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Tundra fire-regimes in the Alaskan Arctic and the link to late-Holocene vegetation change

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1. Background and Rationale

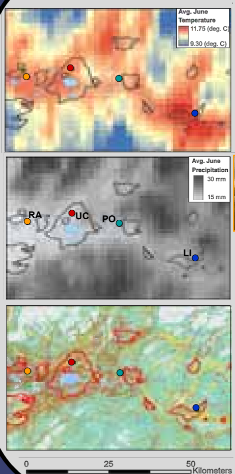
Record-setting tundra burning in 2007 (Fig. 1.1) and paleo evidence of frequent tundra fires in the past (*1*) suggest tundra ecosystems can burn more frequently than is evident in the observational record. Land managers and global change scientists lack critical information on the controls of tundra fire regimes and their potential response to ongoing and predicted climate warming (*2*).

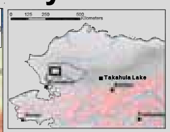
Fig. 1.1 The Anaktuvuk River fire burned 256,000 acres in late summer 2007, making it the largest documented fire north of the Brooks Range and the largest fire of the Alaskan fire season. Warm, dry weather, similar to predicted changes for the next century, promoted the fire. Was this event unprecedented in the recent past? (BLM photo).

Using macroscopic charcoal from lake-sediment cores we are characterizing the 6000-yr fire history in shrub/herb-dominated tundra in three regions across Alaska**.**

Here we present the first long-term, high-resolution records of tundra fire history from four lakes in the Noatak National Preserve, a region encompassing some of the most flammable tundra in Alaska.

2. Study Sites

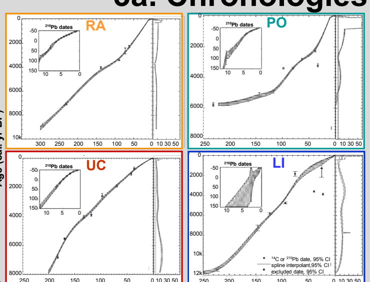




Left: Noatak River Watershed, northeast of Kotzebue, Alaska. Red polygons indicate fires recorded since 1950. **Far Left:** June average temperature (color) and precipitation (greyscale). Regional vegetation map based on the USGS Landfire dataset, 2008. **Below:** Site photos highlight local landscape variability.

We report on four records from the Noatak National Preserve: Raven (RA), Uchugrak (UC), Poktovik (PO) and Little Isac (LI) lakes span an east-west gradient in the Noatak River watershed. The sites are characterized by local differences in climate and vegetation. For example, LI is dominated by high *Betula* cover while RA is the only lake where *Picea* is locally present. PO and UC have abundant *Alnus* and sedge. UC is the only lake with a known archaeological site in the watershed.

3a. Chronologies

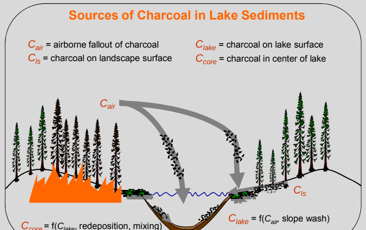


depth below mud-water interface (cm) & resolution (yr/sample)

Chronologies are based on ^{210}Pb dating of the uppermost sediments and radiocarbon dates (calibrated to years before 1950) from terrestrial macrofossils.

Median temporal resolution for each 0.25-cm thick sample is approximately 10-25 yr.

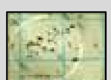
3b. Methods



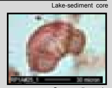
Sources of Charcoal in Lake Sediments

C_{air} = airborne fallout of charcoal; C_{ls} = charcoal on landscape surface; C_{lake} = charcoal on lake surface; C_{core} = charcoal in center of lake; C_{core} = f(C_{lake}, redeposition, mixing); C_{lake} = f(C_{air}, slope wash)

Lake-sediment core



Macroscopic charcoal

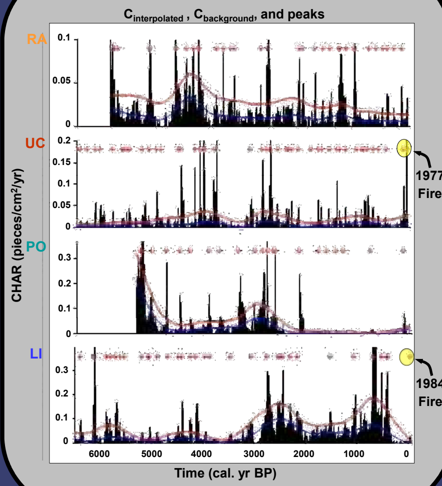


Spruce pollen grain

Macroscopic charcoal (> 180µm) was quantified at continuous ≈10-25 yr intervals for each core. Low-frequency trends in charcoal accumulation rates (CHAR) were removed from each record, and a uniform threshold criteria was applied to separate fire-related variations in CHAR from statistical noise (*3*). Peaks exceeding this threshold are interpreted as past fires within 0.5-1 km of each lake and are used to calculate fire frequency (yr/fire).

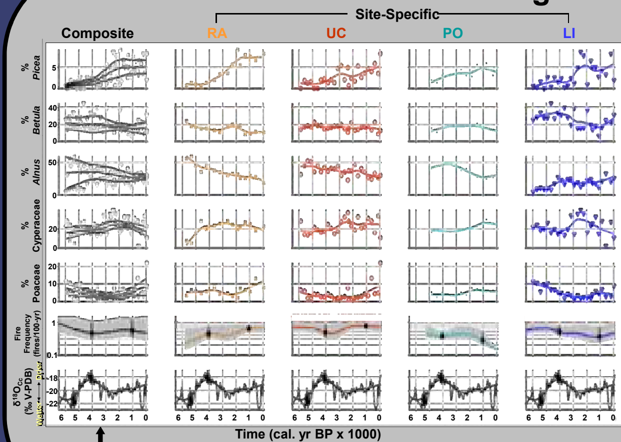
Fossil pollen was quantified at each lake at discontinuous ≈250-500 yr intervals. Pollen percentages at each site reveal local variation through time, and a composite record (combining all four sites) represents regional vegetation change.

4. Charcoal Records



Charcoal records resolve known tundra fires.

5. Local and Regional Trends



▪ Pollen percentages and estimated mean fire frequency (90% CI) for site-specific records, smoothed to a 2000-year window.

▪ Site-specific trends suggest that the impacts of climate change were mediated by local-scale factors. For example, while *Alnus* decreases throughout the late Holocene at RA, UC, and PO, it increases at LI. Likewise, fire frequencies increase at RA but decrease at PO and LI over the same period.

▪ Changes in fire frequency differed between sites at two key intervals (marked with boxes). From 5000-3000 cal. yr BP, a period of regional drought (see below), UC and RA had fewer fires relative to the modern fire regime (ie, 2000 cal BP to present). LI and PO show the opposite trend.

▪ Effective moisture at Takahula Lake (4) reveals a regional drought centered at 4000 cal yr BP.

▪ Composite pollen and fire records with confidence intervals (+/- 2 std error). Millennial-scale changes in regional vegetation are consistent with regional moisture trends. For example, white spruce expands ~ 3 ka, coincident with increased inferred moisture.

CONCLUSIONS

❖ Sediment charcoal records detect known tundra fires and reveal frequent fires in the past.

❖ Climate change can explain regional vegetation patterns, but site-specific variability indicates the importance of local-scale factors.

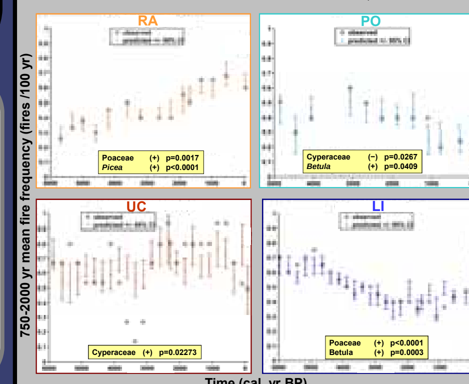
❖ The impacts of Holocene climate change on fire history differed between sites and can be explained largely by variation in local vegetation.

6. Fire-Vegetation Relationships

▪ Multiple linear regression was used to model mean fire frequency at 750-2000 yr time scales as a function of pollen percentages. Variations in pollen from 1-2 taxa explained 17-83% percent of the variability in fire frequency through time, suggesting that disparate fire histories between sites may be explained by changes in local vegetation.

		RA	UC	PO	LI
		r	r	r	r
Taxa-specific correlations	*Picea*	***0.83***	--	--	***-0.57***
	Betula	***-0.75***	-0.22	0.58	0.55
	Alnus	***-0.73***	--	--	***-0.56***
	Cyperaceae	--	0.45	-0.63	--
	Poaceae	***0.50***	--	--	0.70
Multi-taxa model	Model r^2_{adj}	0.832	0.165	0.544	0.676
	Model p_{adj}	0.002	0.009	0.002	0.004
	$Window_{max\ cor}$	2000 yr	750 yr	1000 yr	2000 yr

Table: Significant correlations between pollen types and fire frequency at each site. Bold/italic values = $p < 0.05$; plain text = $p < 0.10$. Yellow boxes = results from multi-taxa models at each site, with the included taxa indicated in model plots. Correlations and models presented with the time scale that maximized r^2_{adj} ($Window_{max\ cor}$).

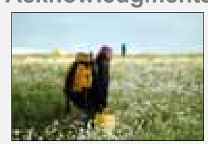


Plots: Predicted (+/- 95% CI) and observed fire frequency based on the best model at each site. Species included in each model are listed with direction of relationship to fire frequency (positive [+] or negative [-]) and p-value.

▪ Most sites exhibit strong vegetation-fire relationships, with over half of the variability in fire frequency explained by *Picea*, *Betula*, Poaceae, and Cyperaceae. Unexplained variance at UC may be related to documented human presence in the watershed, which may have modified local vegetation or fire.

▪ Taxa best predicting fire frequency differed between sites, reflecting variability in local vegetation. The positive relationships with Poaceae and *Betula* in multi-taxon models are consistent with the flammability of these taxa in modern and other paleo settings (*1*).

Acknowledgments



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