Stability of fen and bog peatland types over the Holocene Epoch in the Hudson Bay Lowlands, Canada

SA Finkelstein[1], MS Packalen[2], McLaughlin JM[2], Davies MA[1], Bysouth D[1], DaSilva K[1]

[1]Earth Sciences, University of Toronto; [2]Ontario Ministry of Natural Resources and Forestry, Sault Ste. Marie, Canada

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BACKGROUND

Wetlands have two major impacts on the global carbon (C) cycle:

o Large carbon pool. Wetlands, in particular northern peatlands, have accumulated a significant carbon pool over the Holocene. Previously estimated at 450-550 Gt C[1,2], recent work suggests northern peatland carbon pool could be > 1000 Gt[3]. This larger pool needs to be balanced against sources of carbon to the atmosphere given the relatively stable concentrations of CO_2 in the atmosphere during the Holocene. Thus, better understanding controls on the rate at which C accumulates in northern peatlands is critical to modelling the global C cycle during the Holocene and other time periods.

o Large methane production. Wetlands are the dominant natural source of CH_4 to the atmosphere. Explanations for the fluctuations in deglacial and Holocene trends in ice-core derived atmospheric methane concentration and $\delta^{13}C$ focus on:

i. Climate driven changes in wetland CH_4 production (temperature, effective moisture balance, growing degree days)
ii. Changes in areal extent of wetlands
iii. Changes in wetland ecological processes related to vegetation type, which affect methane production and movement, methanotrophy, storage and/or emission in wetlands

To address knowledge gaps in these two broad domains, this poster explores the role of peatland vegetation ("peat type") in Holocene carbon dynamics in the Hudson Bay Lowlands, with particular focus on carbon accumulation rate.

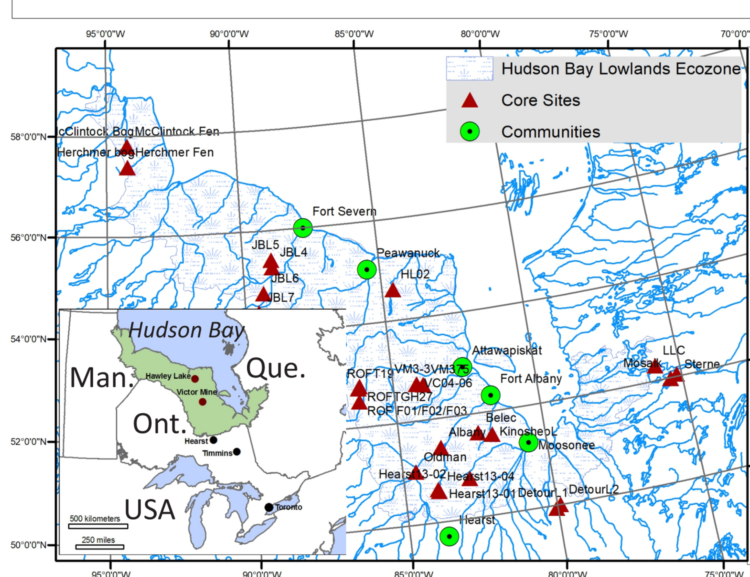

Figure 1: Hudson Bay Lowlands (green shaded area in inset) multi-dated peat core locations

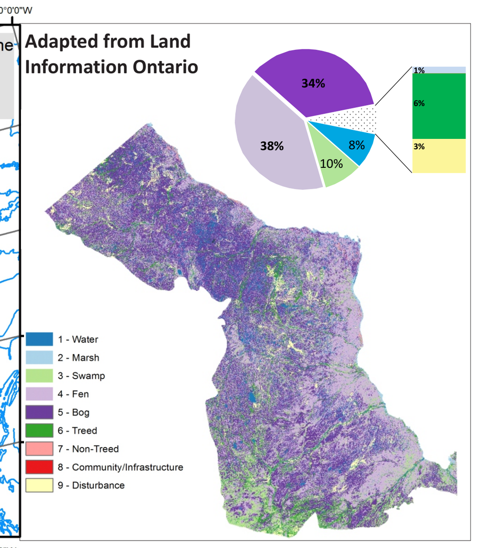

Figure 2: Landcover classification for Hudson Bay Lowlands

STUDY SITE

Hudson Bay Lowlands (HBL) is an extensive nearly continuous peatland situated in north-eastern Canada adjacent to James and Hudson Bays **(Figure 1)**. Present-day areal extent is ~350,000 km^2 with an existing carbon pool of ~30 Gt[4], and mean peat carbon mass of 92 ± 35 kg C/m^2 (ref. 5). Peat basal ages follow a chronosequence with oldest peatlands inland adjacent to the margin of the Canadian Shield, and most recently initiated peatlands adjacent to the coast, reflecting glacial isostatic adjustment (GIA). Analyses of paleovegetation proxies in HBL peat cores indicates a highly diverse suite of successional trajectories including marsh-to-fen and fen-to-bog transitions, paludification of forested substrates, and local persistence of fen peatlands from the middle Holocene to present day[6-9]. Presently the HBL is a mosaic of peatland types (**Figures 2 and 3**), with a preponderance of fens closer to the coast, reflecting hydrological control mediated by GIA and peatland age[4]. Thus, most HBL peat records are composed of several different "peat types".

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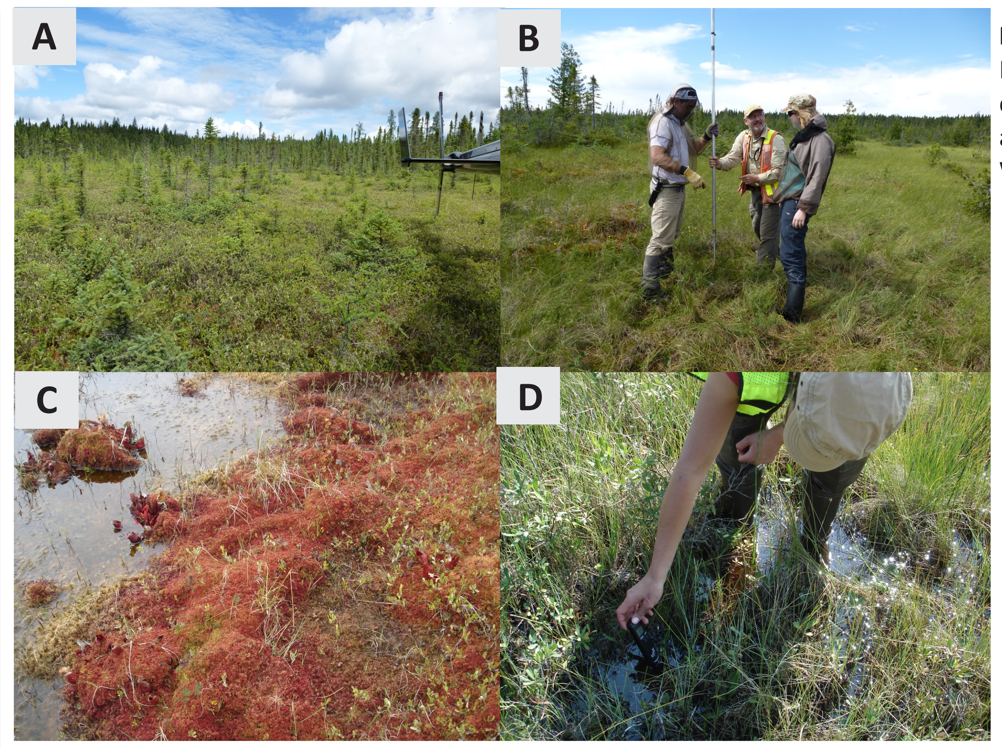

Figure 3: Bog and fen peatland types in the HBL. (A) Present-day bog site 13-01 southern JBL, (B) present-day fen site 13-01 southern JBL, (C) present-day bog and (d) fen surface, VM series sites Attawapiskat Watershed, central HBL

Table 1: 18 sites with peat core samples classifed into peat type

SiteName	Lat (°N)	Long (°W)	Current peat type	Age-depth	Reference	C:N?
Hearst13-01	50.77	-82.78	bog	Bacon	Davies, Finkelstein et al (In review)	N
Hearst13-02	50.63	-83.89	bog	Bacon	Bysouth and Finkelstein (in review)	N
Hearst13-04	50.59	-83.86	fen	Bacon	Bysouth and Finkelstein (in review)	N
Herchmer bog	57.38	-94.20	bog	Bacon	Kuhry, 2008	N
HL02	54.61	-84.60	bog	Bacon	Packalen and Finkelstein, 2014	Y
HL03	54.68	-84.60	fen	Bacon	Packalen and Finkelstein, 2014	Y
KJ2-3	51.59	-81.76	fen	Bacon	Packalen and Finkelstein, 2014	Y
KJ4-3	51.59	-81.78	bog	Bacon	Packalen and Finkelstein, 2014	Y
McClintock Bog	57.80	-94.21	bog	Clam	Kuhry, 2008	N
ROFT19	52.75	-86.22	bog	Bacon	Davies, Finkelstein et al (In prep)	N
ROFTGH27	52.79	-86.17	fen	Bacon	Davies, Finkelstein et al (In prep)	N
VM.3.3	52.71	-84.17	fen	Bacon	O'Reilly et al 2014	Y
VM.4.3	52.71	-84.18	bog	Clam	Bunbury et al., 2012	Y
VM2-5	52.72	-83.94	fen	Bacon	Packalen and Finkelstein, 2014	Y
VM3-2	52.71	-84.17	fen	Bacon	Packalen and Finkelstein, 2014	Y
VM375	52.69	-83.95	bog	Clam	DaSilva, Finkelstein et al., in prep	N
VM4-1	52.71	-84.19	bog	Bacon	Packalen and Finkelstein, 2014	Y
VM4-5	52.70	-84.18	bog	Bacon	Packalen and Finkelstein, 2014	Y

RESEARCH OBJECTIVES

We hypothesize that peat type has an effect on carbon accumulation rates (CAR). If an effect of peat type is documented, then this parameter should be specified in predictive models of carbon uptake and release in northern peatlands. We previously hypothesized that middle Holocene (between 4 – 7 ka BP) maxima in HBL carbon accumulation rates are related to prevalence of minerotrophic fens[10]. Ancillary explanations for peak CAR values during the middle Holocene relate to warmer and moister climates at the Holocene Thermal Maximum (HTM)[11].

Our prediction is that fen peats have higher rates of carbon accumulation than *Sphagnum*-dominated bog peats because of the higher bulk densities and carbon concentrations reported for herbaceous peat in the Lehigh Database of northern peatland soil properties[12]; however any difference in CAR also depends heavily on the peat accretion rate. The overall impact of any difference in CAR between fen and bog peat depends on prevalence of fens through the Holocene in the HBL. To better explain the temporal variability in Holocene CARs in the HBL, we aim here:

1. To compile a dataset of peat core samples of Holocene age from the HBL, classified by peat type, and use it to test the hypothesis of higher CAR in fen peat. Further, by comparing bulk density, %C and rate of peat accretion across peat type, we aim to determine which of the three terms used in the calculation of CAR differ significantly across peat type.
2. To use the dataset to verify if our previous hypothesis of higher CAR in the middle Holocene is supported. If so, we explore whether these high values correspond predominantly with fen peat.

METHODS

Data from 18 multi-dated peat cores from the Hudson Bay Lowlands were combined into a dataset of 1020 peat samples containing measurements of bulk density, % carbon (C), peat vertical accretion rate, carbon accumulation rate, and peat type (Table 1; Figure 1).

Assignment of peat type was done using various proxies as available for each core, including pollen or testate amoeba assemblages, macrofossils, and/or C:N ratio (Table 2). Bulk density was determined using standard methods[13]; %C content was determined either through direct measurement by elemental analyzer, or loss-on-ignition with %C assumed to be 50% organic matter. Bayesian age-depth models[14] were developed for each record using the `rbacon` package for R and were used to calculate the rate of peat accretion for each sample. The mean value was used in the calculation of CAR:

Carbon accumulation rate (CAR) for each sample was calculated as:

CAR (g/cm^2/yr) = bulk density (g/cm^3) * % carbon * peat accretion (cm/yr)

Table 3: (A) distribution of peat types, and (B) Summary statistics for three main peat types (n = 1000 samples classified as bog, poor or rich fen from 18 sites). For comparison, the Lehigh database[12], in which 83/232 (25%) cores had data available on peat type through time, showed for bog peat a mean (+/- SD) bulk density of 0.076 +/- 0.038 g/cm^3 and %C of 46.0 +/- 4.1; for herbaceous peat, mean bulk density is 0.118 +/- 0.0075 g/cm^3 and %C is 50.5 +/-4.9.

A

Peat type	# Samples
Bog (B)	273
Poor fen (PF)	304
Rich fen (RF)	423
Fen (undifferentiated)	9
Marsh	11
TOTAL	**1020**

B

BD = Bulk density (g/cm3)	Bog BD	Poor Fen BD	Rich Fen BD	Overall BD
Min	0.012	0.029	0.017	0.012
Q1	0.059	0.073	0.093	0.073
Median	0.072	0.09	0.11	0.093
Mean	**0.078**	**0.093**	**0.13**	**0.11**
Q3	0.089	0.11	0.13	0.12
Max	0.422	0.21	2.3	2.3
%C = Carbon content	**Bog %C**	**Poor Fen %C**	**Rich Fen %C**	**Overall %C**
Min	15.6	41.6	0.659	0.659
Q1	47.9	46.6	46.5	46.6
Median	49.1	48.9	48.7	48.9
Mean	**48.7**	**48.9**	**47.3**	**48.1**
Q3	50.5	51.3	51.5	51.2
Max	55.1	55.7	54.1	55.7
CAR (g/m2/yr)	**Bog CAR**	**Poor Fen CAR**	**Rich Fen CAR**	**Overall**
Min	3.23	3.78	3.04	3.04
Q1	14.2	13.6	15.3	14.4
Median	18.5	18.7	20.6	19.3
Mean	**21.4**	**24.3**	**24.0**	**23.4**
Q3	25.5	28.2	31.9	28.7
Max	111	96.1	62.3	111

RESULTS

1020 peat samples from 18 multi-dated peat cores were assigned to peat type classes. Ages of samples range from -65 – 8200 cal yr (Figure 4, inset), with few modern samples (> 1950 AD) owing to poor age control on recent peats, and few samples older than ~ 8200 cal yr as this is approximately the basal age for HBL peat initiation following emergence from the Tyrrell Sea. Five peat types were identified; fen samples dominate the dataset (72% of samples).

Bulk density is higher in rich fen samples than in bog samples (Figure 5a; Table 3); mean values reported here agree closely with findings in the Lehigh Database of northern peatland soils[12]. Poor fen samples are intermediate in terms of bulk density.

Carbon content is similar across the bog to rich fen continuum (Figure 5b; Table 3). The distinction recorded between bog peat (mean = 46% C) and fen peat (50.5% C) in the Lehigh Database[12] is not found here (Figure 6).

Carbon accumulation rates are higher in poor and rich fens (24.3 and 24.0 g/m^2/yr) than bogs (21.4 g/m^2/yr) (Figure 5c; Table 3).

The time series of CAR through the Holocene for all sample points (Figure 4) shows above average values between 6000 – 8000 cal yr BP, supporting our previous hypothesis, but refining the time period of maximum CAR.

A major increase in the number of bog samples begins between 3500 – 4000 cal yr BP (fen-to-bog transition) (Figures 7 and 8).

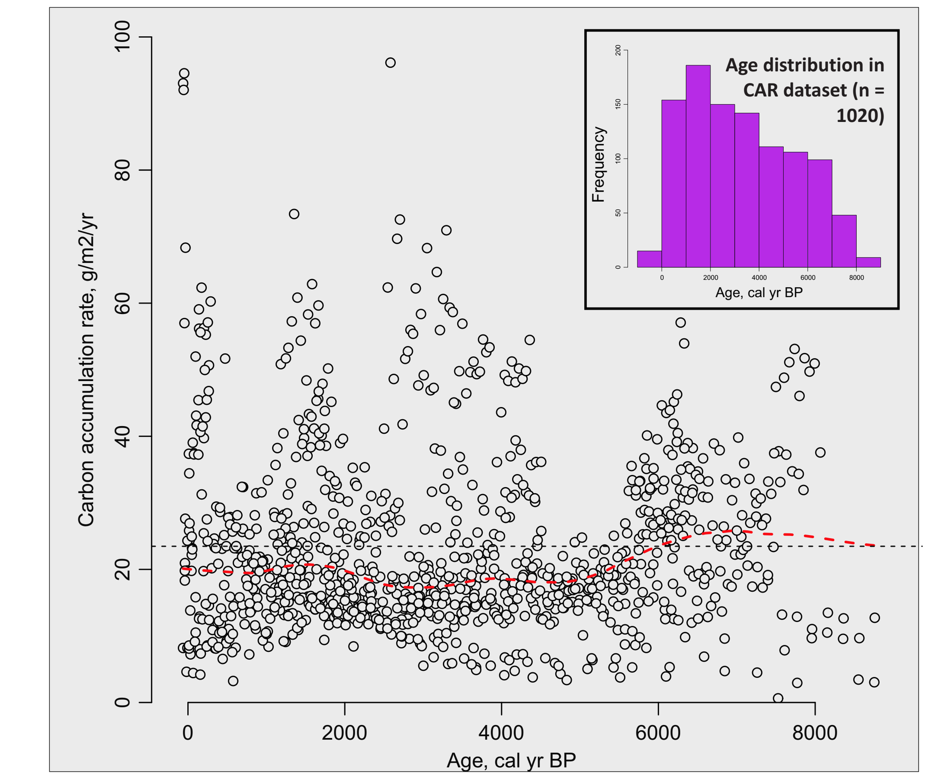

Figure 4: Holocene carbon accumulation rates (CAR) for 1020 samples from 18 multi-dated HBL cores. Red dashed line shows a lowess smoother (span = 0.3, degree = 1 (linear)). Black dashed line is the mean CAR for all sample points. Inset shows histogram of sample frequencies by age class.

Table 2: Peat type assignments from C:N

C:N	Peat type
>80	Bog (*Sphagnum*)
40-80	Poor fen
<40	Rich fen

* This classification is derived from the mean value reported in the Lehigh database[12] for $C:N_{Sphagnum\,bog}$ = 81 and $C:N_{herbaceous\,peat}$ = 34.4; and data from Hudson Bay Lowlands cores6 showing C:N < 25 for fen peat, and C:N = 40-114 following transition to poor fen/bog.

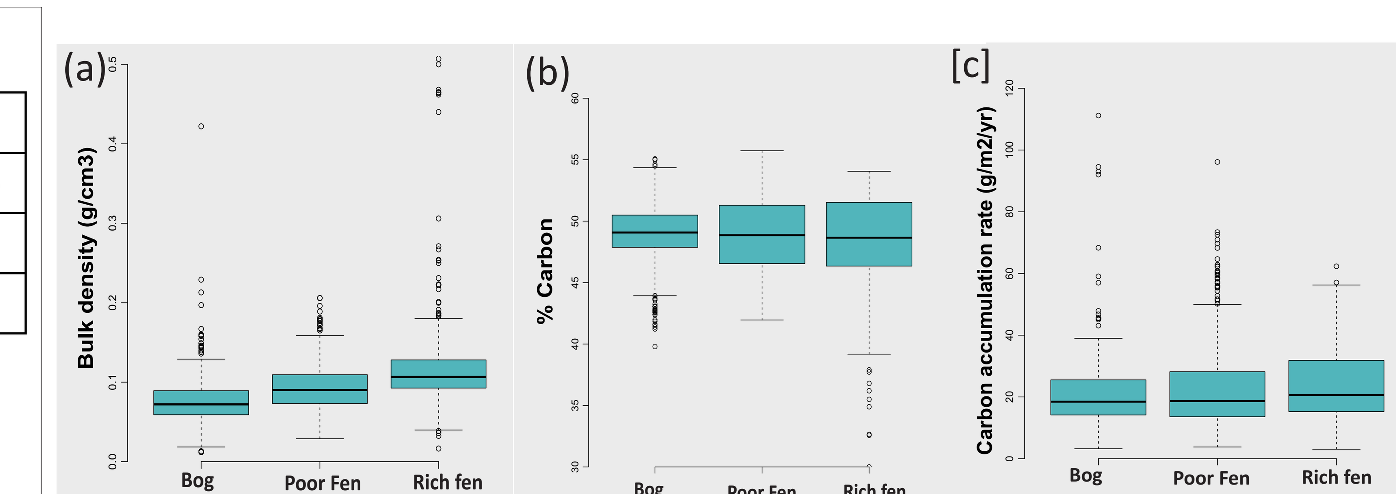

Figure 5: Boxplots comparing peat properties for samples classified as Bog, Poor fen and Rich fen for (a) bulk density (only samples with values < 0.5 g/cm^3 shown, but the whole dataset included in the analysis), (b) %C, and (c) carbon accumulation rate

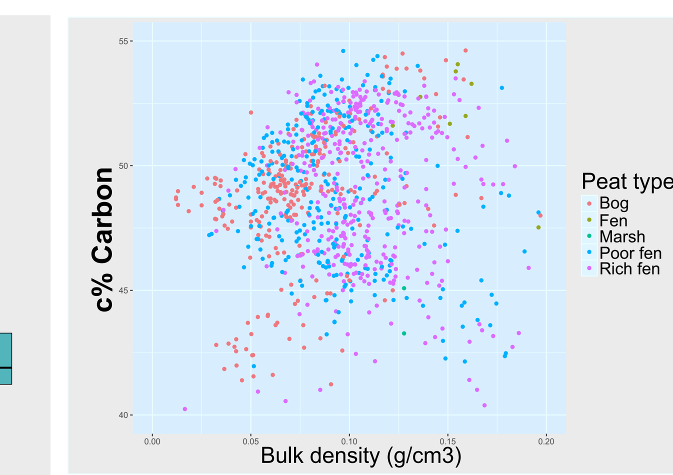

Figure 6: Bulk density and %C for 5 peat types (outliers not shown)

DISCUSSION

Fens show higher carbon accumulation rates, but this is not related to higher %C. While bulk density is higher in fens, the results suggest the need to evaluate the role of peat accretion rate as well.

Fens are the most important wetland class in the HBL landscape today and also dominate the paleo-landscape through the Holocene. Fen-to-bog transitions take place at some sites, with a prominent rise in bog peat types occurring between 3500 – 4000 cal yr BP. Others remain fens for the duration of the Holocene.

The dominant time period for fen-to-bog transition post-dates the high values of CAR by >2000 yrs.

The period between 4000 – 8000 cal yr BP is characterized by sustained dominance by fen sites, but not sustained high rates of CAR across the dataset.

While some sites show positive correlation between CAR and fen peat types, across the whole dataset, they are not strongly correlated. The dominant signal in the CAR time series is above mean values between 6000 – 8000 cal yr BP. This was a time period dominated by rich fens (with some bogs, marshes and poor fens present as well). The combination of faster-accumulating rich fens, as well as high insolation and HTM climates may have promoted faster CAR, consistent with the strong role for climate and insolation found in other studies[3,11,15].

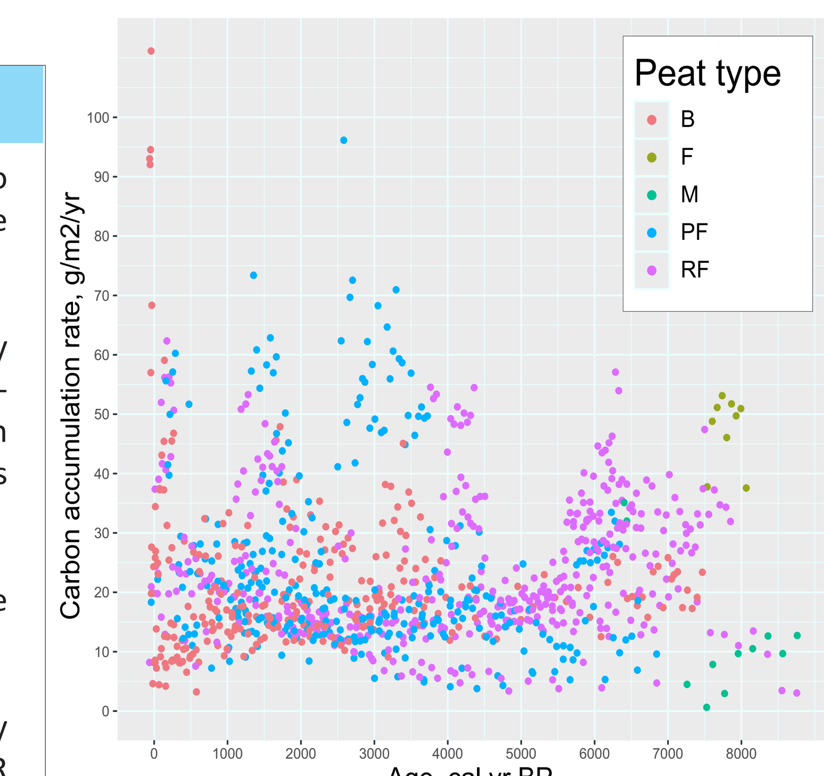

Figure 7: Holocene carbon accumulation rates (CAR) for 1020 samples from 18 multi-dated HBL cores, coded by peat type. Peat types are bog (B), fen (F), marsh (M), poor fen (PF) and rich fen (RF)

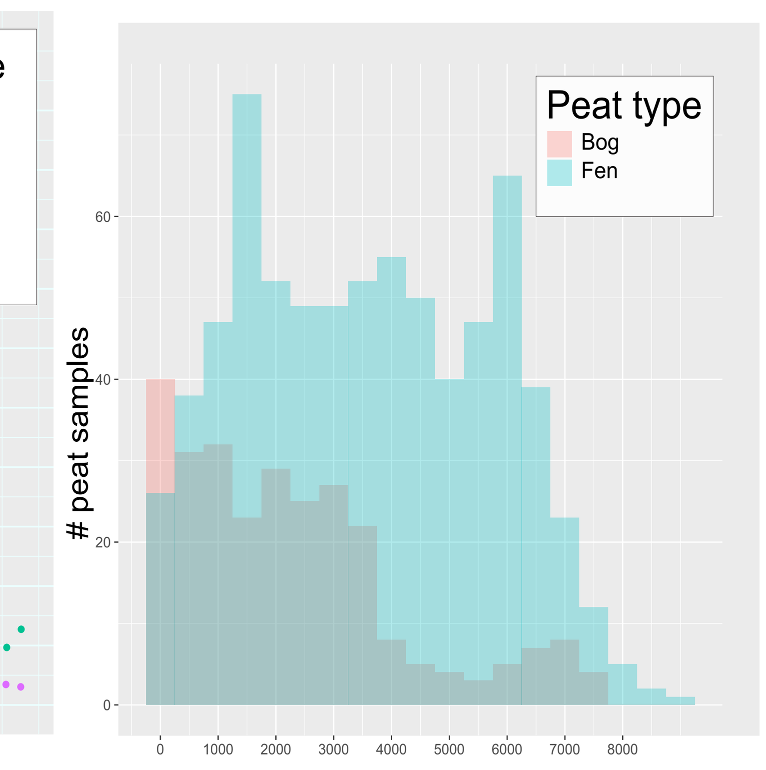

Figure 8: Histogram overlay for frequency of bog samples and fen samples ("fen" includes rich fen, poor fen, and undifferentiated fen)

NEXT STEPS

The rate of peat accretion by peat type is a critical term and is the major source of uncertainty in CAR. Figure 9 shows an example from core 13-04-01 showing uncertainty in carbon influx based on the range of possible peat accretion rates generate in the bacon age-depth model.

Classification of peat types. Biomization of pollen, testate amoeba assemblages; systematic analysis of C:N data.

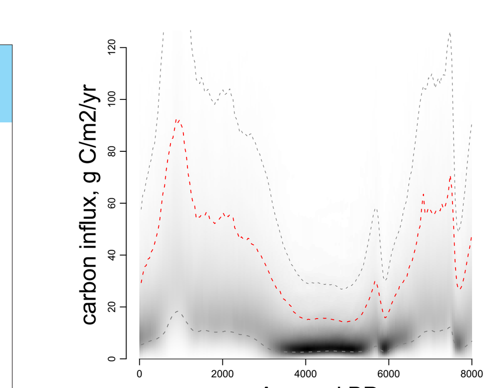

Figure 9: Uncertainties in carbon influx for core 13-04 derived from peat accretion rates specified in the bacon age-depth model. Darker greyscales indicate more likely values.

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FURTHER INFORMATION

Sarah Finkelstein: sarah.finkelstein@utoronto.ca
https://utpaleolab.wordpress.com/
ORCiD: https://orcid.org/0000-0002-8239-399X or scan the bar code -->