Arctic biome changes on Baffin Island within the past 200,000 years: Lessons from past warm times

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Projected major large-scale environmental changes in consequence of a 2 to 4°C climate warming by the end of the 21st century

Arctic Climate Impact Assessment (2005)
Glacial-Interglacial cycles

The study of past warm time can play an important role in helping us understand future climate change and associated tundra ecosystems response.

MIS (Marine Isotope Stage)

- **1** Holocene (last 11,500 years)
- **5** Last Interglacial (LIG) (ca. 125,000 years ago)
- **7** Previous Interglacial (PIG) (ca. 200,000 years ago)
- **9**
- **11**

- Glacial period (cold)
- Interglacial period (warm)
- Studied interglacial periods
Arctic summer surface-temperature anomalies

The Last Interglacial (LIG), i.e. the Marine Isotope Stage (MIS) 5, ca. 125,000 years ago, is considered an interval of relative warmth throughout the circum-Arctic region.

On eastern Baffin Island, the summer temperature was about 4 to 5°C higher than today.

Arctic climate system has a planetary impact!

Otto-Bliesner et al. (2006) Science
The memory of lacustrine muds

How pollen grains can document past vegetation and climate changes?
1. Sedimentation of pollen

- Tree pollen
- Shrub pollen
- Herb pollen

2. Sampling and analysis

3. Pollen diagram

- Herb
- Shrub
- Tree

- Boreal forest
- Shrub tundra
- Herb tundra

Time scale:
- 6000 yrs before present
Climate reconstruction
Modern database
(831 sites, 39 taxa, monthly climate)

Modern Analogue Technique
Vegetation ↔ B ↔ Climate

A. Vegetation vs pollen (%)

<table>
<thead>
<tr>
<th>Site</th>
<th>Tree</th>
<th>Shrub</th>
<th>Herb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,3</td>
<td>36,3</td>
<td>61,4</td>
</tr>
<tr>
<td>2</td>
<td>5,1</td>
<td>20,1</td>
<td>74,8</td>
</tr>
<tr>
<td>3</td>
<td>4,7</td>
<td>15,7</td>
<td>79,6</td>
</tr>
<tr>
<td>4</td>
<td>56,3</td>
<td>30,2</td>
<td>13,5</td>
</tr>
<tr>
<td>5</td>
<td>80,2</td>
<td>15,3</td>
<td>4,5</td>
</tr>
<tr>
<td>6</td>
<td>67,4</td>
<td>26,9</td>
<td>5,7</td>
</tr>
</tbody>
</table>

B. Vegetation vs summer climate

<table>
<thead>
<tr>
<th>Site</th>
<th>T (°C)</th>
<th>S (%)</th>
<th>P (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,3</td>
<td>45,2</td>
<td>103</td>
</tr>
<tr>
<td>2</td>
<td>4,7</td>
<td>40,7</td>
<td>355</td>
</tr>
<tr>
<td>3</td>
<td>7,3</td>
<td>35,3</td>
<td>95</td>
</tr>
<tr>
<td>4</td>
<td>15,2</td>
<td>58,9</td>
<td>280</td>
</tr>
<tr>
<td>5</td>
<td>17,3</td>
<td>49,6</td>
<td>231</td>
</tr>
<tr>
<td>6</td>
<td>12,1</td>
<td>60,6</td>
<td>132</td>
</tr>
</tbody>
</table>

T : Temperature, S : Sunshine, P : Precipitation
Role of Land-Surface Changes in Arctic Summer Warming


Science 2005

Brief Communications

Nature 411, 546-547 (31 May 2001) | doi:10.1038/35079180
Climate change: Increasing shrub abundance in the Arctic
Matthew Sturm4, Charles Racine2 and Kenneth Tape3

Nature 2001

Arctic tundra shrub invasion and soot deposition: Consequences for spring snowmelt and near-surface air temperatures

John E. Strack,1 Roger A. Pielke Sr.,1 and Glen E. Liston2

Journal of Geophysical Research 2007

Snow–Shrub Interactions in Arctic Tundra: A Hypothesis with Climatic Implications

Matthew Sturm,* Joseph P. McFadden,†,** Glen E. Liston,‡ F. Stuart Chapin III,‖ Charles H. Racine,¶ and Jon Holmgren*

Journal of Climate 2001

Plant community responses to experimental warming across the tundra biome

Plant community responses to experimental warming across the tundra biome


Proc. Nat. Ac. of Sciences 2006

During the Last Interglacial the shrub cover on eastern Baffin Island was...

Rapid advancement of spring in the High Arctic

Toke H. Hoje, Eric Post, Hans Mettler†, Niels M. Schmidt and Mads C. Forchhammer

Current Biology 2007
Actual northern limit of shrub birch (akvaqiak)

**Shrub birch (Betula)**

- **1**: Fog Lake (67°11'N, 63°15'W, 460 m asl) (Fréchette, published)
- **2**: Amakuttalik Lake (67°48'N, 64°34'W, 46 m asl) (Fréchette, unpublished)
- **3**: Amarok Lake (66°16'N, 65°15'W, 848 m asl) (Fréchette, published)

**Betula pollen signature**

- **Holocene** (last 11,500 yrs)
  - 1: 25%
  - 2: 6%

- **Last Interglacial** (125,000 yrs ago)
  - 1: 54%
  - 3: 43%
Sedimentology and Chronology (CF8)

Location map

Study site: Lake CF8
70°33'N, 68°57'W, 195 m asl

Sedimentology and chronology
Briner et al. (2007) Geology
Axford et al. (2009) PNAS

Composite depth (cm)

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Unit</th>
<th>MIS</th>
<th>Age (cal yr BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td></td>
<td>101±10</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td></td>
<td>122±12</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td></td>
<td>&gt;194</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VI</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VII</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

Mineral sediment
Organic sediment
Vegetation types (or biomes) of the last three interglacial periods (MIS 1, MIS 5, MIS 7)

What are the floristic differences?

How many Arctic biomes are distinguished?

MIS 1 : Holocene (last 11,500 years)
MIS 5 : Last Interglacial (ca. 125,000 years ago)
MIS 7 : Previous Interglacial (ca. 200,000 years ago)
Summary pollen diagram (CF8)

- Boreal trees
  - Alnus
  - Betula
- Salix
- Ericaceae
- Cyperaceae
- Poaceae
- Rosaceae
- Caryophyllaceae
- Oxyria digyna
- Saxifragaceae
- Pollen conc. (grains/cc)
- Pollen sum
- Sediment

Composite depth (cm)

- Mineral sediment
- Organic sediment

MIS 1

MIS 5

MIS 7
Principal component analysis (CF8)

Only the major taxa loadings are illustrated.
Vegetation type (Biome) reconstruction

1 - Assignment of pollen taxa to plant functional types (PFTs)

Typical taxa | PFT name
--------------|------------------
Arctic herbs | Arctic forb
Poaceae      | Grass and sedge graminoid
Cyperaceae   | Arctic prostrate dwarf shrub
Ericaceae    | Arcto-boreal erect dwarf shrub
Salix        | Arcto-boreal low and high shrub
Dryas        |
Betula       |
Alnus         |

2 - Arctic Biome reconstruction from PFTs and pollen taxa

Biome name (typical PFT)
- [pink] Cushion-forb
- [light blue] Prostrate dwarf-shrub tundra
- [green] Hemiprostrate dwarf-shrub tundra
- [dark blue] Erect dwarf-shrub tundra
- [brown] Low- and high-shrub tundra

(Gould et al., 2002; Walker et al., 2020, CAVM Team, 2003, Kaplan et al., 2003)
Biome reconstruction (CF8)

Arctic Biome

(CAVM Team, 2003)

Pollen (PFT) Biome

MIS

Time

Composite depth (cm)

PFT: Plant Functional Type

Biome name
- Cushion-forb (CUSH)
- Prostrate dwarf-shrub tundra (PROS)
- Hemiprostrate dwarf-shrub tundra (HEMP)
- Erect dwarf-shrub tundra (DWAR)
- Low- and high-shrub tundra (SHRU)

PFT name
- Arctic forb
- Grass and sedge graminoid
- Arctic prostrate dwarf shrub
- Arcto-boreal erect dwarf shrub
- Arcto-boreal low and high shrub
Biome and climate changes on eastern Baffin Island during the MIS 1 and MIS 5

During the Last Interglacial (MIS 5) the northern limit of shrub birch was…?

What were the July air temperature and the growing season (JJAS) sunshine?

MIS 1 : Holocene (last 11,500 years)
MIS 5 : Last Interglacial (ca. 125,000 years ago)
**Biome changes**

**Arctic Biome**

- Northern limit of shrub birch
- Northern limit of alder

**Arctic Biome and typical PFT**

- CUSH (< 2°C)
- PROS (2 - 5°C)
- HEMP (5 - 7°C)
- DWAR (7 - 9°C)
- SHRU (9 - 12°C)

Modern July air T (Gould et al., 2002)

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**Northern HEMP**

**Holocene (MIS 1 : last 11,500 years)**

1. **Lake CF8**
   - PFT
   - July T
   - JJAS S

2. **Amakuttalik Lake**
   - PFT
   - July T
   - JJAS S

**Last Interglacial (MIS 5 : 125,000 years ago)**

1. **Lake CF8**
   - PFT
   - July T
   - JJAS S

2. **Fog Lake**
   - PFT
   - July T
   - JJAS S

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(CAVM Team, 2003)
During the Last Interglacial (MIS 5), at Lake CF8...

1. The July air T was about 4°C higher than today.
2. Shrub birches were present locally at 70°N.
3. Therefore, the northern limit of shrub birch populations on eastern Baffin Island was about 400 km north.
4. This northward migration of shrub is in agreement with the projected treeline expansion by the end of the 21st century in consequence of a 2 to 4°C climate warming (ACIA, 2005).

In a global warming scenario, it is important that we improve our understanding of how changes in shrub cover likely influence the behaviour of the climate system, notably through a decrease in albedo (e.g., Walker et al., 2006, PNAS).
THANKS FOR YOUR ATTENTION