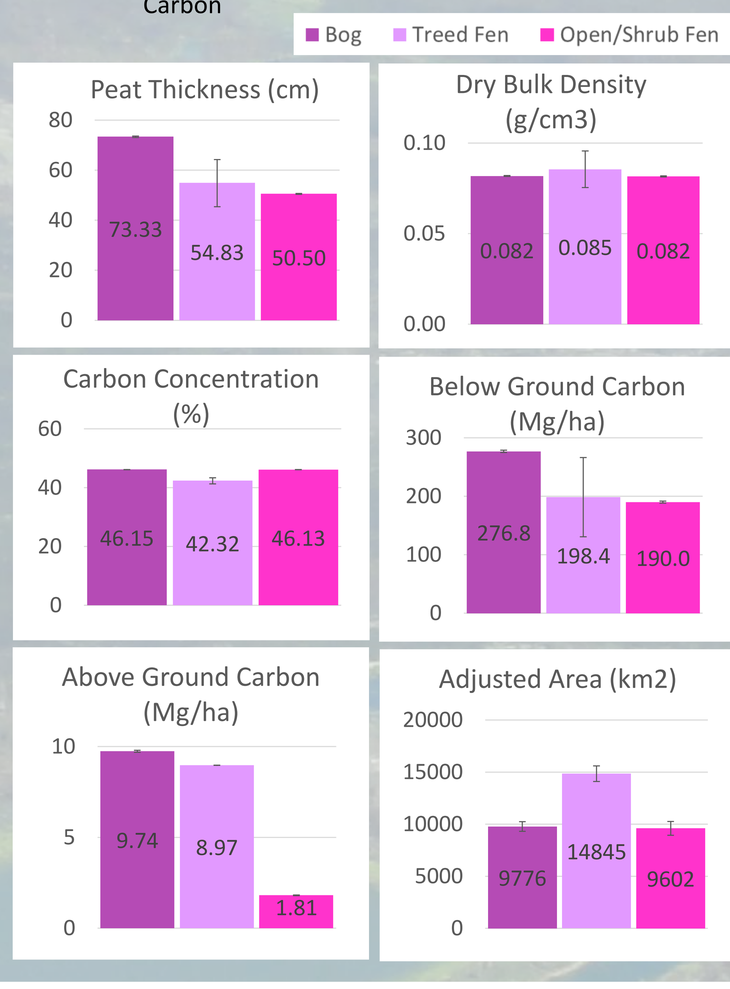
Total peatland carbon pool (Pg); Total # peatland ecosystems; Peat thickness (m); Dry bulk density (kg/m³); Carbon concentration (% mass of C in dry peat); Area (m²); Below Ground Carbon; Above Ground Carbon

Page, S.E., Rieley, J.O., and Banks, C.J. (2011) Global and regional importance of the tropical peatland carbon pool Glob. Change Biol. **17** 798–818

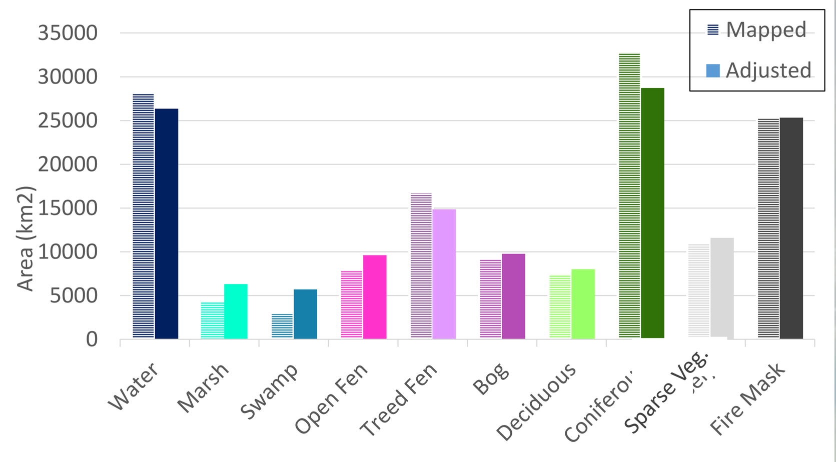
Field Data:
Due to small sample sizes, mean and confidence intervals were generated from a bootstrap distribution resampled 1000x for each peatland type in R Studio

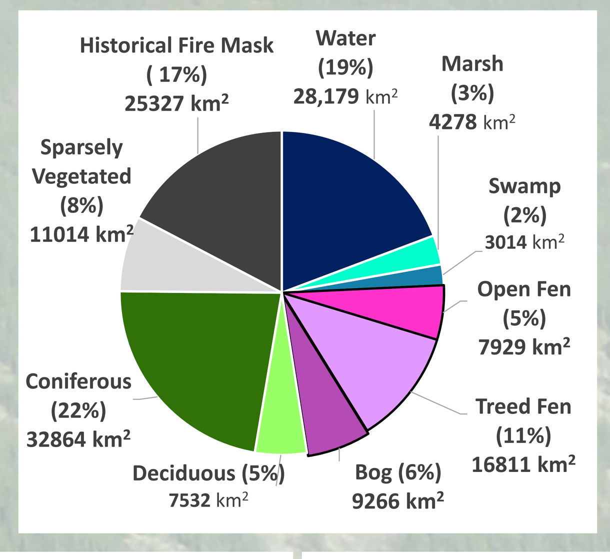
Below Ground Carbon (BGC):
Peat thickness (cm), bulk density (g/cm3) and carbon concentrations (%) for bog, treed fen, and merged open and shrub fen came from field measurements. Peat thickness is the thickness of organic peat soil layer. Bulk density is the mass of dry soil per unit volume. % C was calculated from collected samples.

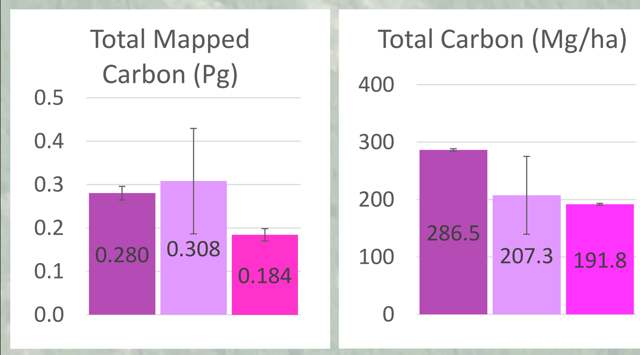
Above Ground Carbon (AGC):
Estimates were assumed to be 50% of the calculated above ground biomass derived from allometric equations from field data by species.



Map Area:
Adjusted area was estimated using error matrix and % of land cover on the map. Using a stratified estimator to calculate peatland cover area based on error matrix.







Results:

- 228.5 (+/- 23.8) Mg of C/ha or 0.772 Pg of C total
- Bog contributed most on per ha basis; treed fens contributed the most within study region due to area on the landscape.
- Estimates are lower than literature, which are variable and many acknowledge lack of or insufficient field data. High-resolution mapping with geospatial information on peatland type helps reduce uncertainty in C storage estimates
- Shallower organic soils makes wildfire a threat. With increasing drought and intensifying wildfire regimes, the vulnerability of peatlands to wildfire is a concern.

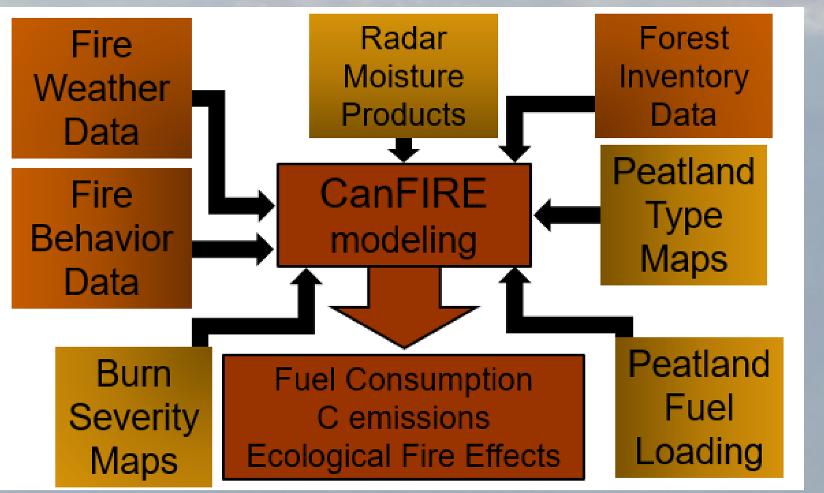
Peatland Type		Area (km²)	Dry Bulk Density (g/cm³)	Peat Thickness (cm)	Carbon Concentration (%)	BGC (Mg/ha)	BCG Mapped Area (Pg)	ACG (Mg/ha)	AGC Mapped Area (Pg)	Total C (Mg/ha)	Total C Mapped Area (Pg)
Bog	mean	9776	0.0818	73.33	46.15	276.79	0.2706	9.7447	0.0095	286.5375	0.2801
	95% CI	469	0.0003	0.28	0.03	2.10	0.0151	0.0543	0.0005	2.1536	0.0156
Treed Fen	mean	14845	0.0855	54.83	42.32	198.38	0.2945	8.9687	0.0133	207.3485	0.3078
	95% CI	754	0.0101	9.40	1.04	67.82	0.1207	0.0041	0.0007	67.8224	0.1215
Open/ Shrub Fen	mean	9602	0.0815	50.50	46.13	189.96	0.1824	1.8090	0.0017	191.7662	0.1841
	95% CI	664	0.0003	0.18	0.05	1.62	0.0143	0.0236	0.0001	1.6394	0.0144
Total Mean		34223	0.2488	178.66	134.60	665.13	0.7475	20.5223	0.0246	685.6522	0.7721
95% CI		1887	0.0107	9.86	1.12	71.53	0.1501	0.0820	0.0014	71.6154	0.1515
Peatland Mean		11408	0.0829	59.5532	44.8666	221.7100	0.2492	6.8408	0.0082	228.5507	0.2574
95% CI		629	0.0036	3.2864	0.3718	23.8445	0.0500	0.0273	0.0005	23.8718	0.0505

Data Analysis 2. How much C is lost from emissions?

Modeling:
Wildfire emission model CanFIRE (Bill De Groot, NRCAN) is widely used in Canada to estimate C emissions from upland ecosystems.

Field data from 75 sites (417 plots) across 11 fires from 2014-2016 were used to parameterize CanFIRE for peatlands to compare to uplands.

The ecotype map was used to distinguish peatlands and uplands Each pixel was then treated as a separate "stand" for input to CanFIRE and aggregated.



Schematic of CanFIRE model. Orange inputs relate to fire weather data and yellow inputs depict fuel loading data derived from field measurements.

**Assumption: inputs for each ecotype will be similar across the same fire.*

Since no validation data exists for wildfire emissions, model results were compared to Wildland Fire Emissions Inventory System (WFEIS). Total C estimates compared well, with similar magnitudes, with slight variation by ecoregion. WFEIS overestimates Taiga shield fires and underestimates for Taiga plains which have higher proportion of peatlands.

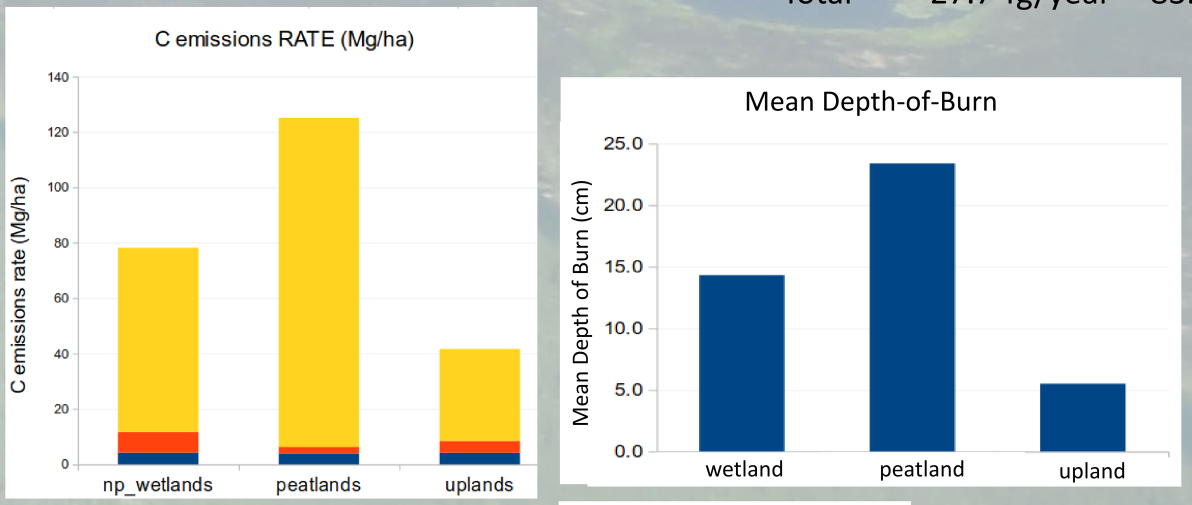
CanFIRE Results:

Ecotypes were grouped to compare contributions of peatlands vs uplands:
- Uplands (deciduous and coniferous forest)
- Peatlands (open & treed fen, bog)
- Non-peatland wetlands (marsh, swamp)

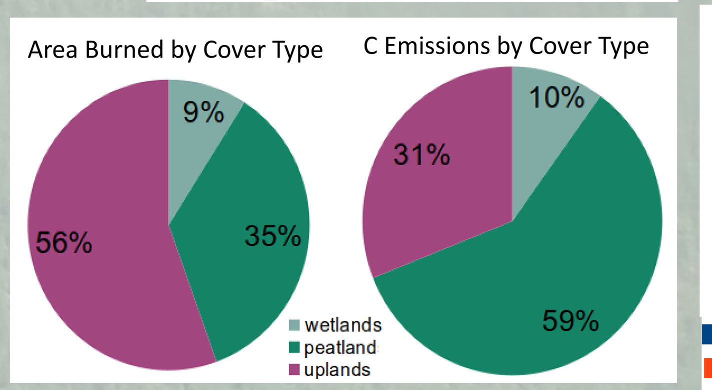
CanFIRE C Wildfire Emissions

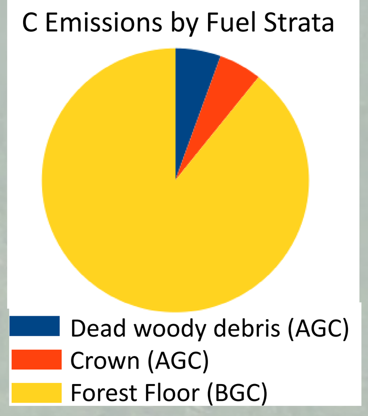
Cover Type	Yearly	Total
Uplands	2.6 Tg/year	6.7 Tg
Peatlands	16.5 Tg/year	49.4 Tg
Non-Peatland Wetlands	8.6 Tg/year	25.9 Tg
Total	27.7 Tg/year	83.2 Tg

On a rate basis (Mg/ha), non-peatland wetlands emit 2x as much carbon as uplands and peatlands emit over 3x as much carbon as uplands during wildfires.



Peatlands account for 59% of C emissions despite making up only 35% of the area burned





Below-ground carbon accounts for 89% of wildfire emissions.

Extreme drought has changed vulnerability to wildfires (Bourgeau-Chavez et al. 2022). From 2014-2016:
- 83.2 Tg of 772 Tg carbon stored (10.8%) was emitted during wildfires;
- 28 Tg or 3.6% per year lost to wildfires

How do carbon accumulation rates compare?
- Based on studies: 7-19 Tg C per year accumulates across our area
- ~2x as much C was emitted per year than is accumulated

Note: this area/time period was chosen due to higher-than-usual fire activity