# WHAT LIES BENEATH?

# Peat Expansion in the Arctic Tundra

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## TundraPEAT

The impacts of amplified climate warming in the Arctic ('greening' and 'browning') on belowground processes and carbon (C) budgets are uncertain.

We focus on two key elements of changing terrestrial ecosystems:

- 'peat patches', i.e., landscapes with a surface organic layer too thin (< 30 cm) to be classified as peatlands, but which clearly represent net C sinks since their inception, and which may become key players in Arctic C sequestration in the 21st century
- the role of peat moss, *Sphagnum,* in the formation, persistence, and rapid rates of C sequestration of these potentially 'incipient' peatlands.


*Will the warming Arctic transform into a peat- and carbon-rich landscape, as the boreal zone is now, or are there essential conditions lacking in a warming Arctic that will prevent this?*

The **overall goal** of TundraPEAT is to understand organic soil (peat) accumulation processes in the tundra biome, and to assess the role of peat in regional and pan-Arctic carbon budgets at decadal and centennial timescales. We aim to develop a predictive understanding of how, when, and why peatlands may develop in the Arctic.

Our multidisciplinary research project integrates:

(1) A **synthesis** of existing data from the tundra and boreal biomes;

(2) Collection of **new data** from multiple tundra sites along the northernmost peat-forming frontiers of the North American Arctic;

(3) Soil **incubation** experiments;

(4) Ecosystem-scale process **model simulations.**

The results may be of importance to northerners who seek to:

- **understand** why and how the ecosystems are changing, and **adapt** to future conditions e.g., permafrost thaw and fire;
- **manage, conserve and protect** future carbon-rich ecosystems, essential on national and global scales.

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NNA: Collaborative Research: MSB-FRA: Peat Expansion in Arctic Tundra - Pattern, Process, and the Implication for the Carbon Cycle (TundraPEAT)

## (1) DATA SYNTHESIS

The global data synthesis for boreal and tundra biomes is the first version of the PAGES C-PEAT (Carbon in Peat on EArth through Time) Global Peatland Carbon Database (GD), available on the PANGAEA data repository.

PANGAEA hosts 875 C-PEAT datasets:

- 322 geochemistry, 317 age determination, and 236 calibrated ages;
- Collected from 268 distinct sites (North American sites in **Figure 1**);
- Referring to 88 journal articles.

Loisel et al., in prep., C-PEAT's Global Peatland Carbon Database, *ESSD*

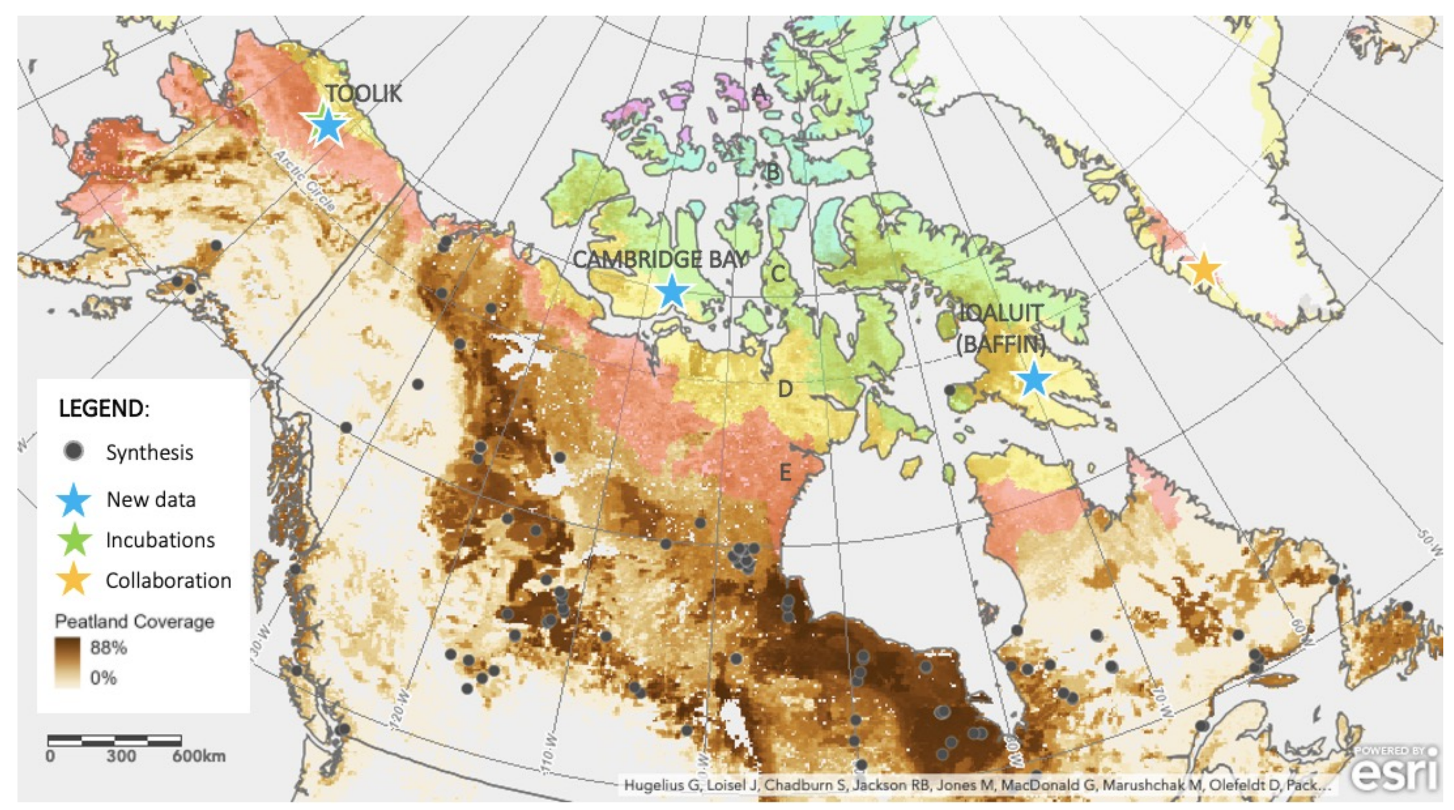



***Figure 1.*** *Map of TundraPEAT study sites:* ***C-PEAT GD sites for boreal and tundra peat in North America, new data collection sites****, location of* ***incubation experiment cores****, and* ***international collaboration sites*** *in Greenland). Peatland coverage map adapted from Hugelius et al. (2020) & Wildlife Conservation Society of Canada (WCS, 2022). Arctic bioclimatic subzones, A-E from coldest to warmest, adapted from the Circumpolar Arctic Vegetation Map (CAVM, Walker et al., 2005)*

## (2) NEW DATA COLLECTION

Peat patches established on the North Slope (Alaska):

- Little Ice Age (LIA): cold climate and reduced evapo-transpiration led to persistent waterlogging, low decomposition, and preservation of organic matter.
- Late 20th century, along with *Sphagnum* expansion.

**ONGOING WORK:**

New cores from Toolik (2019), Cambridge Bay (2019 & 2022) and Iqaluit (Baffin, 2022):

- Vegetation succession (plant macrofossil analysis);
- Water table depth (testate amoebae);
- Radiocarbon dating ($^{14}C$) (Bacon age-depth models);
- Comparing with climatic and hydrological data.

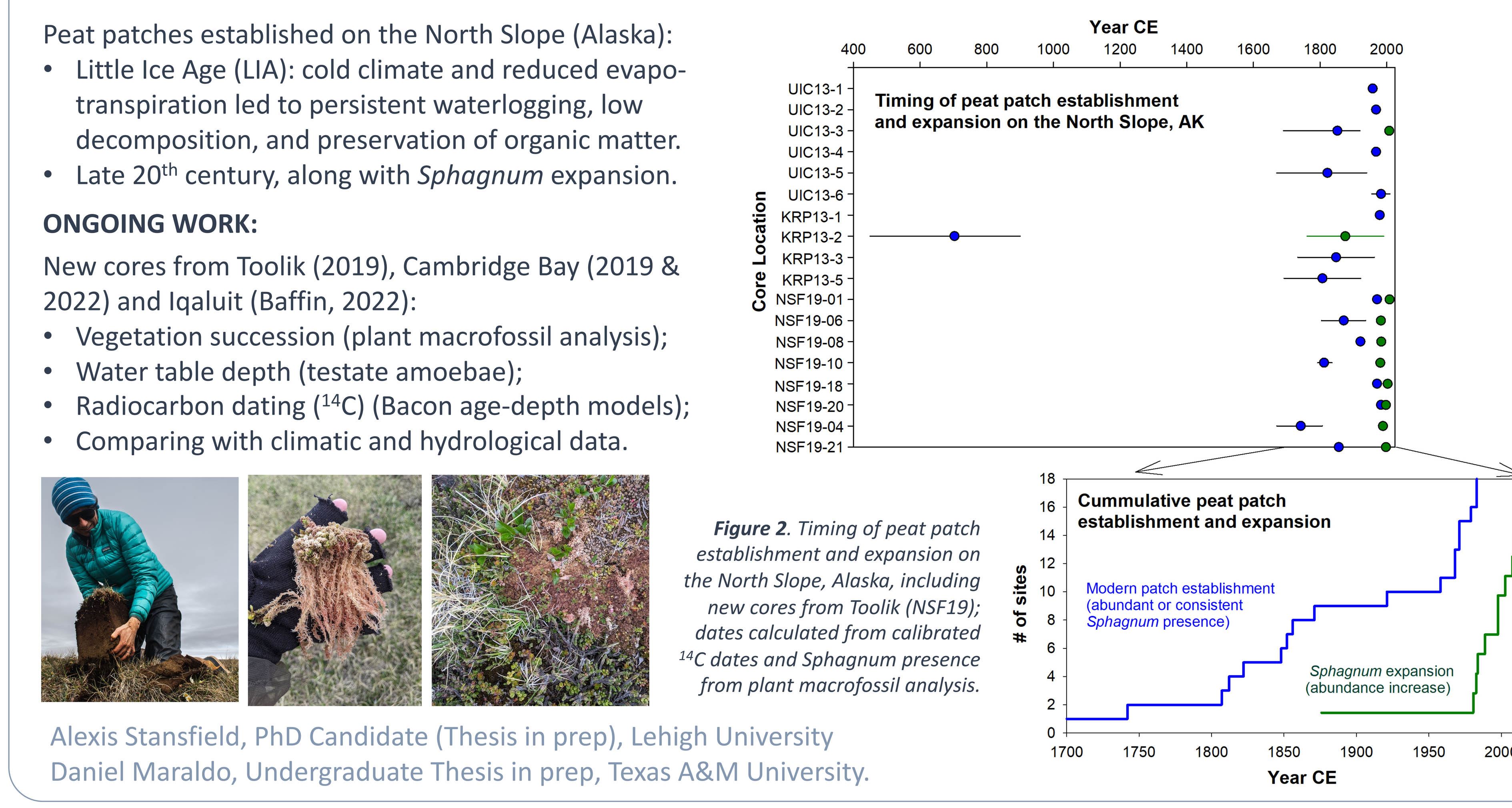
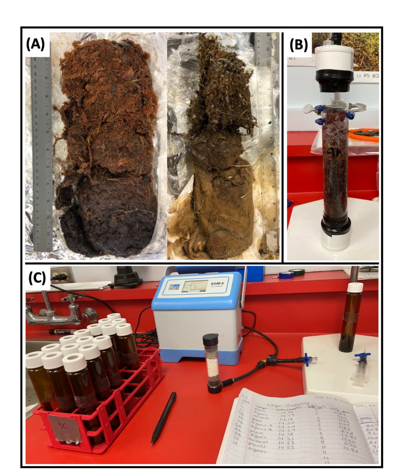



***Figure 2****. Timing of peat patch establishment and expansion on the North Slope, Alaska, including new cores from Toolik (NSF19); dates calculated from calibrated $^{14}C$ dates and Sphagnum presence from plant macrofossil analysis.*

Alexis Stansfield, PhD Candidate (Thesis in prep), Lehigh University

Daniel Maraldo, Undergraduate Thesis in prep, Texas A&M University.

## (3) INCUBATION EXPERIMENTS



*^* ***Figure 3.*** *(A) Lowland (left) and upland (right) soil sample pictures. (B) Intact core sample. (C) Homogenized soil layers in amber vials & EGM-5.*

KEY FINDINGS:

- Arctic mineral soils lose soil organic carbon (SOC) more easily than peat soils following permafrost thaw;
- Fast-cycling carbon in Arctic soils is influenced by litter quality and soil type more than temperature;
- Traditional soil incubation methods (homogenization) overestimate soil carbon decomposition: C-CO2 production is ~6x greater in partitioned vs. intact incubation.

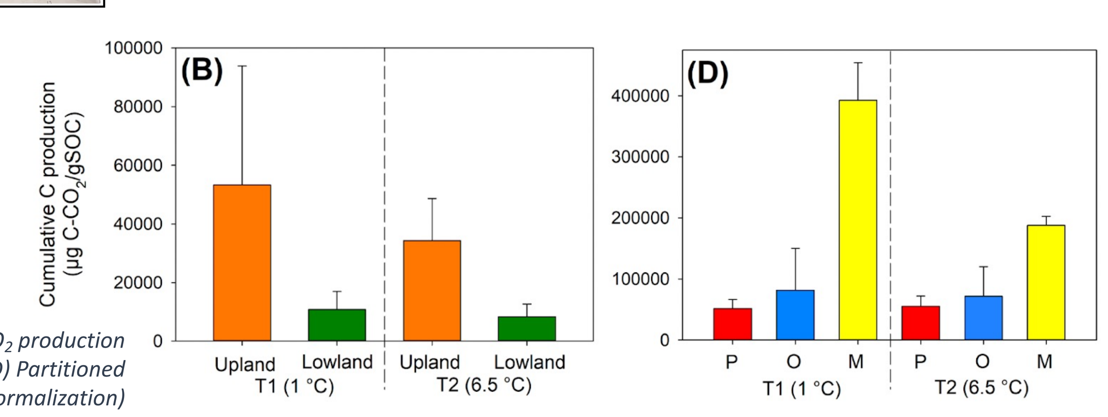



***Figure 4.*** *Cumulative $CO_2$ production (B) Intact cores and (D) Partitioned layers (SOC normalization)*
*P = plant; O = organic; M = mineral*

Jillian Sanders (2022), MSc Thesis, Texas A&M University

## (4) MODELLING PERMAFROST PEAT EXPANSION & FUTURE CARBON BALANCE

PTEM2.2 (Peatland Terrestrial Ecosystem Model):

- Estimated pan-Arctic peatland C stock = 396-421 Pg C, Holocene C accumulation rate = 22.9 g C·m$^{-2}$ yr$^{-1}$
- In Little Ice Age-permafrost and permafrost-free regions: C sink capacity decreases (decomp. > NPP) **Persistent permafrost** regions: higher carbon accumulation as NPP > decomp (**Fig.4**; Zhao et al. 2002b)
- With future climate warming (1990-2300), as current permafrost regions thaw, the peat C accumulation rate of the entire pan-Arctic region will likely decrease

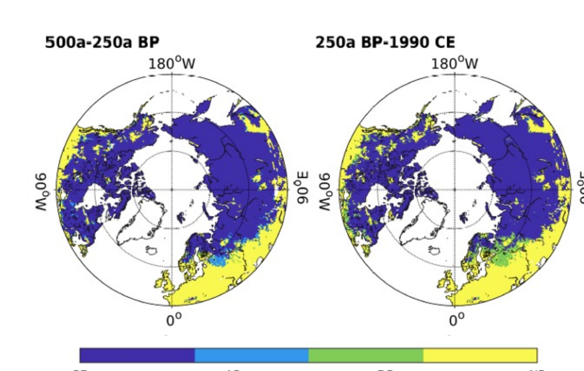



***Figure 5:*** *Selected model outputs from Holocene peatland permafrost dynamics (Zhao et al., 2022b)*
*Permafrost types:*
***PP: persistent***
***AP: aggrading***
***DP: degrading / thaw***
***NP: none***

HPM (Holocene Peat Model):

- Largest effect related to landscape setting, basin hydrology (Treat et al. 2022), and permafrost history (Treat et al., 2021) due to permafrost controls on decomposition, suggesting an important sensitivity to changing runoff patterns.

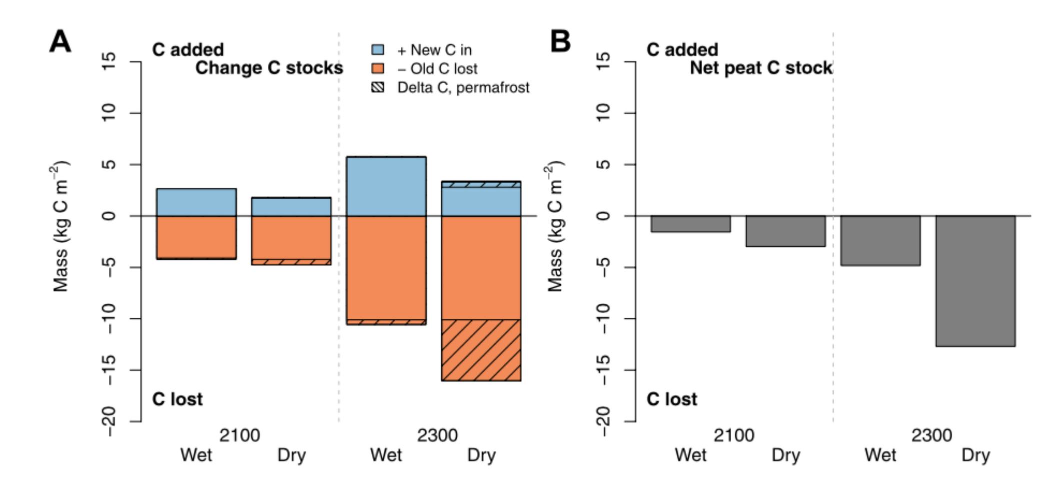



***Figure 6:*** *Simplified peat profile diagrams for changes in C stock for wet and dry scenarios (2100 CE and 2300 CE relative to 2015 CE). (A) C stock change: new peat C added and old peat C lost.* ***Black stripes****: new peat added, or old peat lost from permafrost. (B) Net change in peat C stocks (wet and dry scenarios). All scenarios showed a net peat C loss.*

**PTEM and HPM both highlight the importance of water availability, from insufficient precipitation or runoff patterns (Zhao et al., 2022a; Treat et al., 2021). These subtle hydrological effects will be difficult to capture at circumpolar scales but are important for the C balance of permafrost peatlands under future climate warming.**

Zhao et al. (2022a) *JGR: Biogeosciences*, doi: 10.1029/2021JG006762

Zhao et al. (2022b) Accepted in *JGR: Biogeosciences* [ESSOAR preprint]

Treat et al. (2021) *JGR: Biogeosciences*, doi: 10.1029/2020JG005872

Treat et al (2022) *Frontiers in Enviro.Sci.*, doi: 10.3389/fenvs.2022.892925

ONGOING WORK: HPM to investigate peat response to hiatus (A. Stansfield) & peat patch inception and shifts (N. Sanderson)