Beyond boreal forests: Holocene fire history in Alaskan tundra ecosystems

Philip Higuera
Montana State Univ. and Univ. of Illinois
Melissa Chipman Univ. of Illinois
Jennifer Allen National Park Service
Scott Rupp Univ. of Alaska
Mike Urban, Feng Sheng Hu Univ. of Illinois

Photo: Dale Woitas, AFS, BLM
Shrub expansion:

- Will tundra area burned increase?
Tundra fire frequencies could increase with shrub abundance and climatic drying.

Higuera et al., 2009, Ecological Monographs
- Approximately 90% area burned in boreal forest
- More than 1.8 million hectares burned in tundra
- 1332 citations: "boreal forest + fire"
- 139 citations: "tundra + fire"
II. Objectives

1. Quantify tundra fire history over the past 6000 years

2. Infer climate-vegetation-fire relationships from pollen and independent paleoclimatic records

3. Inform ecosystem model (ALFRESCO) for assessing fire and fuels hazards in tundra under future climate / veg.
III. Study Design

- **Noatak NP**
  - graminoid
  - shrub

- **Bering Land Bridge NP**
  - graminoid
  - shrub

- **Anaktuvuk River Fire**
Noatak Study Area

**Graminoid Tundra:**
Cyperaceae, Poaceae, dwarf shrubs

**Shrub Tundra:**
Betula, Alnus, Salix
IV. Tundra Fire History

Age Models

- Raven
- Little Isac
- Uchugrak
- Poktovik

- $^{14}$C or $^{210}$Pb date, 95% CI
- cubic spline interpolant, 95% CI
- excluded date, 95% CI

depth (cm)
Fire History from Sed. Charcoal

\[ C_{air} = \text{airborne fallout of charcoal} \]
\[ C_{ls} = \text{charcoal on landscape surface} \]
\[ C_{lake} = \text{charcoal on lake surface} \]
\[ C_{core} = \text{charcoal in center of lake} \]

\[ C_{air} = f(d) \]
\[ C_{ls} = f(d) \]
\[ C_{lake} = f(C_{air}, \text{slope wash}) \]
\[ C_{core} = f(C_{lake}, \text{redemption, mixing}) \]
1. Tundra burns

- Records appropriate for peak identification
- Recent large fires detected
2. Location matters:
- vegetation

**Graminoid (2-0 ka BP):**
Wbl $c = 1.94$ (1.55-3.34)
$N = 27$

$\text{FRI}_{\text{median}} = 135 \text{ yr (105-150)}$

**Shrub (2-0 ka BP):**
Wbl $c = 1.58$ (1.16-2.75)
$N = 13$

$\text{FRI}_{\text{median}} = 180 \text{ yr (165-375)}$
Fire regimes of the last 2000 years

2. Location matters:
   - vegetation
   - climate

**Graminoid (2-0 ka BP):**
Wbl c = 1.94 (1.55-3.34)  
N = 27

FRI\textsubscript{median} = 135 yr (105-150)

**Shrub (2-0 ka BP):**
Wbl c = 1.58 (1.16-2.75)  
N = 13

FRI\textsubscript{median} = 180 yr (165-375)

July max Temp.

Ann. Precip.
Temporal Scales of Change

Uchugrak Lake

age (cal. yr BP)

fire frequency (fires 100 yr⁻¹)

CHAR (# cm⁻² yr⁻¹)
temporal scale (yr)
Temporal Scales of Change

Uchugrak Lake

Raven

Age (cal. yr BP)

Temporal Scale (yr)

Fire Frequency (fires 100 yr⁻¹)
Millennial-scale synchrony

Raven-Uchugrak: 6.5-0 ka BP
2. Synchrony suggests climatic controls:
   - Raven-Uchugrak: 6.5-0 ka BP
   - Poktovik-Little Isac: 6.5-0 ka BP
   - Raven-Uchugrak-Little Isac: 6.5-3.0 ka BP
Brooks Range Relative Moisture

\[
\delta^{18}O \text{ (‰V-PDB)}
\]

- b) Wolverine Lake
- e) Takahula Lake
  - drier
  - wetter

\[
\text{fire frequency (fires 1000 yr}^{-1})
\]

\[
\text{sand accumulation (g cm}^{-2}\text{yr}^{-1})
\]

Mann et al. 2002, QSR; Clegg and Hu in review

age (cal. yr BP)
4. Role of vegetation dependent on climate:
   - shrub tundra more flammable in drier climate
V. Conclusions

1. Sediment charcoal reveals that tundra can burn as frequently as boreal forest.

2. Synchronous changes and paleorecords suggest climate and possibly vegetation drivers of tundra fire regimes.

3. Tundra fire regimes should be sensitive to ongoing environmental change.
Acknowledgements and Questions

**Funding:** Joint Fire Science Program and the National Park Service.

**Field Assistance:** Denali National Park fire personnel

**Lab Assistance:** Triet Vuong and Jennifer Schwarz