Interactions of climate, vegetation, and fire during the Holocene: insights to future change

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Research Supporting Sound Decisions
“As a result of climate change, we are in essence conducting a global experiment such that future wildland fire activity is highly uncertain.”

– Flannigan et al. 2009
Conceptual Framework

Global
Regional
Wildfire
Microsite

SPACE

Conceptual Framework

Fire Regime
CLIMATE
VEGETATION
ignition

Fire Regime

Fire Behavior

Weather
topography

Seconds
Days
Decades
 Millennia

TIME

Conceptual Framework

Flame

oxygen
heat

conceptual

fuel

Conceptual Framework

fuel

Conceptual Framework

Conceptual Framework

Modified from Moritz et al. 2005, PNAS
Conceptual Framework

![Graph showing temperature over time]

- Years before present (x 1000)
- Temp. (°C)

Fire Regime

CLIMATE

VEGETATION

- Holocene
Overview

1. Climate-vegetation-fire interactions
   - Reconstructing fire history
   - Insights from Alaska
   - Context for ongoing change

2. Conceptual challenges
   - Defining regimes and detecting change
Reconstructing the past

- pollen:
- macrofossils:
- charcoal:
Fire history from continuous sediment records

Empirical support:

Theoretical support:

\[ C_{air} = f(d) \]

\[ C_{lake} = f(C_{air}, \text{slope wash}) \]

\[ C_{core} = f(C_{lake}, \text{redistribution, mixing}) \]

Stand age & fire scars

Charcoal accumulation

Higuera et al. 2007; Peters and Higuera, 2007

Higuera et al. 2005
Fire history from continuous sediment records

1. Raw CHAR
2. “Background”
3. Residual CHAR
   (background removed)
4. Threshold
5. Peaks
Climate Change and Fire Regimes

Vegetation mediates the impacts of climate change on fire regimes
Climate Change

- Picea
- Betula
- Alnus
- Salix
- Populus
- Artemisia
- Cyperaceae
- Poaceae

Veg. Zone

14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

Years before present (x 1000)

Vegetation: Higuera et al. 2009, Ecological Monographs

No-analog
Climate Change

 Cooler much drier → warmer drier → modern: cool moist

Vegetation Change

Herb Tundra → Shrub Tundra → Deciduous Woodland → Forest-tundra → Boreal Forest
Frequent Fires in Ancient Shrub Tundra: Implications of Paleorecords for Arctic Environmental Change

Philip E. Higuera, Linda B. Brubaker, Patricia M. Anderson, Thomas A. Brown, Alison T. Kennedy, Feng Sheng Hu

CLIMATE → VEGETATION

+ FIRE REGIME

SHRUB TUNDRA

DECID. WOOD.

Fire return interval (yr)

Proportion OR density (x20)

144 (120-169)
N = 45

251 (156-347)
N = 11

Higuera et al. 2009 *Ecological Monographs*
Higuera et al. 2009 *Ecological Monographs*; Also: Lynch et al. 2002

CLIMATE → VEGETATION

- FIRE REGIME

**Forest-tundra**

<table>
<thead>
<tr>
<th>Fire Return Interval (yr)</th>
<th>Proportion OR Density (x20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>227 (170-287)</td>
<td>N = 21</td>
</tr>
<tr>
<td>145 (130-163)</td>
<td>N = 110</td>
</tr>
</tbody>
</table>

**Boreal Forest**

Forest-tundra

Boreal Forest
Modeling climate-veg.-fire interactions:

\[ \text{fire} = f(\text{climate}, \text{vegetation}) \]

e.g. Rupp, T. S. et al. 2000. *Landscape Ecology*

Veg. and climate change required for data-model match

Simulated years before present

As in the past, future fire regimes determined by:

- If fire is limited more by the abundance and/or continuity of fuels, then vegetation change can be more important than climate change.
Western Brooks Range, Alaskan tundra

Locally-mediated response to climate change

Raven Lake
Tundra burns

- Records appropriate for peak identification
- Recent large fires detected
Little Isac
Raven
Picea
Betula
Alnus
Cyperaceae
Poaceae

Fire frequency
(fires 100-yr⁻¹)

% pollen

age (cal. yr BP x 1000)

Coherent pattern

Site-specific patterns
Square root-transformed pollen percentage

Raven

- *Picea*
  - $r = 0.83$

- *Poaceae*
  - $r = 0.50$

Little Isac

- *Betula*
  - $r = 0.55$

- *Poaceae*
  - $r = 0.70$

$r^2_{adj} = 0.83$

$r^2_{adj} = 0.68$
Context for ongoing change
Unprecedented Tundra Burning During Extreme Sea-Ice Retreat

F. S. Hu, P.E. Higuera, J. E. Walsh, W. L. Chapman, L. B. Brubaker, M. L. Chipman

Photo: Dale Woitas, AFS, BLM

Hu, Higuera, et al., In prep.
Overview

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Temporal scale of fire regimes

Temporal window (yr)

FRI (yr)

CHAR (# cm$^2$ yr$^{-1}$)

Years before present

Fire frequency (fires 100 yr$^{-1}$)
Temporal scale of fire regimes

Modified from Whitlock, Higuera, et al. 2010; The Open Ecology Journal
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Questions?

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