Tundra Ecosystems: a Regional Scale Case Study and the Impact of Climate Change

Professor Graeme Swindles

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Learning outcomes

After this session you should have an understanding of:

- Features of Tundra ecosystems
- Differences between Tundra and Boreal ecosystems
- Climate Change impacts on Tundra ecosystems
- Cutting-edge research
- Two case studies

Tundra ecosystems

What do Tundra environments look like?

Lake me take you on a fieldtrip to Svalbard

S V A L B A R D   A N D   J A N   M A Y E N

The fastest-warming place on Earth

Svalbard has jumped 4°C in the past 50 years.

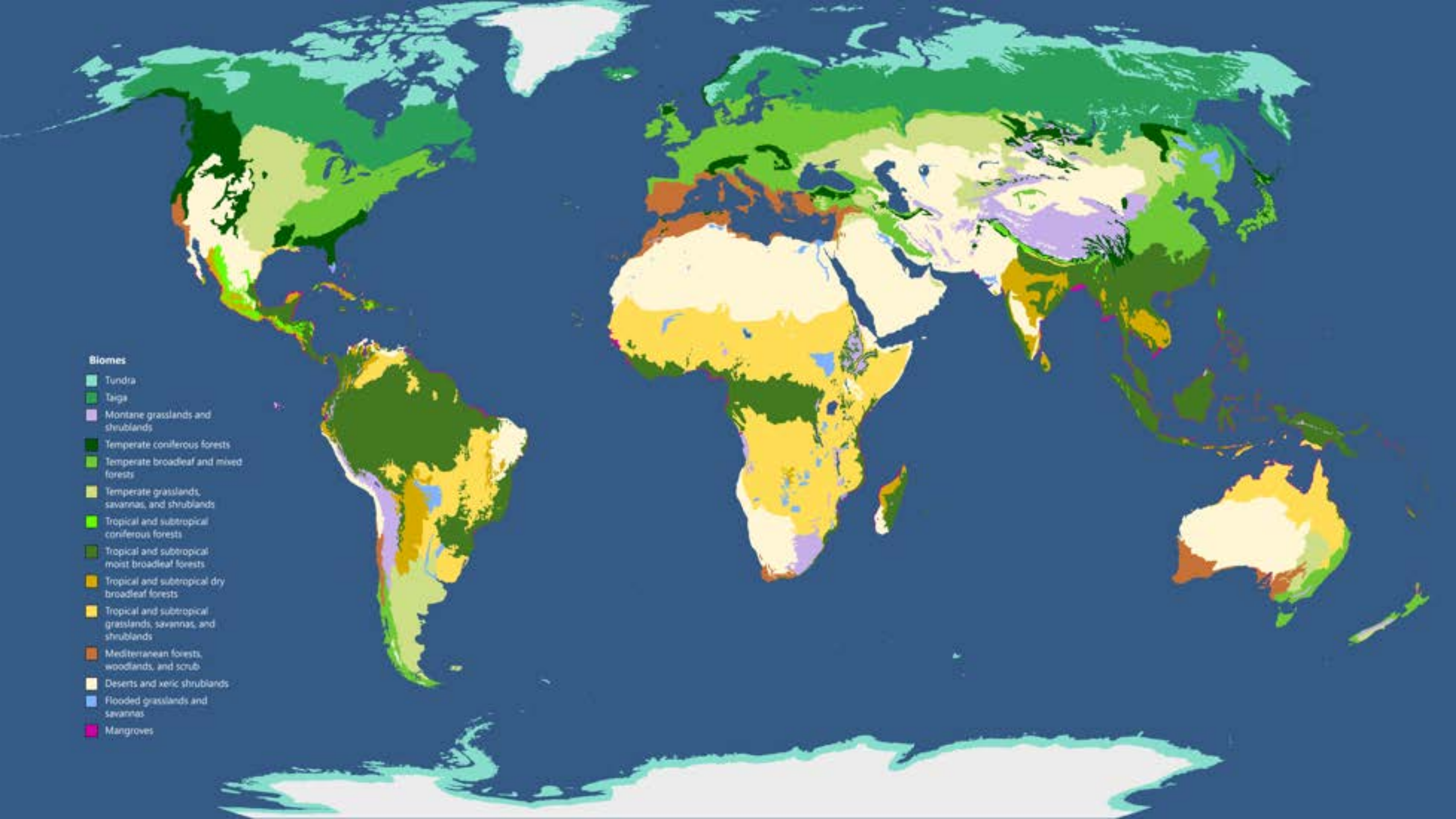

KAPS

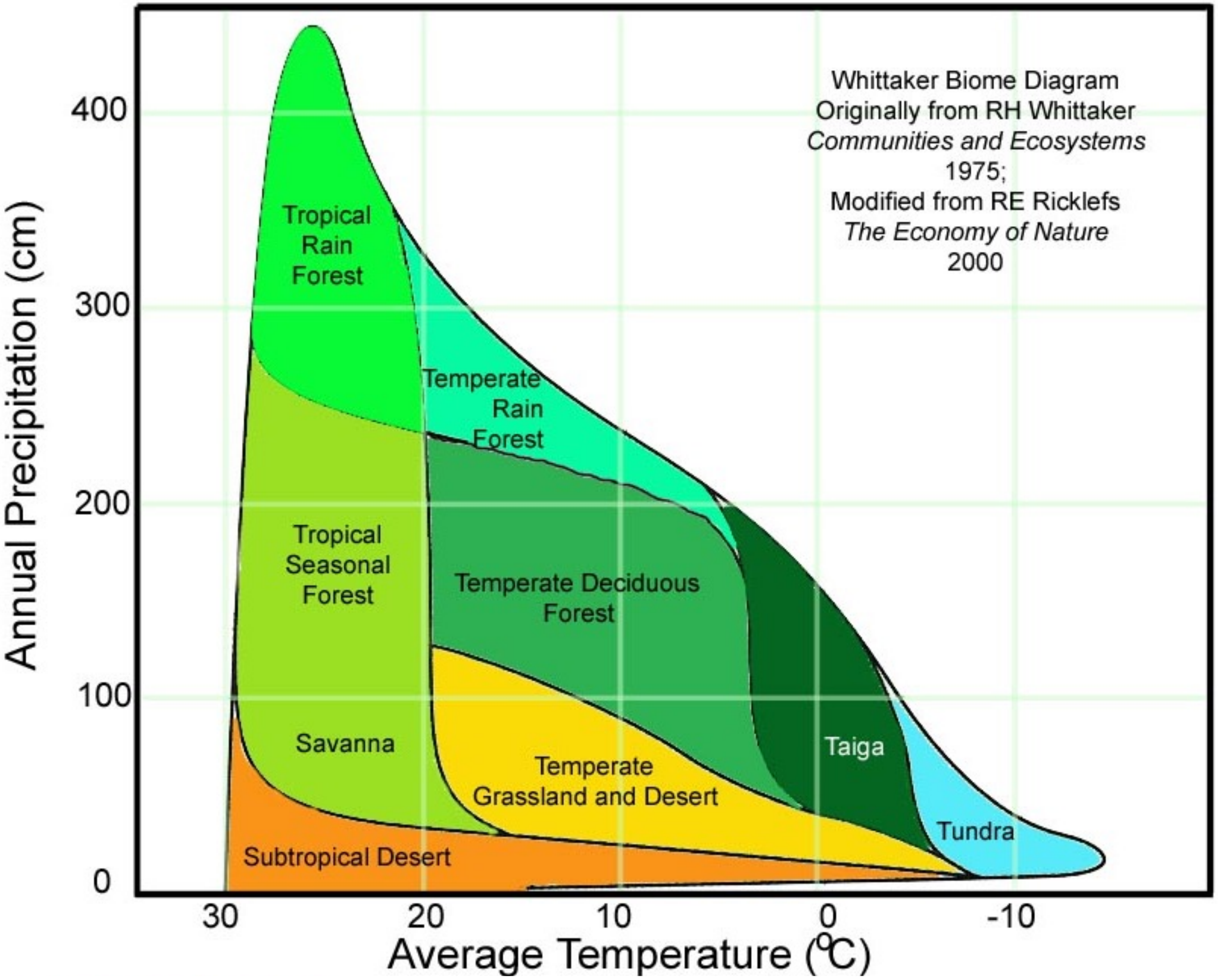
What about the Boreal/Taiga?


The world’s largest terrestrial biome!

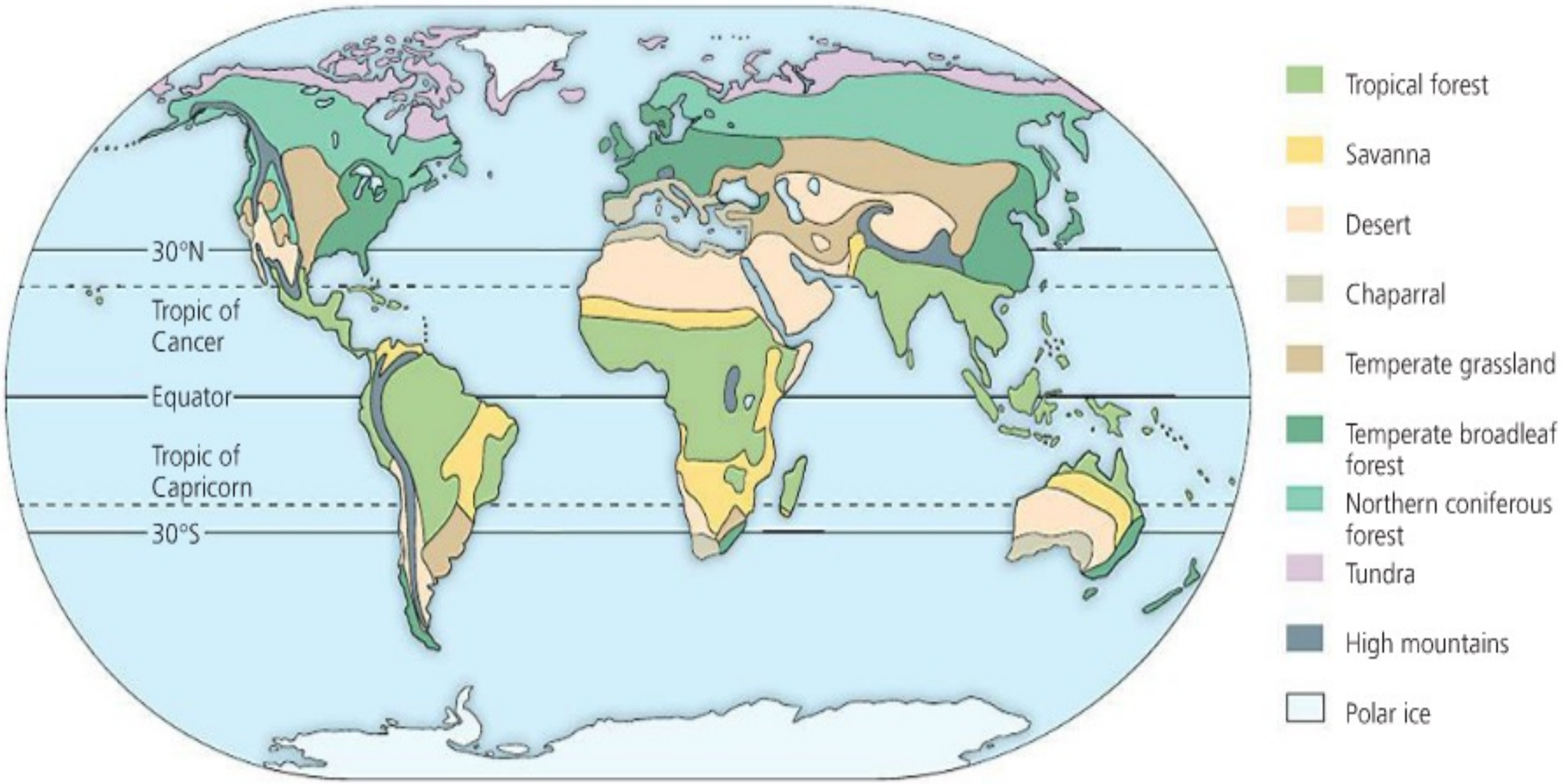
Definitions and concepts

- The biome where tree growth is hindered by frigid temperatures and short growing seasons.
- Russian тундра (tundra) from the Kildin Sámi word тӯндар (tūndâr) meaning "uplands", "treeless mountain tract”.
- Arctic tundra, Alpine tundra and Antarctic tundra
- Tundra vegetation is composed of dwarf shrubs, sedges, grasses, mosses, and lichens with some scattered trees. Scattered trees grow in some tundra regions.
- Ecotone or treeline
- Soils are often highly organic, rich in N and P
- Permafrost
- Carbon sink, store, Greenhouse gases
- Climate change impacts on stored carbon?


Biomes
Tundra
Taiga
Montane grasslands and shrublands
Temperate coniferous forests
Temperate broadleaf and mixed forests
Temperate grasslands, savannas, and shrublands
Tropical and subtropical coniferous forests
Tropical and subtropical moist broadleaf forests
Tropical and subtropical dry broadleaf forests
Tropical and subtropical grasslands, savannas, and shrublands
Mediterranean forests, woodlands, and scrub
Deserts and xeric shrublands
Flooded grasslands and savannas
Mangroves

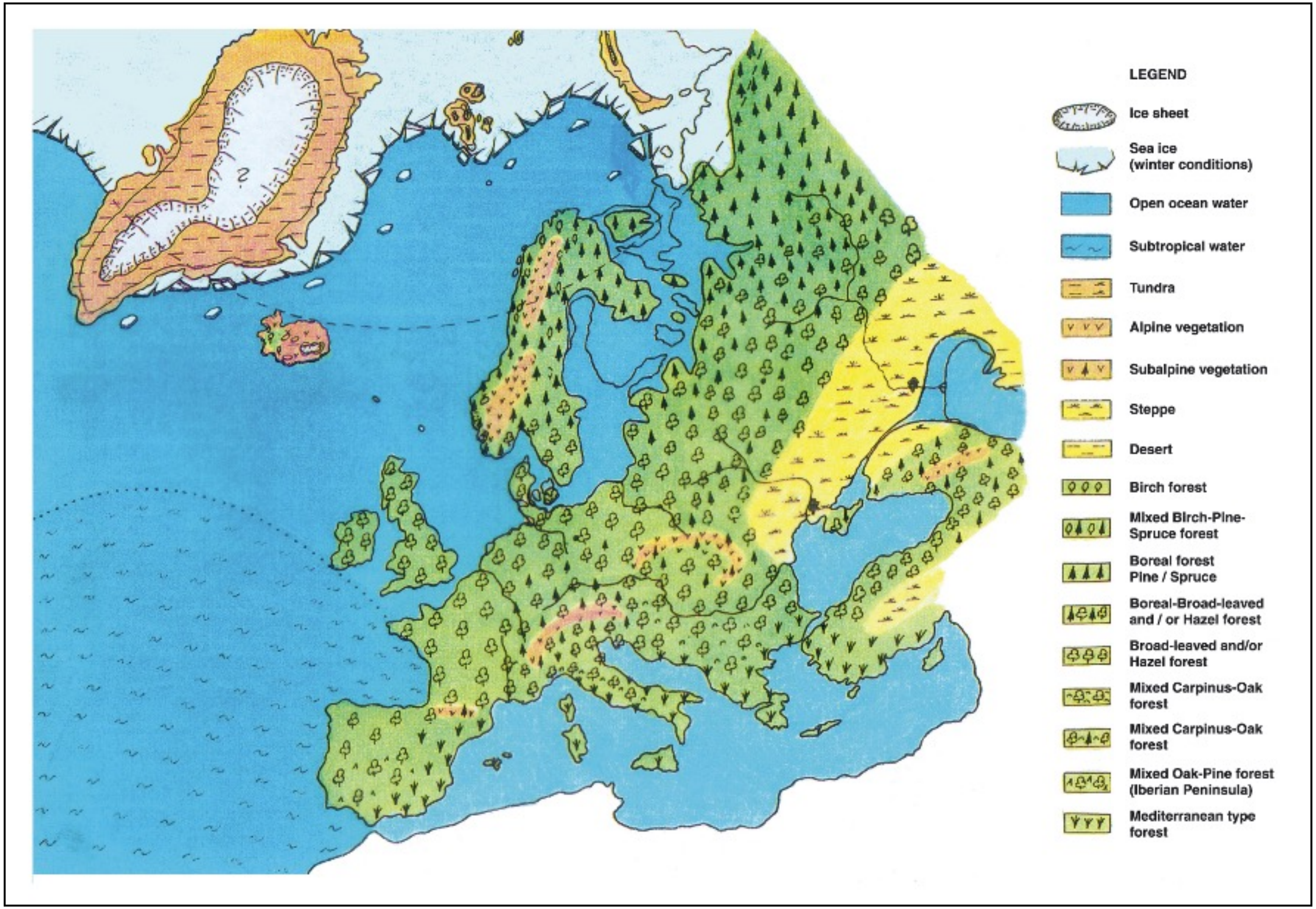


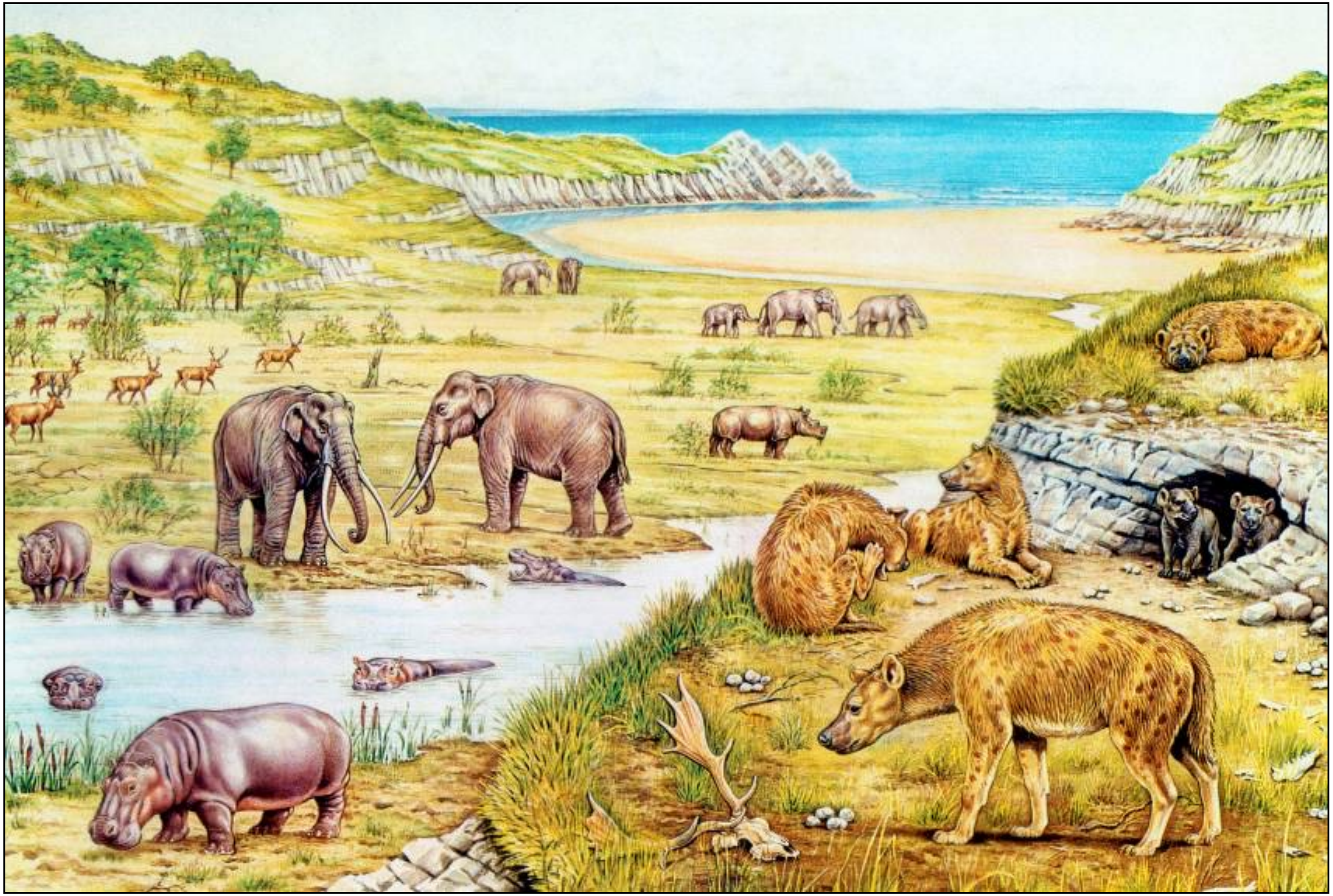
Climate exerts a major control on global patterns of diversity and productivity.


30°N
Tropic of Cancer
Equator
Tropic of Capricorn
30°S
Tropical forest
Savanna
Desert
Chaparral
Temperate grassland
Temperate broadleaf forest
Northern coniferous forest
Tundra
High mountains
Polar ice

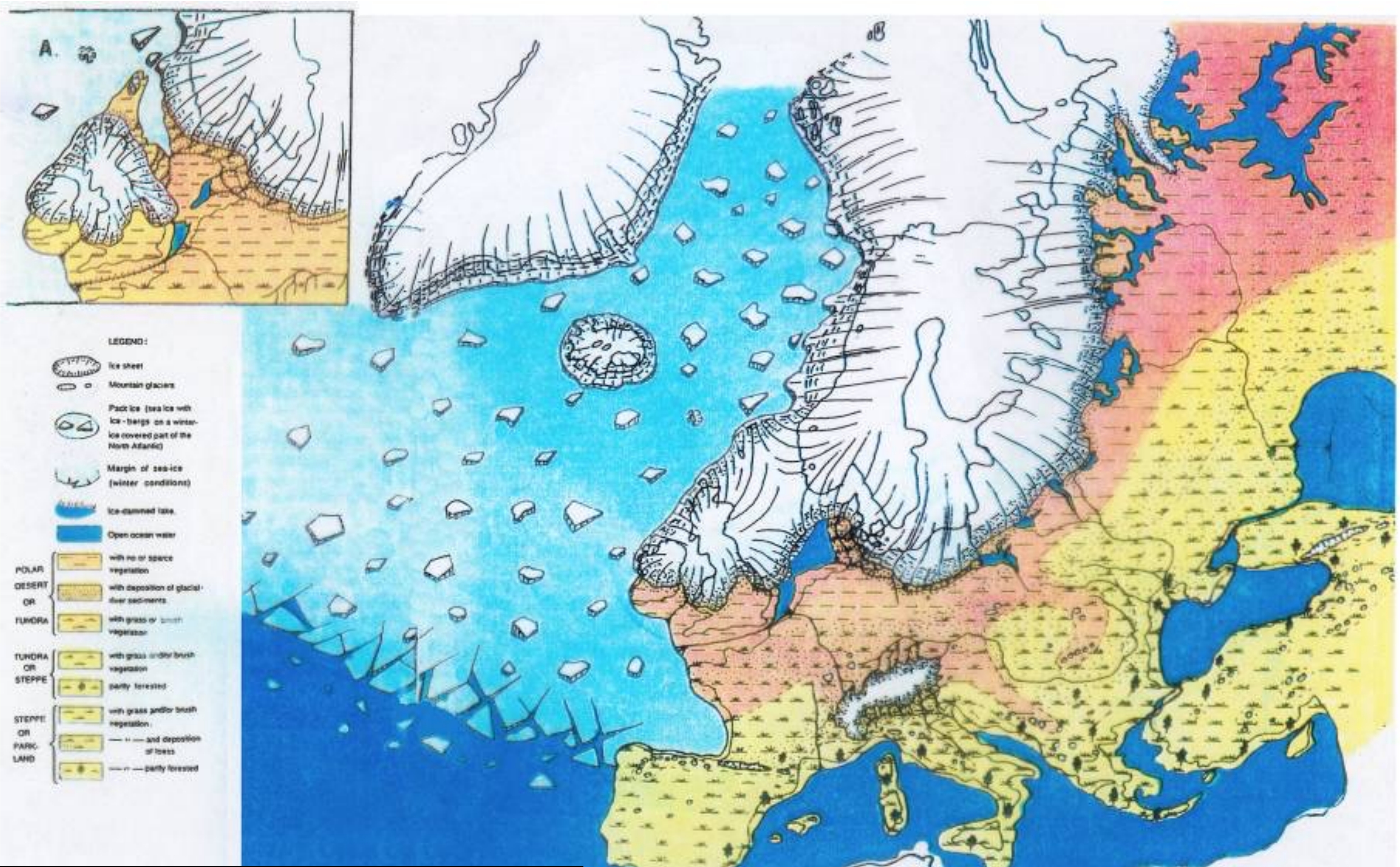
It hasn’t always been like this!

Interglacials





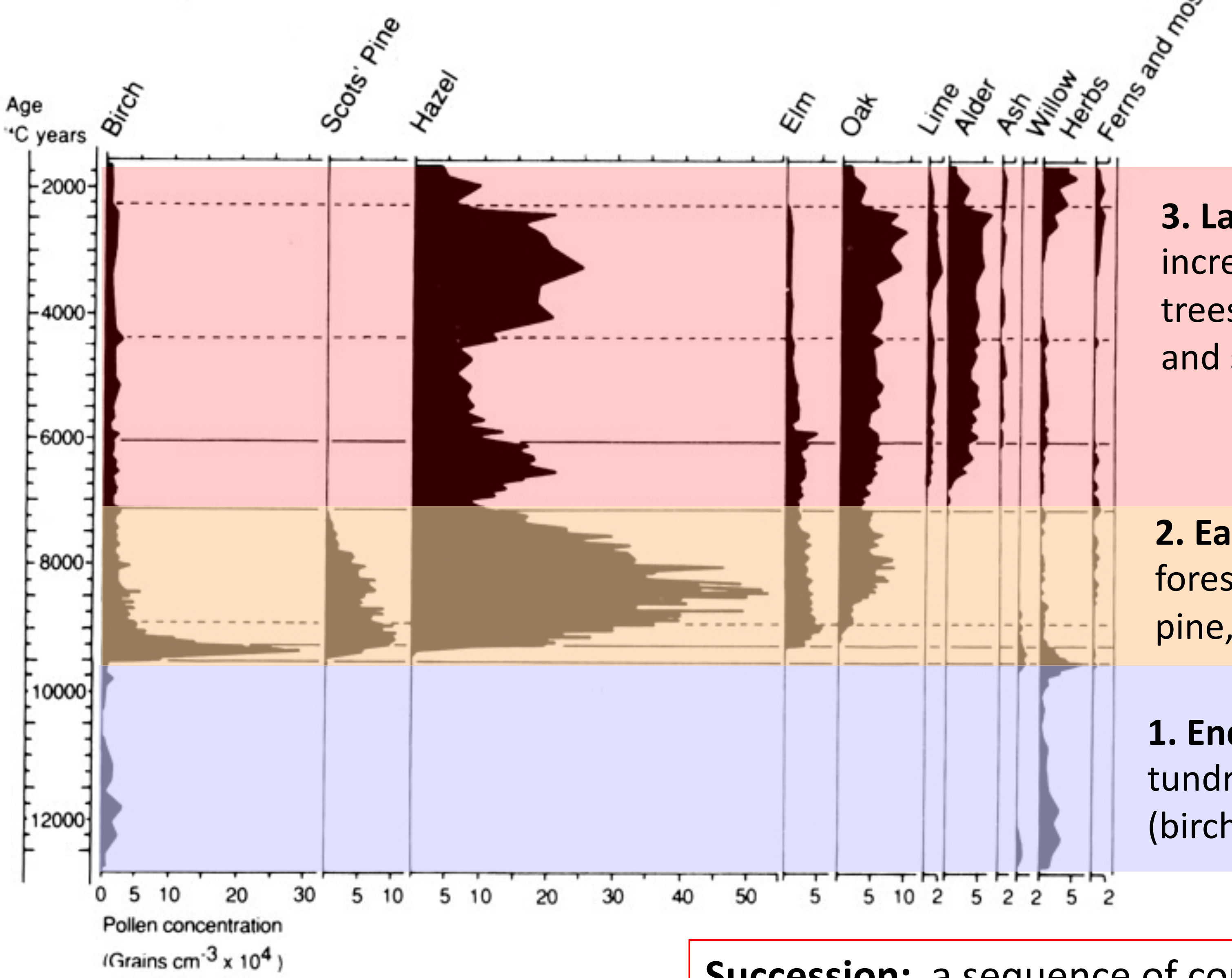
Glacials



Sea-level ~120 m lower than present

A pollen diagram: **Hockham Mere, Norfolk, UK**

(Bennett 1983)

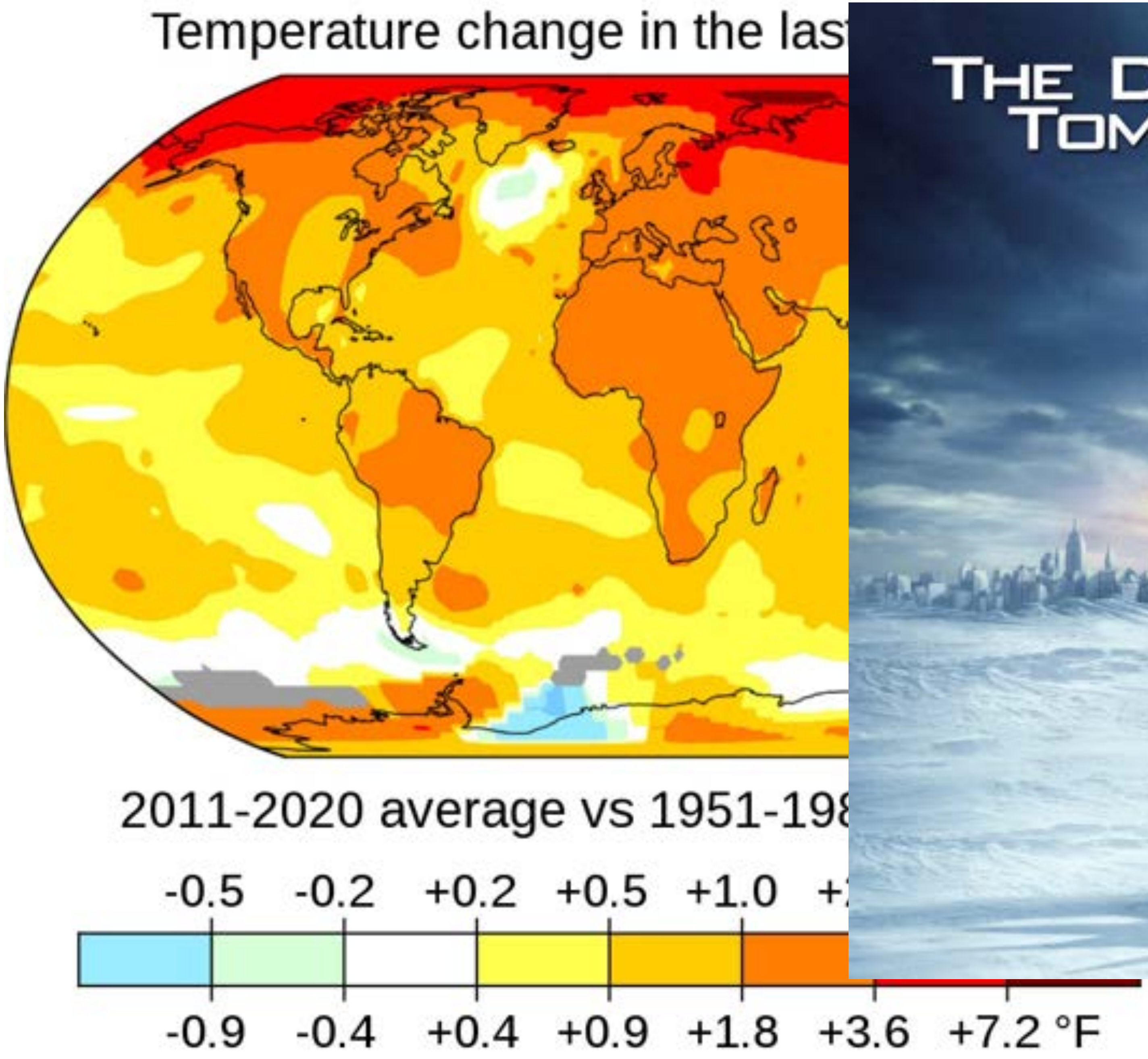


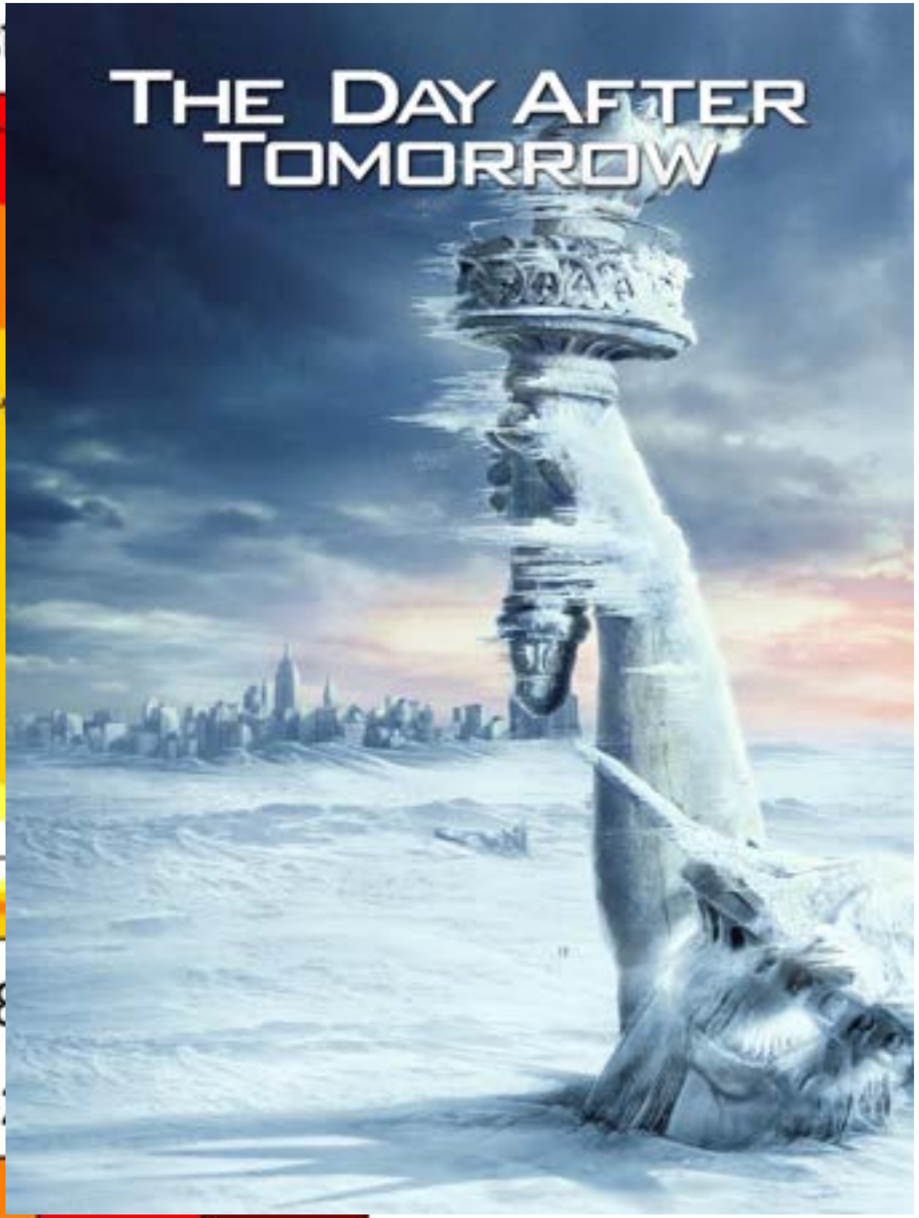
3. Late Holocene: increasing diversity of trees as climate warms and soils mature

2. Early Holocene: boreal forest develops (birch, pine, hazel…)

1. End of last glacial: tundra, very few trees (birch)

Succession: a sequence of communities


Temperature change in the las
2011-2020 average vs 1951-19
-0.5 -0.2 +0.2 +0.5 +1.0
-0.9 -0.4 +0.4 +0.9 +1.8 +3.6 +7.2 °F


THE DAY AFTER TOMORROW

What are the effects of climate change in Tundra ecosystems?

- Boreal forest is marching northwards (ecotone/treeline is moving)
- Ecosystems are changing
  - Northward migration
  - Longer growing season
- Carbon cycling is changing
- Lots more ponds and open water in summer
- New peatlands are “switching on” in the Tundra

Projected Treeline
Present Treeline
Arctic Circle
60°
60°

Optimum conditions

- All organisms have an optimum set of environmental variables for their survival.
- Around this there is a range of conditions which they can survive.
- Different organisms have evolved for different conditions.

Optimum Environment

One organisms stress maybe another's optimum

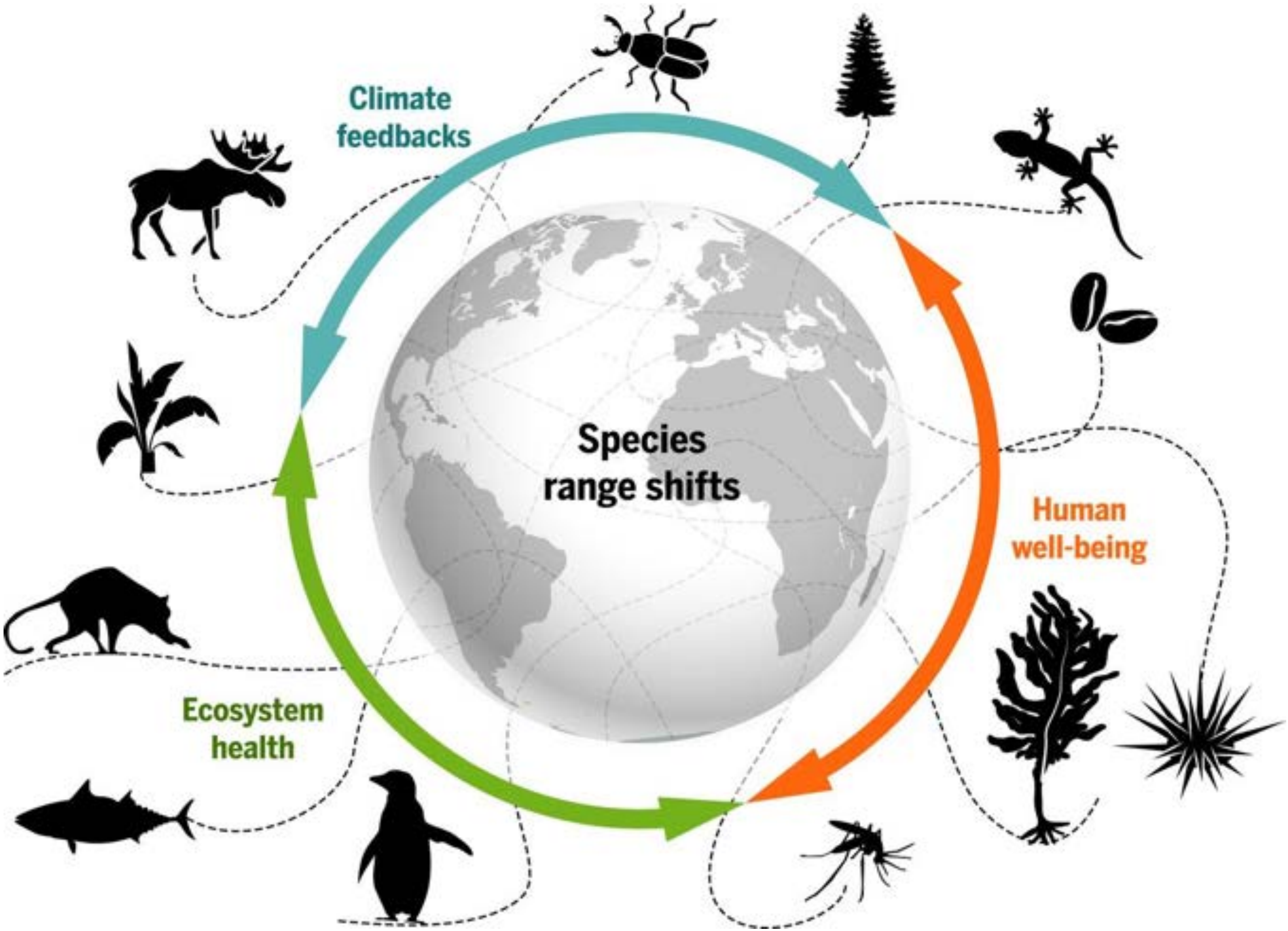
Human optimum conditions, 25 degrees, on the beach

vs.

polar bear, -25 degrees, on an ice-flow

Distribution

- Many organisms move north or to a higher altitude.



PECL ET AL (2017).
Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being
SCIENCE
https://science.sciencemag.org/content/355/6332/eaai9214.abstract

Cutting-edge research

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Climate-induced hydrological fluctuations shape Arctic Alaskan peatland plant communities

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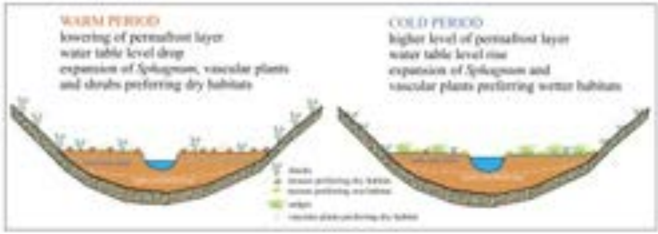
HIGHLIGHTS

- palaeoecological studies reveal environmental changes over the last 700 years
- plant communities in Arctic Alaska follow hydrological shifts triggered by climate change
- dominance of sedges and mosses growing in wetter habitats during cooler periods
- exceptional low water table depth over the last three decades
- expansion of dry habitat *Sphagnum* moss and woody taxa species over the last decades

GRAPHICAL ABSTRACT



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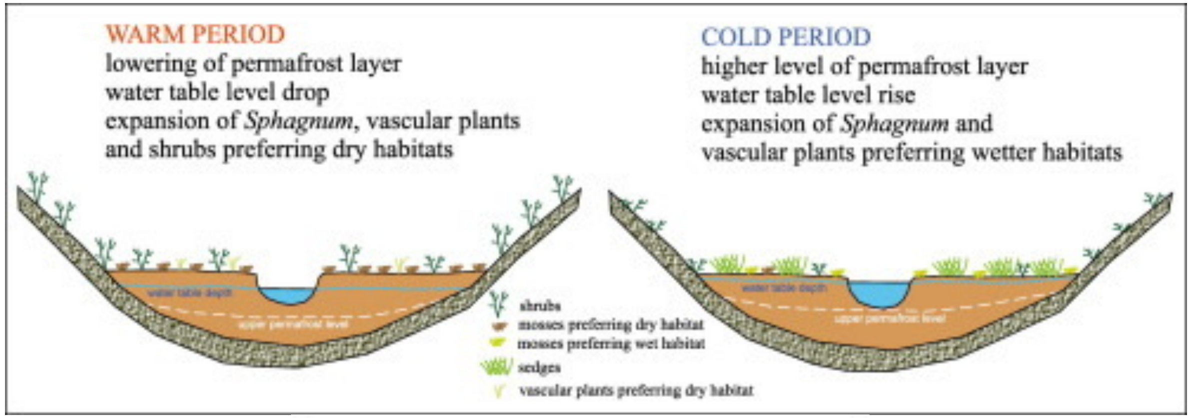
ABSTRACT

Rapidly increasing temperatures in high-latitude regions are causing major changes in wetland ecosystems. To assess the impact of concomitant hydroclimatic fluctuations, mineral deposition, and autogenous succession on the rate and direction of changing arctic plant communities in Arctic Alaska, we conducted detailed palaeoecological analyses using plant macrofossil, pollen, testate amoebae, elemental analyses, and radiocarbon and lead (^{210}Pb) dating on two replicate monoliths from a peatland that developed in a river valley on the northern foothills of the Brooks Range. We observed an expansion of *Sphagnum* populations and vascular plants preferring dry habitats, such as *Sphagnum warnstorfii*, *Sphagnum teres/squarrosum*, *Polytrichum strictum*, *Aulacomnium palustre* and *Salix* sp., in recent decades between 2000 and 2015 CE, triggered by an increase in temperature and



AGU ADVANCING EARTH AND SPACE SCIENCES

Water Resources Research

RESEARCH ARTICLE
10.1029/2023WR035398

Key Points:

- Depth and humification are important controls for horizontal saturated hydraulic conductivity in a degrading Swedish palsa complex
- Peat hydraulic properties did not significantly differ between desiccating and collapsed areas of the palsa complex
- An existing model, trained on lower-latitude peatlands, predicted horizontal saturated hydraulic conductivity adequately, with low bias

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Controls on Saturated Hydraulic Conductivity in a Degrading Permafrost Peatland Complex

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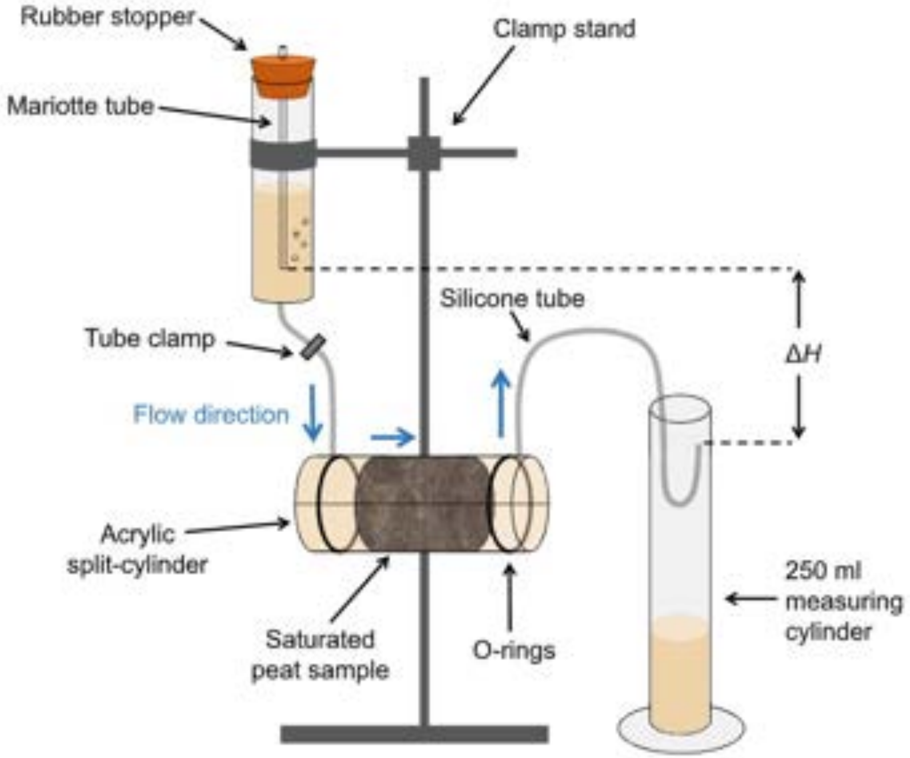
Abstract Permafrost peatlands are vulnerable to rapid structural changes under climatic warming, including vertical collapse. Peatland water budgets, and therefore peat hydraulic properties, are important determinants of vegetation and carbon fluxes. Measurements of hydraulic properties exist for only a limited number of permafrost peatland locations, primarily concentrated in North America. The impacts of thaw-induced collapse upon properties such as horizontal saturated hydraulic conductivity (K_h), and thus lateral drainage, remain poorly understood. We made laboratory determinations of K_h from 82 peat samples from a degrading Swedish palsa mire. We fitted a linear mixed-effects model (LMM) to establish the controls on K_h, which declined strongly with increasing depth, humification and dry bulk density. Depth exerted the strongest control on K_h in our LMM, which demonstrated strong predictive performance ($r^2 = 0.605$). Humification and dry bulk density were influential predictors, but the high collinearity of these two variables meant only one could be included reliably in our LMM. Surprisingly, peat K_h did not differ significantly between desiccating and collapsed palsas. We compared our site-specific LMM to an existing, multi-site model, fitted primarily to boreal and temperate peatlands. The multi-site model made less skillful predictions ($r^2 = 0.528$) than our site-specific model, possibly due to latitudinal differences in peat compaction, floristic composition and climate. Nonetheless, low bias means the multi-site model may still be useful for estimating peat K_h at high latitudes. Permafrost peatlands remain underrepresented in multi-site models of peat hydraulic properties, and measurements such as ours could be used to improve future iterations.



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Holocene vegetation dynamics of circum-Arctic permafrost peatlands

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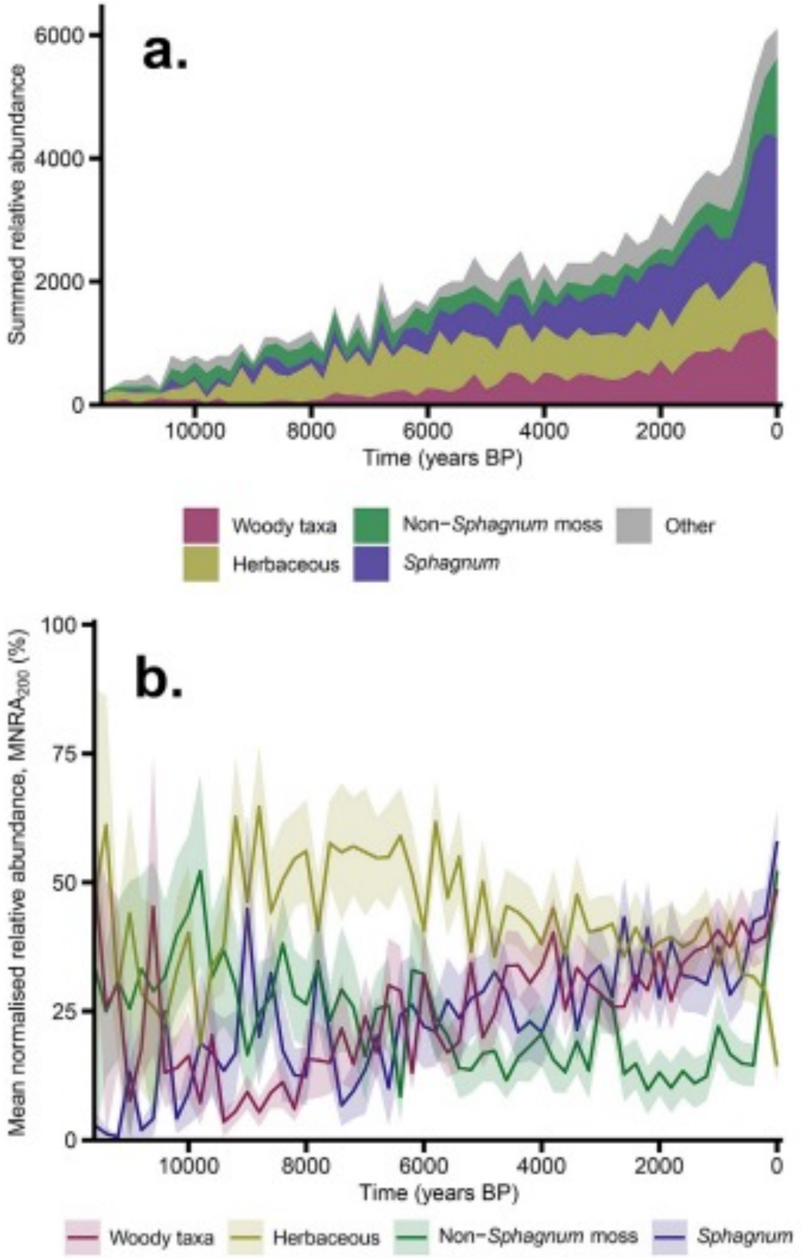
ABSTRACT

Vegetation shifts in circum-Arctic permafrost peatlands drive feedbacks with important consequences for peatland carbon budgets and the extent of permafrost thaw under changing climate. Recent shrub expansion across Arctic tundra environments has led to an increase in above-ground biomass, but the long-term spatiotemporal dynamics of shrub and tree growth in circum-Arctic peatlands remain unquantified. We investigate changes in peatland vegetation composition during the Holocene using previously-published plant macrofossil records from 76 sites across the circum-Arctic permafrost zone. In particular, we assess evidence for peatland shrubification at the continental scale. We identify increasing abundance of woody vegetation in circum-Arctic peatlands from ~8000 years BP to present, coinciding with declining herbaceous vegetation and widespread *Sphagnum* expansion. Ecosystem shifts varied between regions and present-day permafrost zones, with late-Holocene shrubification most pronounced where permafrost coverage is presently discontinuous and sporadic. After ~600 years BP, we find a proliferation of non-*Sphagnum* mosses in Fennoscandia and across the present-day continuous permafrost zone; and rapid expansion of *Sphagnum* in regions of discontinuous and isolated permafrost as expected following widespread fen-bog succession, which coincided with declining woody vegetation in eastern and western Canada. Since ~200 years BP, both shrub expansion and decline were identified at different sites across the pan-Arctic, highlighting the complex ecological responses of circum-Arctic peatlands to post-industrial climate warming and permafrost degradation. Our results suggest that shrubification of circum-Arctic peatlands has primarily occurred alongside surface drying, resulting from Holocene climate shifts, autogenic peat accumulation, and permafrost aggradation. Future shrubification of circum-Arctic peatlands under 21st century climate change will likely be spatially heterogeneous, and be most prevalent where dry microforms persist.



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Article

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Recent climate change has driven divergent hydrological shifts in high-latitude peatlands

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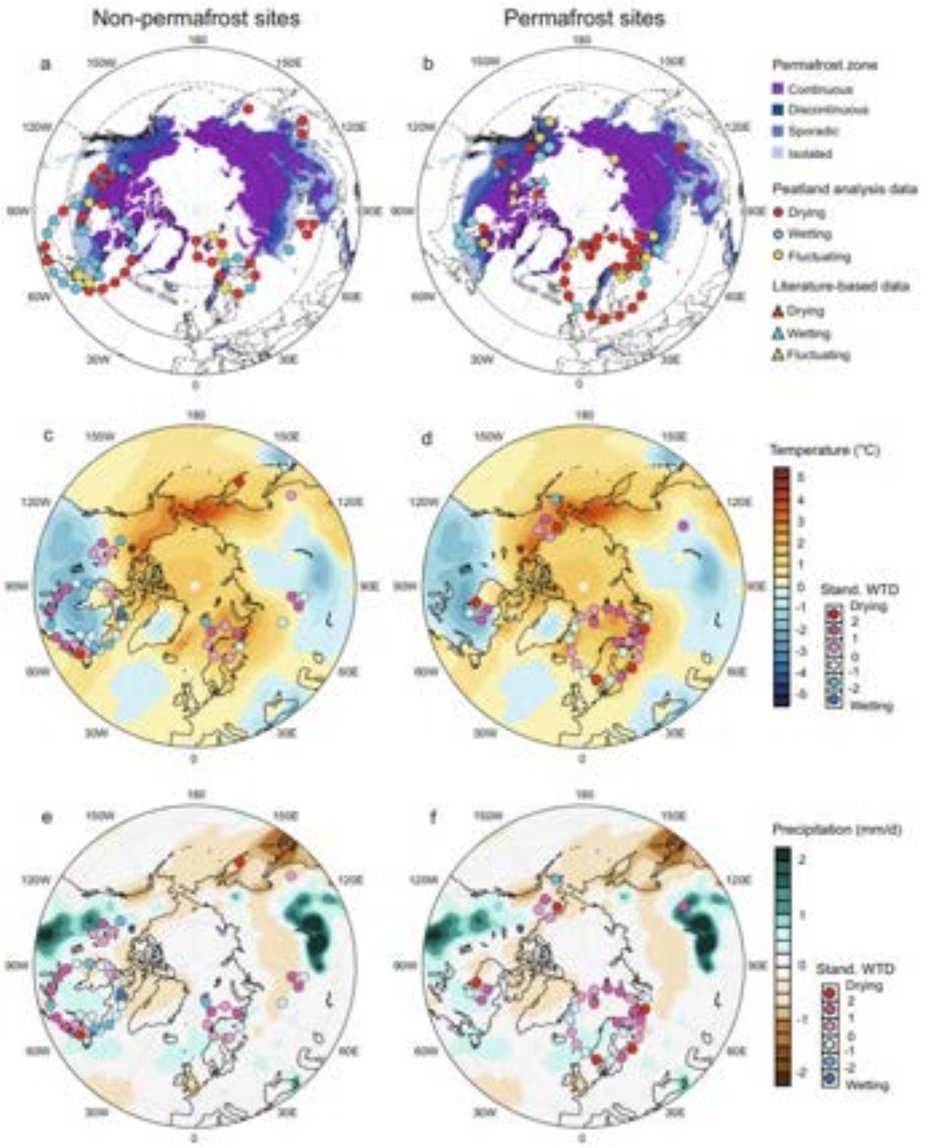
Hui Zhang[1,2], Minna Väliranta[2,3], Graeme T. Swindles[4,5], Marco A. Aquino-López[6], Donal Mullan[4], Ning Tan[1], Matthew Amesbury[2,7], Kirill V. Babeshko[8,9], Kunshan Bao[10], Anatoly Bobrov[8], Viktor Chernyshov[11], Marissa A. Davies[12], Andrei-Cosmin Diaconu[13], Angelica Feurdean[14,15], Sarah A. Finkelstein[12], Michelle Garneau[16], Zhengtang Guo[1], Miriam C. Jones[17], Martin Kay[18], Eric S. Klein[19], Mariusz Lamentowicz[20], Gabriel Magnan[16], Katarzyna Marcisz[20], Natalia Mazei[8], Yuri Mazei[8,9,21], Richard Payne[22,32], Nicolas Pelletier[23], Sanna R. Piilo[2,3], Steve Pratte[24], Thomas Roland[7], Damir Saldaev[8,9], William Shotyk[25], Thomas G. Sim[7,26], Thomas J. Sloan[26], Michał Słowiński[27], Julie Talbot[23], Liam Taylor[26], Andrey N. Tsyganov[8,21], Sebastian Wetterich[28,29], Wei Xing[30] & Yan Zhao[31]

High-latitude peatlands are changing rapidly in response to climate change, including permafrost thaw. Here, we reconstruct hydrological conditions since the seventeenth century using testate amoeba data from 103 high-latitude peat archives. We show that 54% of the peatlands have been drying and 32% have been wetting over this period, illustrating the complex ecohydrological dynamics of high latitude peatlands and their highly uncertain responses to a warming climate.

The majority of peatlands are located in high latitudes[1] and store *ca.* one third of the global soil carbon (C)[2]. The balance between photosynthesis-driven carbon dioxide (CO_2) sequestration and decomposition-driven CO_2 and methane (CH_4) emissions determines the peatland net C budget and subsequently the overall climate feedback. Peatland water-table position is a decisive factor in this balance.



nature climate change

ARTICLES

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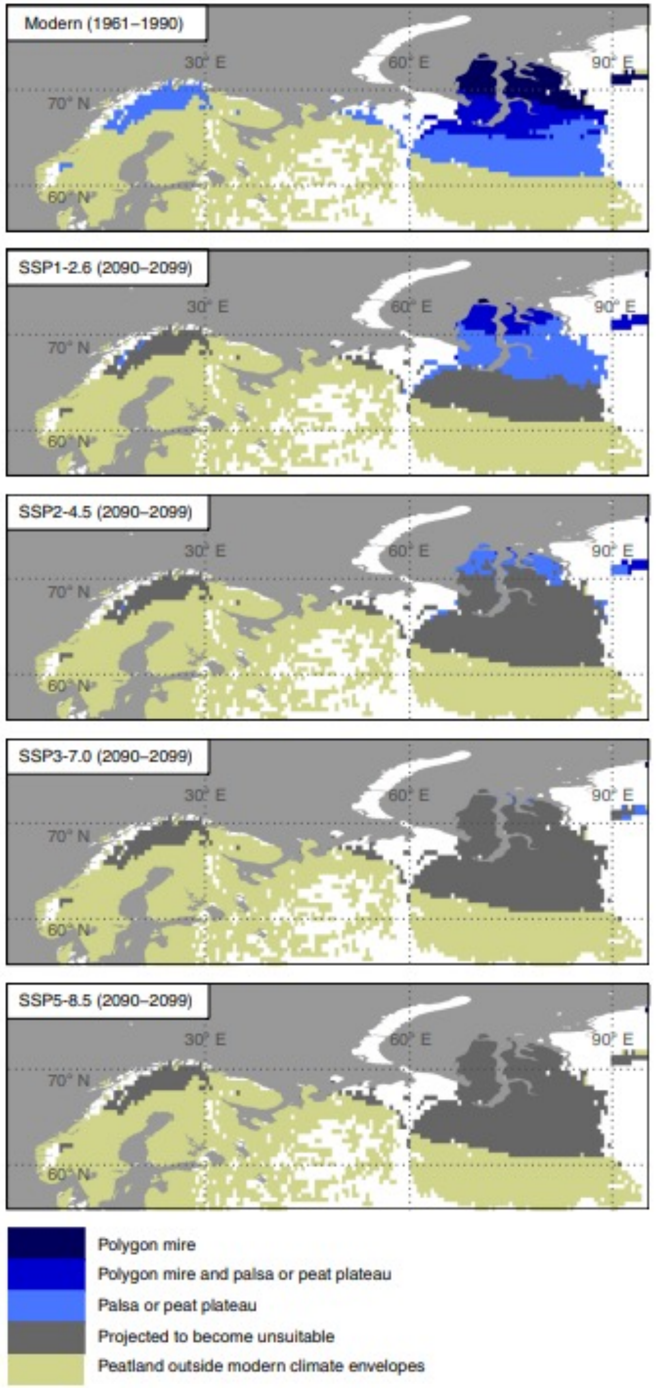
Imminent loss of climate space for permafrost peatlands in Europe and Western Siberia

Richard E. Fewster [1]✉, Paul J. Morris [1], Ruza F. Ivanovic [2], Graeme T. Swindles [3,4], Anna M. Peregon [5,6] and Christopher J. Smith [2,7]

Human-induced climate warming by 2100 is expected to thaw large expanses of northern permafrost peatlands. However, the spatio-temporal dynamics of permafrost peatland thaw remain uncertain due to complex permafrost-climate interactions, the insulating properties of peat soils and variation in model projections of future climate. Here we show that permafrost peatlands in Europe and Western Siberia will soon surpass a climatic tipping point under scenarios of moderate-to-high warming (Shared Socioeconomic Pathway (SSP) 2-4.5, SSP3-7.0 and SSP5-8.5). The total peatland area affected under these scenarios contains 37.0–39.5 Gt carbon (equivalent to twice the amount of carbon stored in European forests). Our bioclimatic models indicate that all of Fennoscandia will become climatically unsuitable for peatland permafrost by 2040. Strong action to reduce emissions (SSP1-2.6) by the 2090s could retain suitable climates for permafrost peatlands storing 13.9 Gt carbon in northernmost Western Siberia, indicating that socio-economic policies will determine the rate and extent of permafrost peatland thaw.



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ENVIRONMENTAL RESEARCH
LETTERS

LETTER

CrossMark

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Divergent responses of permafrost peatlands to recent climate change

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Supplementary material for this article is available online

Abstract

Permafrost peatlands are found in high-latitude regions and store globally-important amounts of soil organic carbon. These regions are warming at over twice the global average rate, causing permafrost thaw, and exposing previously inert carbon to decomposition and emission to the atmosphere as greenhouse gases. However, it is unclear how peatland hydrological behaviour, vegetation structure and carbon balance, and the linkages between them, will respond to permafrost thaw in a warming climate. Here we show that permafrost peatlands follow divergent ecohydrological trajectories in response to recent climate change within the same rapidly warming region (northern Sweden). Whether a site becomes wetter or drier depends on local factors and the autogenic response of individual peatlands. We find that bryophyte-dominated vegetation demonstrates resistance, and in some cases resilience, to climatic and hydrological shifts. Drying at four sites is clearly associated with reduced carbon sequestration, while no clear relationship at wetting sites is observed. We highlight the complex dynamics of permafrost peatlands and warn against an overly-simple approach when considering their ecohydrological trajectories and role as C sinks under a warming climate.

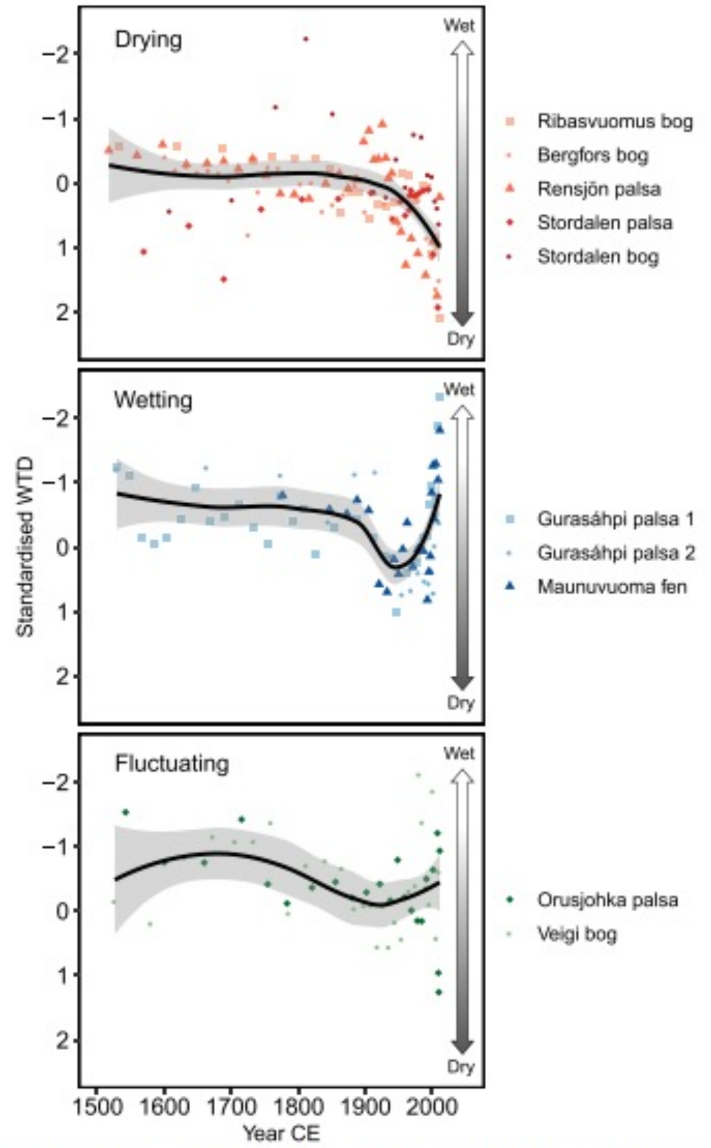

Figure 3. Water-table depth (WTD) data from all peat profiles since 1500 CE. WTD data are standardised for all peat profiles from 1500 CE. Results are divided into peat profiles exhibiting recent drying, wetting (preceded by drying) and asynchronously fluctuating WTD trends. For each panel a locally estimated scatterplot smoothing (loess) model is shown in black, with grey shading indicating the 95% confidence range of the loess function.

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Evidence for ecosystem state shifts in Alaskan continuous permafrost peatlands in response to recent warming

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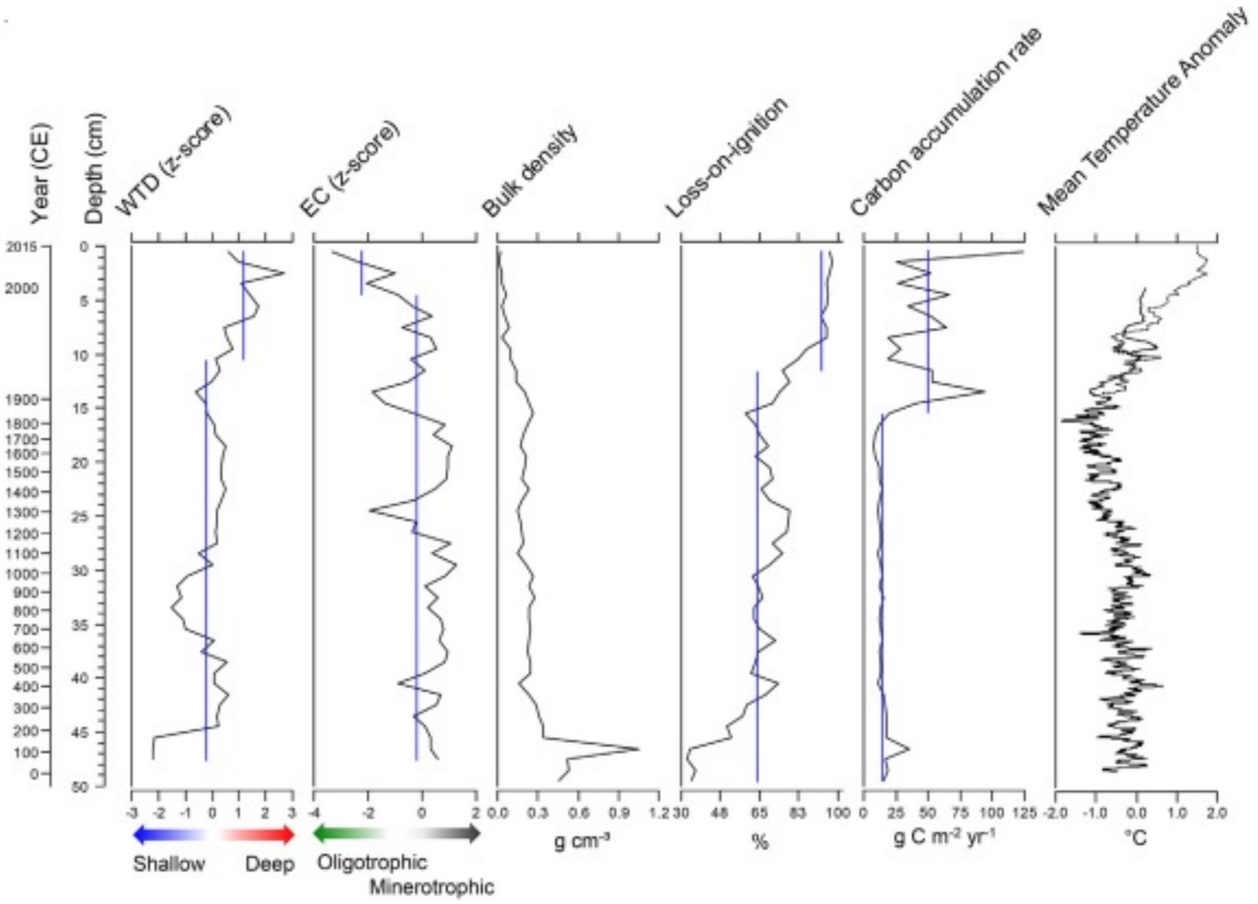
A B S T R A C T

Peatlands in continuous permafrost regions represent a globally-important store of organic carbon, the stability of which is thought to be at risk under future climatic warming. To better understand how these ecosystems may change in a warmer future, we use a palaeoenvironmental approach to reconstruct changes in two peatlands near Toolik Lake on Alaska's North Slope (TFS1 and TFS2). We present the first testate amoeba-based reconstructions from peatlands in continuous permafrost, which we use to infer changes in water-table depth and porewater electrical conductivity during the past two millennia. TFS1 likely initiated during a warm period between 0 and 300 CE. Throughout the late-Holocene, both peatlands were minerotrophic fens with low carbon accumulation rates (means of 18.4 and 14.2 g C m^{-2} yr^{-1} for cores TFS1 and TFS2 respectively). However, since the end of the Little Ice Age, both fens have undergone a rapid transition towards oligotrophic peatlands, with deeper water tables and increased carbon accumulation rates (means of 59.5 and 48.2 g C m^{-2} yr^{-1} for TFS1 and TFS2 respectively). We identify that recent warming has led to these two Alaskan rich fens to transition into poor fens, with greatly enhanced carbon accumulation rates. Our work demonstrates that some Arctic peatlands may become more productive with future regional warming, subsequently increasing their ability to sequester carbon.



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Holocene fire regimes and treeline migration rates in sub-arctic Canada

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ABSTRACT

Holocene climate change resulted in major vegetation reorganization in sub-arctic Canada near modern treeline. However, little is known of the effects of long-term climate change on boreal forest composition and fire regimes below treeline in this region. We present a high-resolution vegetation and fire history from two sites within the modern boreal forest in the central Northwest Territories, Canada, to provide new insight on sub-arctic vegetation response to Holocene climate dynamics and the role of fire in boreal ecosystems. Palynological analysis of sediments retrieved from Waite and Danny's lakes (informal) is used to reconstruct regional vegetation dynamics and boreal fire regimes. The longer Danny's Lake record documents treeline expansion beginning at ca. 7430–7220 cal yr BP. Integration of our new data with previous work shows that treeline expanded between ca. 4050 cal. yr BP and ca. 3840 cal yr BP at a rate of ca. 50 m/yr in response to the 1–2 °C increase in temperature estimated for the Holocene Thermal Maximum. Forest fires were relatively frequent during the early Holocene, before declining in frequency in response to development of cooler and wetter climate conditions associated with the Neoglacial (beginning after ca. 2200–2320 cal yr BP). We document a trend of increasing fire frequency in the 20th century that is correlated with warming at this time. These dynamics south of modern treeline provide insight into factors creating heterogeneity in plant community responses to large-scale climate events in high northern latitudes and suggest that large scale reorganization of boreal vegetation and fire regimes can be expected over the coming decades.

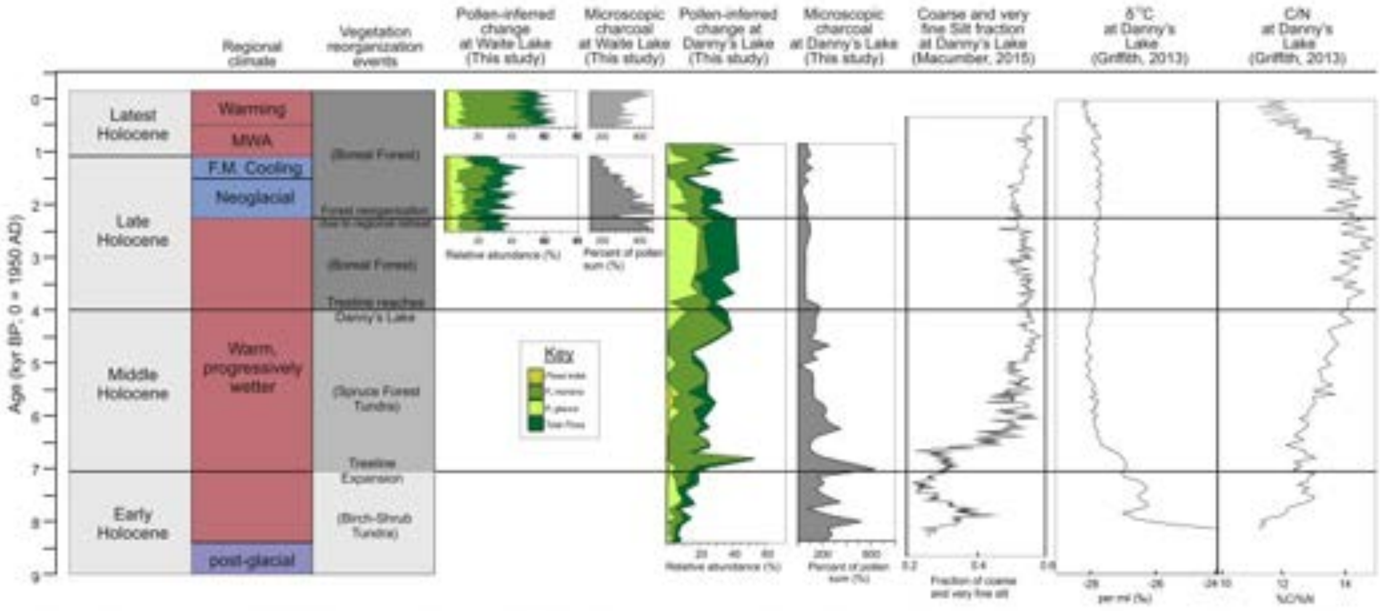
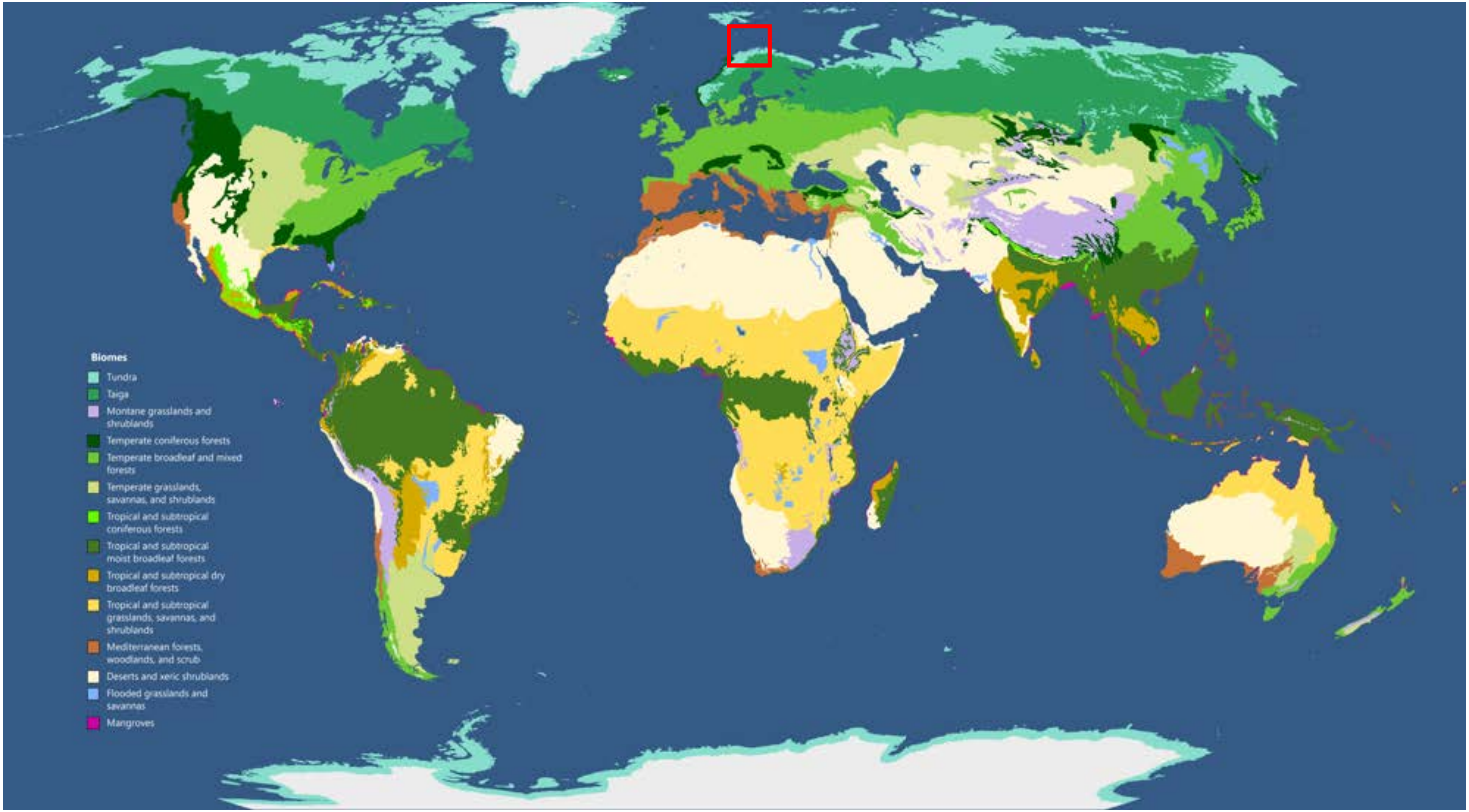


Fig. 6. Summary diagram showing interpreted regional climate and vegetation reorganization events alongside spruce pollen, microscopic charcoal, coarse and very fine silt fraction, $\delta^{13}C$ and C/N ratios of Danny's and Waite lakes.

Case Study 1: Abisko


Biomes
Tundra
Taiga
Montane grasslands and shrublands
Temperate coniferous forests
Temperate broadleaf and mixed forests
Temperate grasslands, savannas, and shrublands
Tropical and subtropical coniferous forests
Tropical and subtropical moist broadleaf forests
Tropical and subtropical dry broadleaf forests
Tropical and subtropical grasslands, savannas, and shrublands
Mediterranean forests, woodlands, and scrub
Deserts and xeric shrublands
Flooded grasslands and savannas
Mangroves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The long-term fate of permafrost peatlands under rapid climate warming

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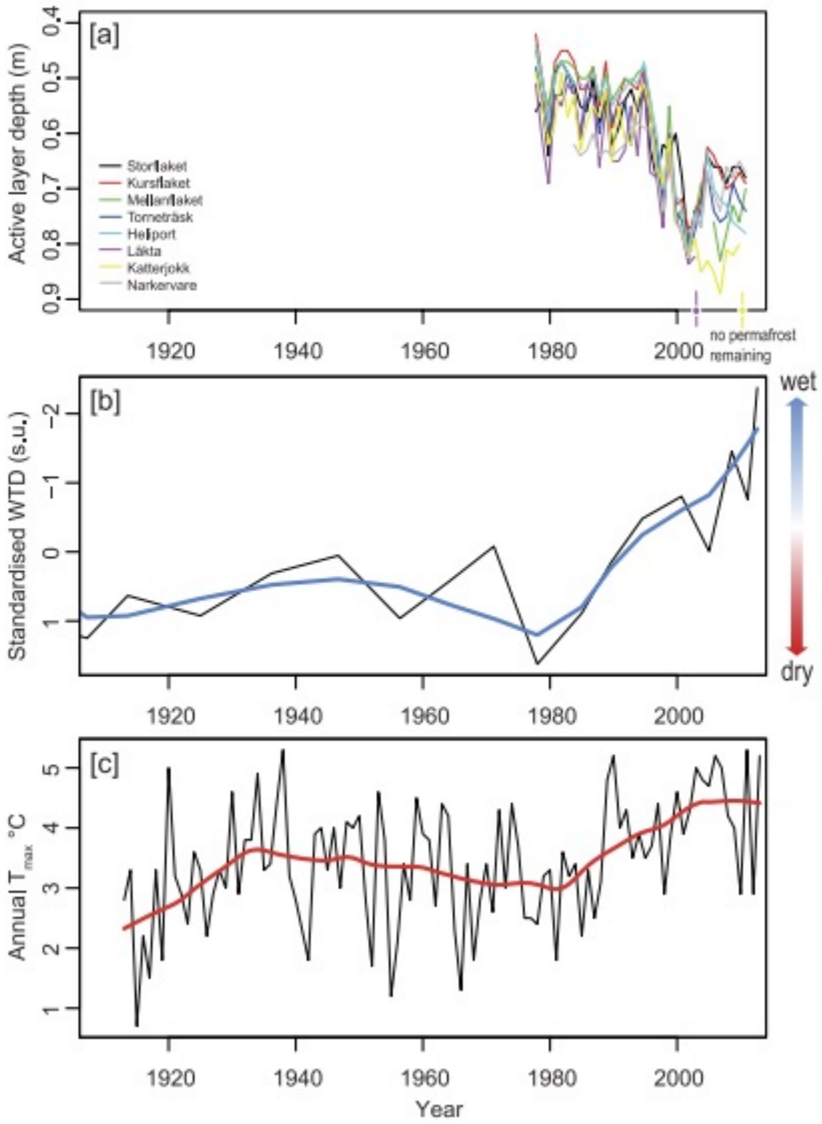
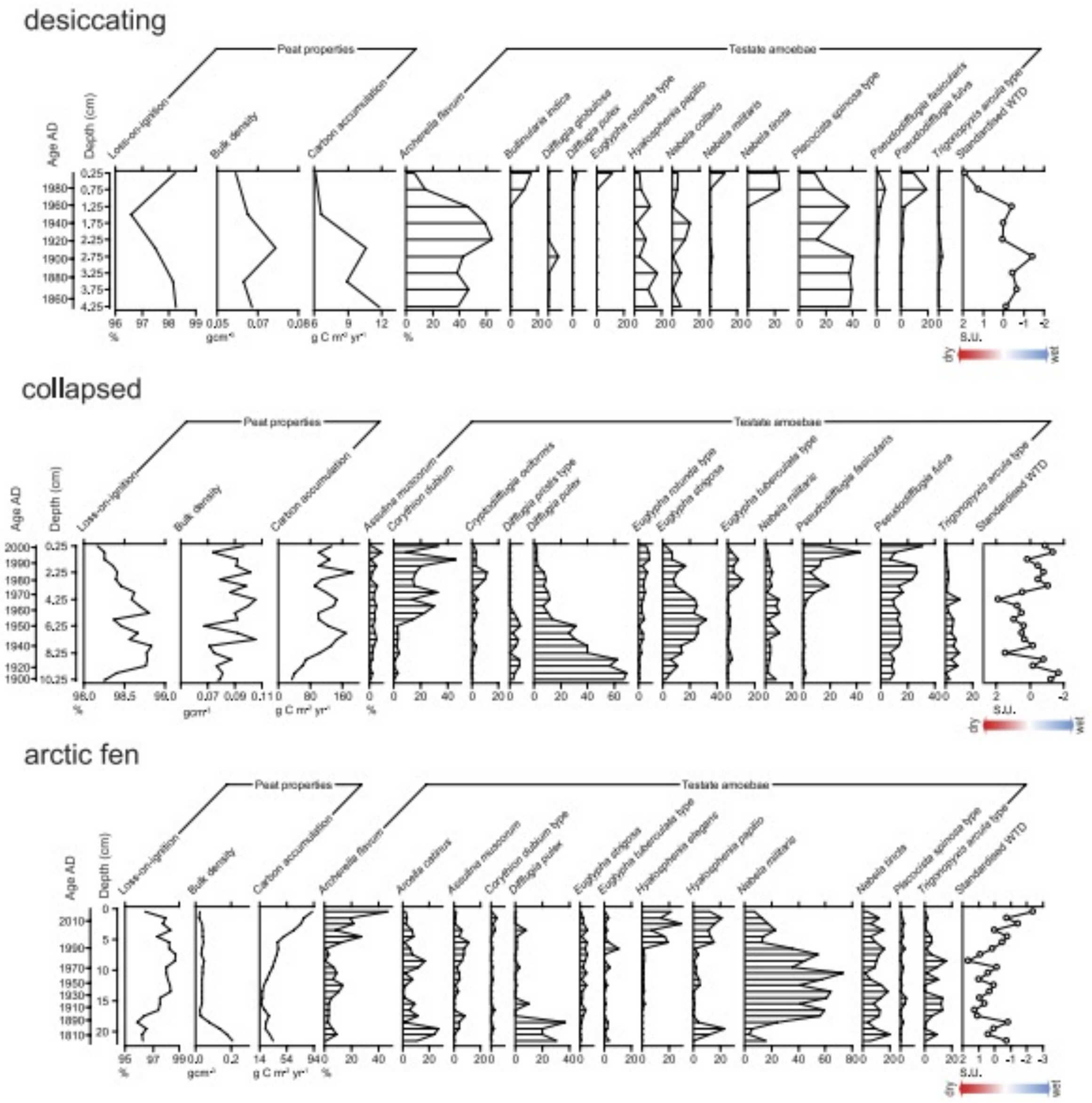
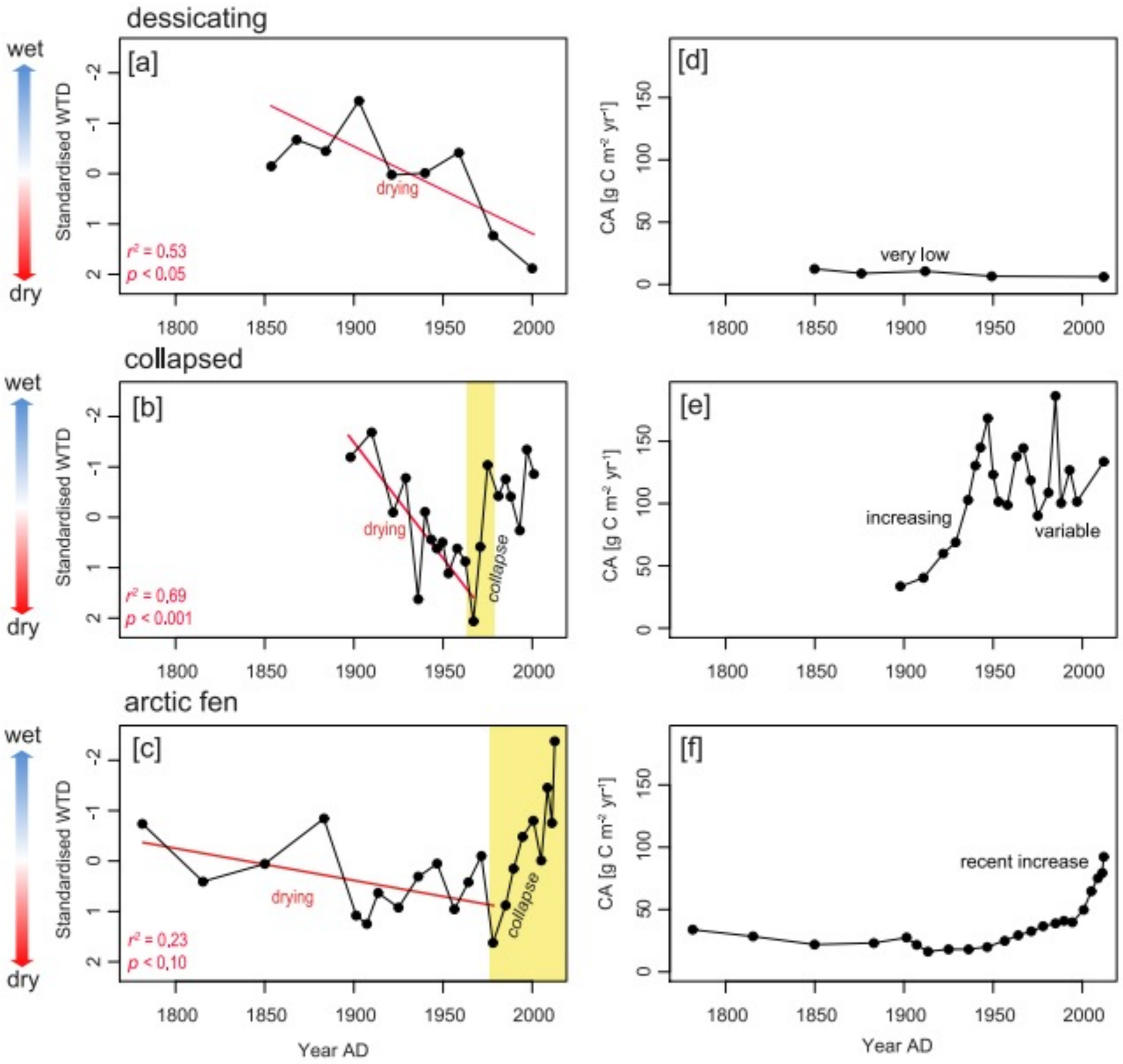
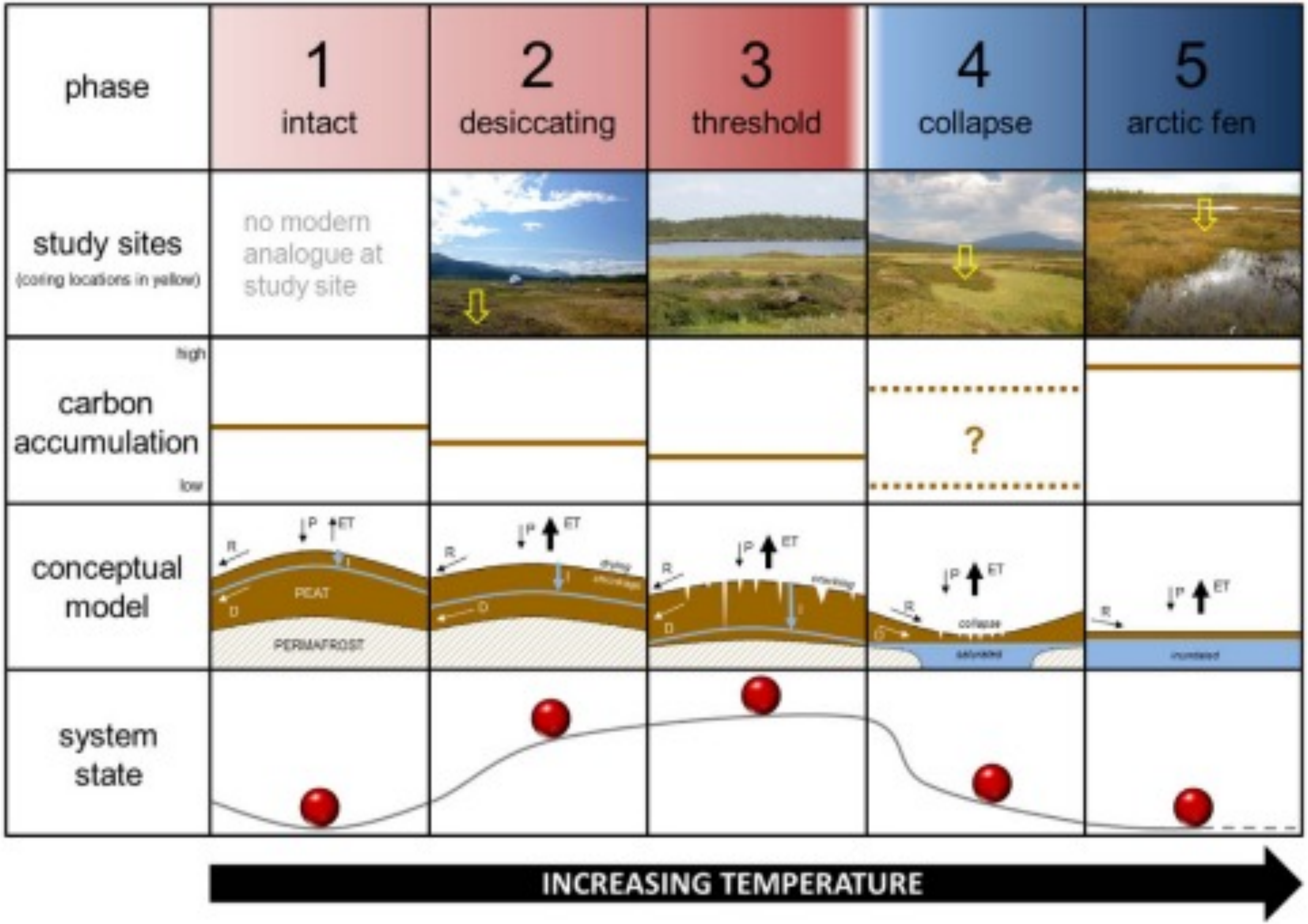
Graeme T. Swindles[1], Paul J. Morris[1], Donal Mullan[2], Elizabeth J. Watson[1], T. Edward Turner[1], Thomas P. Roland[3], Matthew J. Amesbury[3], Ulla Kokfelt[4], Kristian Schoning[5], Steve Pratte[6], Angela Gallego-Sala[3], Dan J. Charman[3], Nicole Sanderson[3], Michelle Garneau[6], Jonathan L. Carrivick[1], Clare Woulds[1], Joseph Holden[1], Lauren Parry[7] & Jennifer M. Galloway[8]

Permafrost peatlands contain globally important amounts of soil organic carbon, owing to cold conditions which suppress anaerobic decomposition. However, climate warming and permafrost thaw threaten the stability of this carbon store. The ultimate fate of permafrost peatlands and their carbon stores is unclear because of complex feedbacks between peat accumulation, hydrology and vegetation. Field monitoring campaigns only span the last few decades and therefore provide an incomplete picture of permafrost peatland response to recent rapid warming. Here we use a high-resolution palaeoecological approach to understand the longer-term response of peatlands in contrasting states of permafrost degradation to recent rapid warming. At all sites we identify a drying trend until the late-twentieth century; however, two sites subsequently experienced a rapid shift to wetter conditions as permafrost thawed in response to climatic warming, culminating in collapse of the peat domes. Commonalities between study sites lead us to propose a five-phase model for permafrost peatland response to climatic warming. This model suggests a shared ecohydrological trajectory towards a common end point: inundated Arctic fen. Although carbon accumulation is rapid in such sites, saturated soil conditions are likely to cause elevated methane emissions that have implications for climate-feedback mechanisms.


[a]
Active layer depth (m)
Storflaket
Kursflaket
Mellanflaket
Torneträsk
Heliport
Läkta
Katterjokk
Narkervare
no permafrost remaining
[b]
Standardised WTD (s.u.)
wet
dry
[c]
Annual T_{max} °C
Year

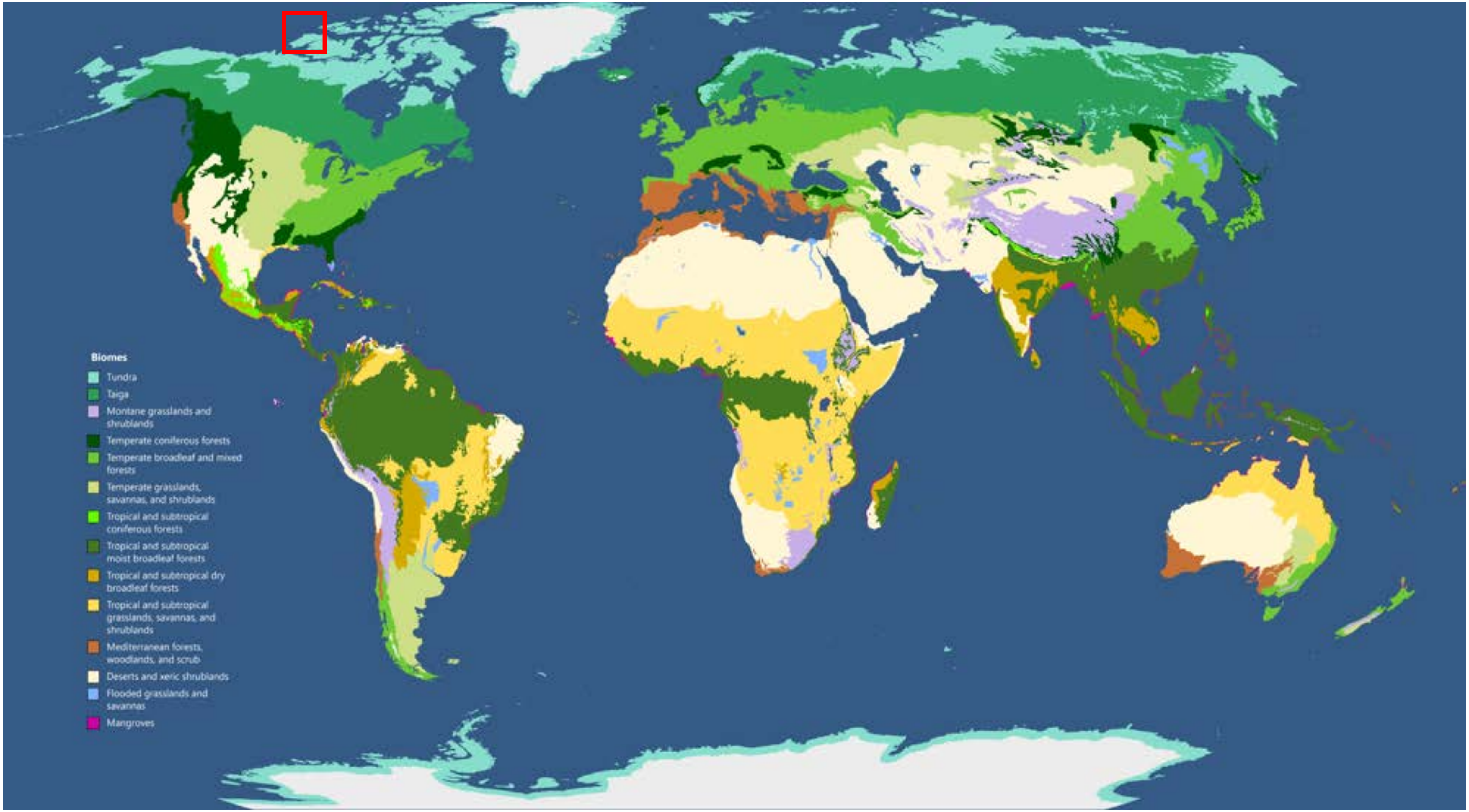

desiccating
Peat properties
Testate amoebae
Age AD
Depth (cm)
Loss-on-ignition
Bulk density
Carbon accumulation
Archerella flavum
Bullinularia indica
Difflugia globulosa
Difflugia pulex
Euglypha rotunda type
Hyalosphenia papilio
Nebela collaris
Nebela militaris
Nebela tincta
Placocista spinosa type
Pseudodifflugia fasicularis
Pseudodifflugia fulva
Trigonopyxis arcula type
Standardised WTD
S.U.
dry
wet
collapsed
Peat properties
Testate amoebae
Age AD
Depth (cm)
Loss-on-ignition
Bulk density
Carbon accumulation
Assulina muscorum
Corythion dubium
Cryptodifflugia oviformis
Difflugia pristis type
Difflugia pulex
Euglypha rotunda type
Euglypha strigosa
Euglypha tuberculata type
Nebela militaris
Pseudodifflugia fasicularis
Pseudodifflugia fulva
Trigonopyxis arcula type
Standardised WTD
S.U.
dry
wet
arctic fen
Peat properties
Testate amoebae
Age AD
Depth (cm)
Loss-on-ignition
Bulk density
Carbon accumulation
Archerella flavum
Arcella catinus
Assulina muscorum
Corythion dubium type
Difflugia pulex
Euglypha strigosa
Euglypha tuberculata type
Hyalosphenia elegans
Hyalosphenia papilio
Nebela militaris
Nebela tincta
Placocista spinosa type
Trigonopyxis arcula type
Standardised WTD
S.U.
dry
wet


dessicating
collapsed
arctic fen
[a]
[b]
[c]
[d]
[e]
[f]
wet
dry
Standardised WTD
CA [g C m-2 yr-1]
drying
collapse
r^2 = 0.53
p < 0.05
r^2 = 0,69
p < 0.001
r^2 = 0,23
p < 0,10
very low
increasing
variable
recent increase
Year AD



phase
1
intact
2
desiccating
3
threshold
4
collapse
5
arctic fen
study sites
(coring locations in yellow)
no modern analogue at study site
carbon accumulation
high
low
?
conceptual model
PEAT
PERMAFROST
P
ET
R
D
collapse
saturated
inundated
system state
INCREASING TEMPERATURE

Case Study 2: Canadian High Arctic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Mediterranean forests, woodlands, and scrub
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Flooded grasslands and savannas
Mangroves

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Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL082611

Pathways for Ecological Change in Canadian High Arctic Wetlands Under Rapid Twentieth Century Warming

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Key Points:
- The ecological, hydrological, and C accumulation responses of Arctic wetlands to climate warming may be strongly influenced by wetland type
- Contrasting site-specific responses to an increase in growing degree days include increased moss diversity and a shift to shrub dominance
- Intensive grazing from Arctic geese may be an important driver for recent vegetation change in High Arctic coastal wetlands

Supporting Information:
- Supporting Information S1
- Data Set S1

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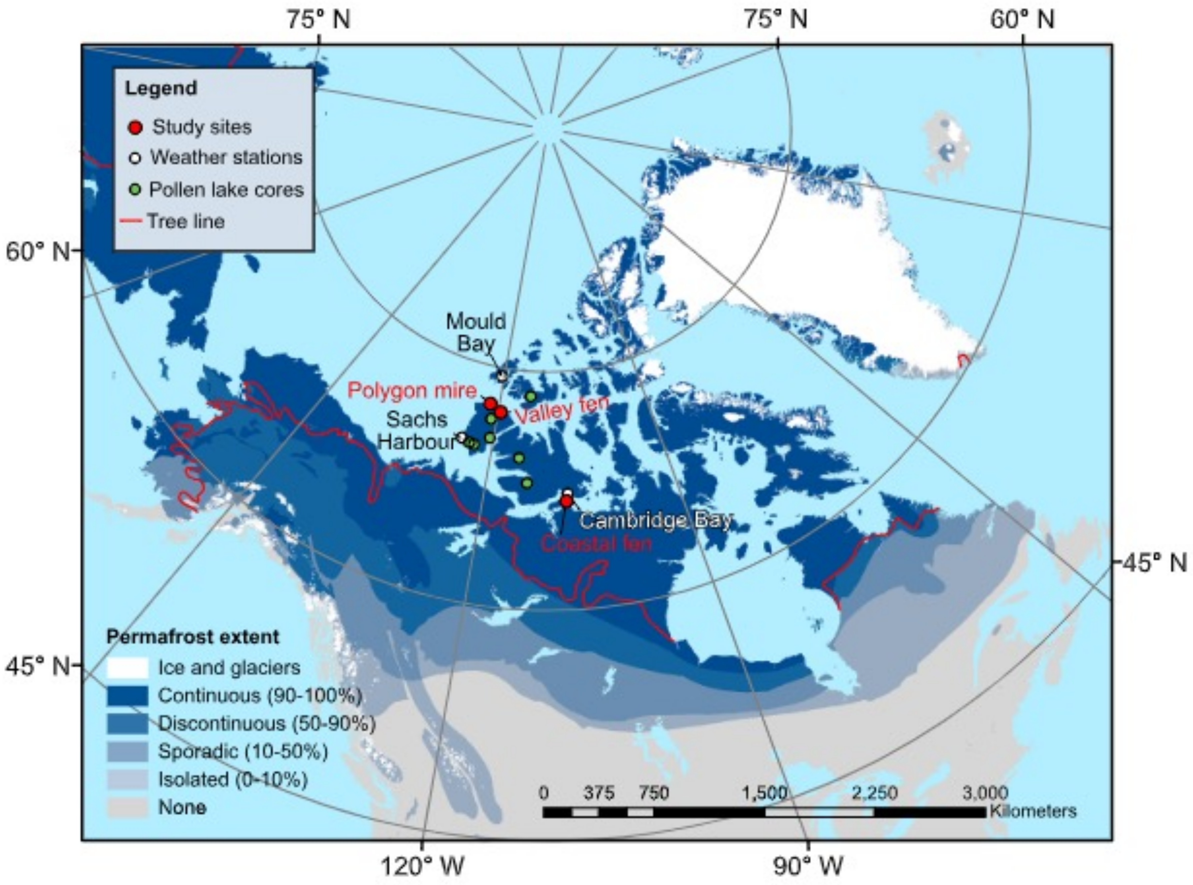
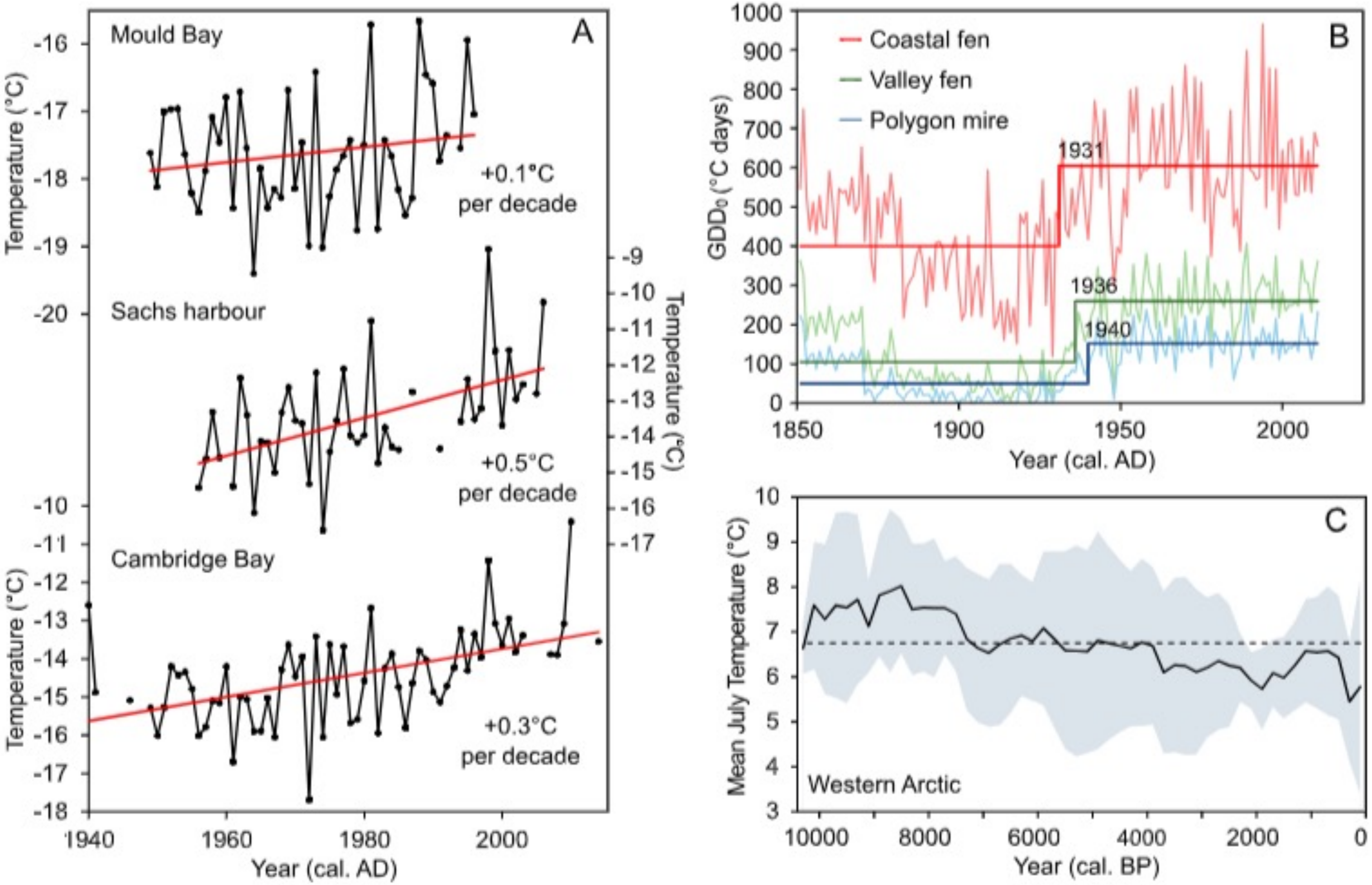
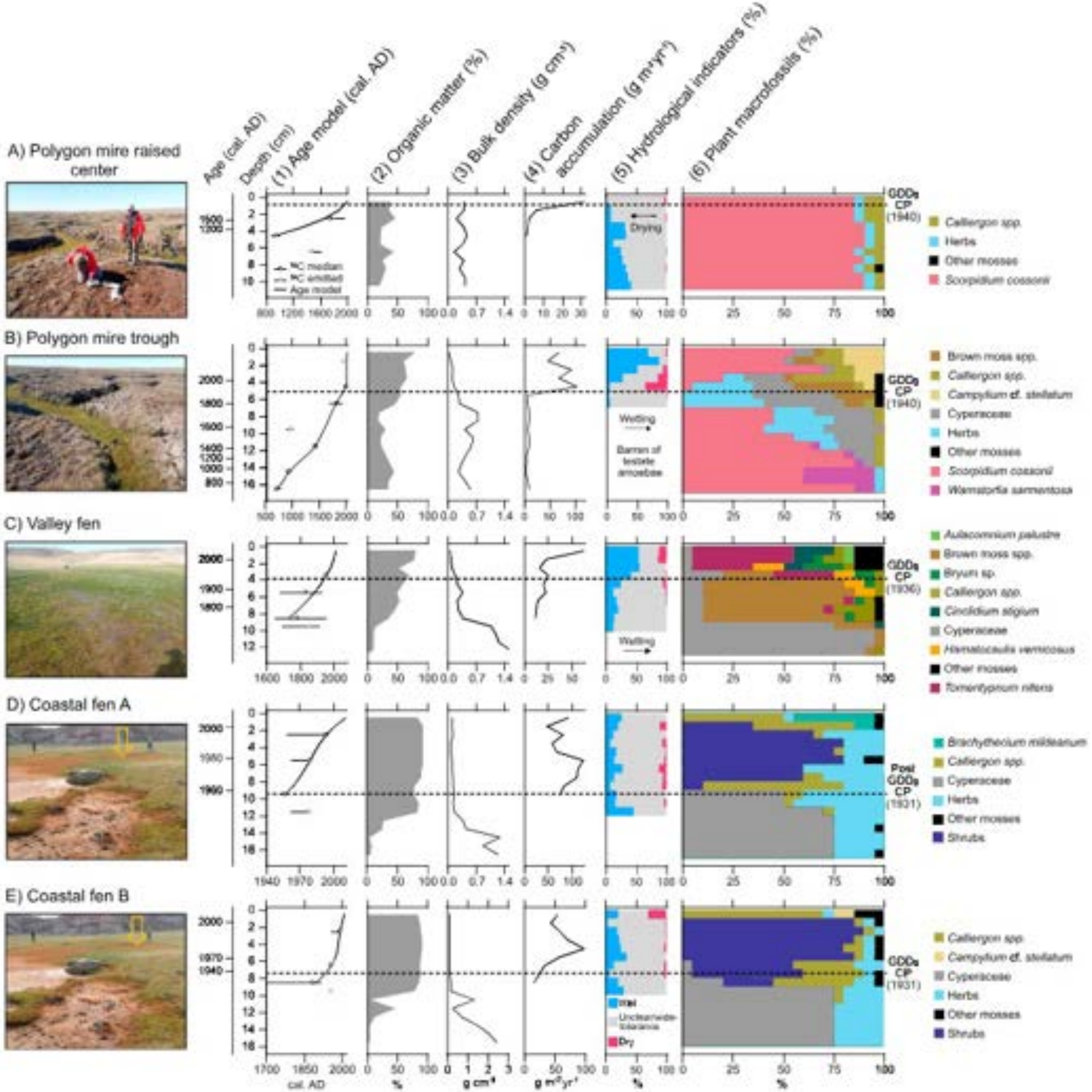
Abstract We use paleoecological techniques to investigate how Canadian High Arctic wetlands responded to a mid-twentieth century increase in growing degree days. We observe an increase in wetness, moss diversity, and carbon accumulation in a polygon mire trough, likely related to ice wedge thaw. Contrastingly, the raised center of the polygon mire showed no clear response. Wet and dry indicator testate amoebae increased concomitantly in a valley fen, possibly relating to greater inundation from snowmelt followed by increasing evapotranspiration. This occurred alongside the appearance of generalist hummock mosses. A coastal fen underwent a shift from sedge to shrub dominance. The valley and coastal fens transitioned from minerogenic to organic-rich wetlands prior to the growing degree days increase. A subsequent shift to moss dominance in the coastal fen may relate to intensive grazing from Arctic geese. Our findings highlight the complex response of Arctic wetlands to warming and have implications for understanding their future carbon sink potential.

Plain Language Summary The response of Arctic wetland ecosystems and carbon stores to climate change is uncertain. We investigate the response of wetland ecosystems in the Canadian High Arctic to twentieth century climate warming. We use proxies for changes in vegetation (plant macrofossils) and wetness (testate amoebae) preserved in the wetland soil in combination with radiocarbon dating to reconstruct the past ecology of these wetlands. This approach allows us to explore beyond the timeframe of monitoring studies. Our results suggest that wetland type is an important determinant of the response of ecological, hydrological, and soil carbon accumulation to climate warming. Our findings highlight the clear but complex response of Arctic wetlands to twentieth century warming. This has important implications for understanding the future carbon sink potential of these ecosystems.





A
Mould Bay
+0.1°C per decade
Sachs harbour
+0.5°C per decade
Cambridge Bay
+0.3°C per decade
Temperature (°C)
Year (cal. AD)
B
Coastal fen
Valley fen
Polygon mire
1931
1936
1940
GDD0 (°C days)
Year (cal. AD)
C
Western Arctic
Mean July Temperature (°C)
Year (cal. BP)



A) Polygon mire raised center
B) Polygon mire trough
C) Valley fen
D) Coastal fen A
E) Coastal fen B
Age (cal. AD)
Depth (cm)
(1) Age model (cal. AD)
(2) Organic matter (%)
(3) Bulk density (g cm⁻³)
(4) Carbon accumulation (g m⁻² yr⁻¹)
(5) Hydrological indicators (%)
(6) Plant macrofossils (%)
Drying
Wetting
Barren of testate amoebae
GDDs CP (1940)
GDDs CP (1936)
Post GDDs CP (1931)
GDDs CP (1931)
Callergon spp.
Herbs
Other mosses
Scorpidium cossonii
Brown moss spp.
Campylium cf. stellatum
Cyperaceae
Warnstorfia sarmentosa
Aulacomnium palustre
Bryum sp.
Cinclidium stigium
Hamatocaulis vernicosus
Tomentypnum nitens
Brachythecium mildeanum
Shrubs
Wet
Unclear/wide-tolerance
Dry
cal. AD
%
g cm⁻³
g m⁻² yr⁻¹

Key findings – one size doesn't fit all!

- Warming of the western Canadian Arctic has caused a mid-twentieth century increase in growing degree days above 0 °C (GDD_0)
- We observe an increase in wetness, moss diversity, and carbon accumulation in a polygon mire trough, likely related to ice wedge thaw.
- The coastal fen underwent a shift from sedge to shrub dominance.
- The valley and coastal fens transitioned from minerogenic to organic-rich wetlands (~peatlands) prior to the growing degree days increase.
- Our findings highlight the complex response of Arctic wetlands to warming and have implications for understanding their future carbon sink potential

Nightmare scenarios of permafrost thaw

- The carbon bomb
- The pollution bomb
- Unknown viruses/bacteria being released!

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Permafrost dynamics and the risk of anthrax transmission: a modelling study

Elisa Stella[1], Lorenzo Mari[2], Jacopo Gabrieli[1], Carlo Barbante[1,3] & Enrico Bertuzzo[1,3]

A recent outbreak of anthrax disease, severely affecting reindeer herds in Siberia, has been reportedly associated to the presence of infected carcasses or spores released from the active layer over permafrost, which is thawing and thickening at increasing rates, thus underlying the re-emerging nature of this pathogen in the Arctic region because of warming temperatures. Anthrax is a global zoonotic and epizootic disease, with a high case-fatality ratio in infected animals. Its transmission is mediated by environmental contamination through highly resistant spores which can persist in the soil for several decades. Here we develop and analyze a new epidemiological model for anthrax transmission that is specifically tailored to the Arctic environmental conditions. The model describes transmission dynamics including also herding practices (e.g. seasonal grazing) and the role of the active layer over permafrost acting as a long-term storage of spores that could be viable for disease transmission during thawing periods. Model dynamics are investigated through linear stability analysis, Floquet theory for periodically forced systems, and a series of simulations with realistic forcings. Results show how the temporal variability of grazing and active layer thawing may influence the dynamics of anthrax disease and, specifically, favor sustained pathogen transmission. Particularly warm years, favoring deep active layers, are shown to be associated with an increase risk of anthrax outbreaks, and may also foster infections in the following years. Our results enable preliminary insights into measures (e.g. changes in herding practice) that may be adopted to decrease the risk of infection and lay the basis to possibly establish optimal procedures for preventing transmission; furthermore, they elicit the need of further investigations and observation campaigns focused on anthrax dynamics in the Arctic environment.

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Anthrax kills one, infects 21 others as melting permafrost causes outbreak in Russia's far north

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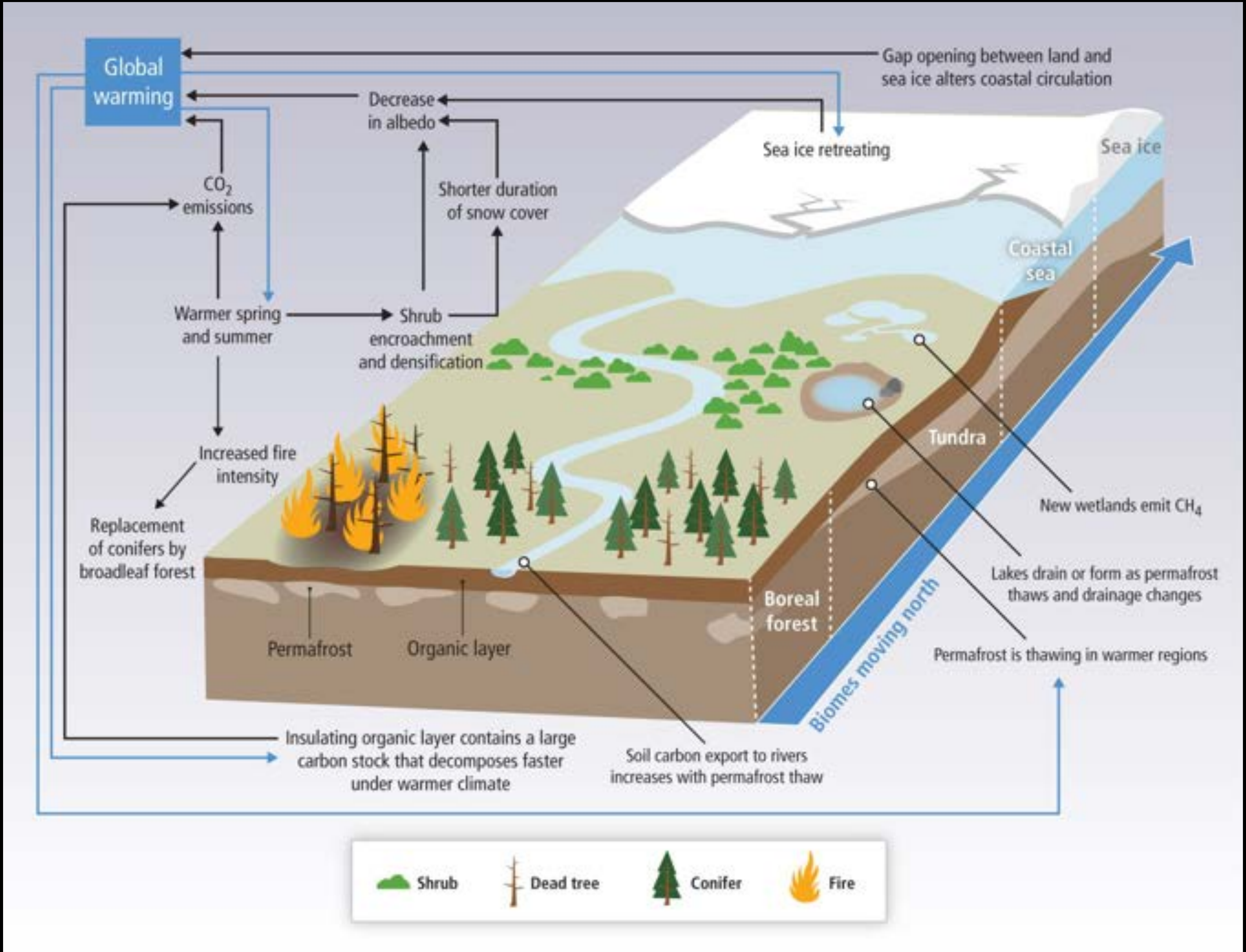
Scientists Fear Cataclysmic 'Factor X' Will Emerge From Earth's Permafrost

Story by Pandora Dewan • 1d

There could be something big lurking in the Earth's permafrost.

As the planet continues to warm, scientists fear a host of deadly diseases will be unleashed from the frozen earth, after lying dormant for decades, centuries, and even millennia. The war between Russia and Ukraine has crippled our attempts to prepare ourselves, and the expansion of mining in the polar regions could nudge us even closer to opening this Pandora's Box.

In summary


Global warming
Gap opening between land and sea ice alters coastal circulation
Decrease in albedo
Sea ice retreating
Sea ice
CO_2 emissions
Shorter duration of snow cover
Coastal sea
Warmer spring and summer
Shrub encroachment and densification
Tundra
Increased fire intensity
Replacement of conifers by broadleaf forest
New wetlands emit CH_4
Lakes drain or form as permafrost thaws and drainage changes
Boreal forest
Biomes moving north
Permafrost
Organic layer
Permafrost is thawing in warmer regions
Insulating organic layer contains a large carbon stock that decomposes faster under warmer climate
Soil carbon export to rivers increases with permafrost thaw
Shrub
Dead tree
Conifer
Fire

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