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Fires and forests: A reconstruction of Holocene fire vegetation relationships in Central Yakutia, Siberia

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Background

- After extreme fire seasons, **Central Yakutia is now among the most fire-prone regions** of eastern Siberia and the whole boreal zone. It is predicted that **fire regimes will further intensify**
- The unique **deciduous and larch-dominated boreal forest** of eastern Siberia provides many important ecosystem services: It protects permafrost from degradation, contains resources and infrastructure, and is home to millions of people, including indigenous communities
- **Long-term feedbacks** between **changes in fire regimes and forest structure** and composition are not yet well understood. Data on **long timescales** is scarce, but needed for thorough evaluation

Q: Can we identify long-term regional relationships between changing fire regimes and boreal forest structure?

Methods

- **Sediment core** (120 cm) from thermokarst lake Satagay, spanning the last c. 10,800 years
- **For reconstructing wildfires:** 1) **Macroscopic charcoal particles** (>150 µm) extracted by wet-sieving sediment samples, bleaching [1] (for all 111 samples); 2) **Microscopic charcoal particles** (< 150 µm) on pollen slides (for 12 samples)
- **For reconstucting vegetation composition:** 1) **REVEALS-transformed pollen record** [2, 3] (for 48 samples); 2) **Sedimentary ancient DNA** (sedDNA) of terrestrial plant metabarcoding (for 61 samples)

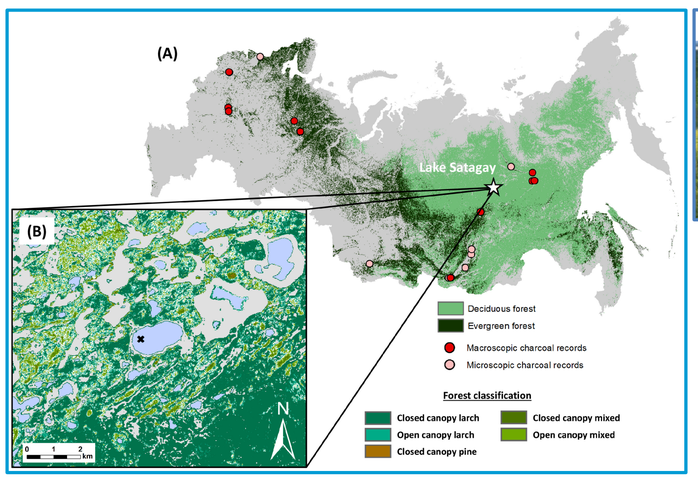

Figure 1 (top): Drone view of Lake Satagay (facing towards SE; S. Kruse)

Figure 2 (left): (A): Location of Lake Satagay in Russia (evergreen/deciduous forest classification based on © ESA Climate Change Initiative LLC via CEDA. Red dots mark available sedimentary charcoal data (extracted from Global Paleofire Database, only sites where data was provided, see [4]). **(B):** Lake Satagay and its surrounding vegetation, based on land cover classification from Sentinel 2 acquisitions with ground truthing from expedition observations ([5, 6, 7])

Photos from the 2021 joint German-Russian expedition to Central Yakutia, where an extraordinary fire season occurred.
Top left photo: R. Jackisch;
all others: R. Glückler

Results and Discussion

- **Reconstructed wildfire activity:** High amounts of biomass burned in Early Holocene (c. 9600 yrs BP), followed by intermediate phase, with modern, low-severity fire regime since c. 4500 yrs BP
- **Reconstructed vegetation composition:** Early Holocene dominated by larch/birch woodland and grasses. Typical disturbance indicators (*Populus*, fireweed) identified by sedDNA. In Mid-Holocene forest composition becomes more mixed with introduction of *Pinus* (c. 5400 yrs BP) and more Cyperaceae. Late Holocene is characterized by fewer grasses and a dense, larch-dominated forest
- We suggest: **Early to Mid-Holocene fire regime changes** driven by **long-term vegetation shifts** & modified by **short-term fire weather** variations. In **modern forest state**, **climate** becomes main driver

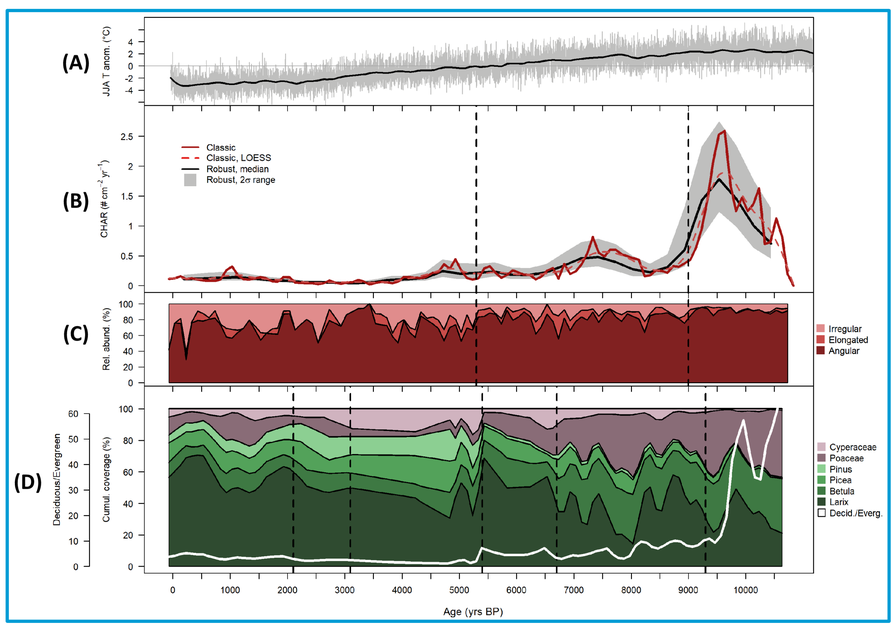

Figure 3 (left):
(A): TraCE 21ka climate model data [8] for Lake Satagay, displayed as annual June-August (JJA) temperature anomaly. **(B):** Classic and robust charcoal accumulation rates (CHAR), with zone separations from cluster analysis. **(C):** Relative abundance of charcoal morphotype classes, with zone separations from cluster analysis. **(D):** Coverage of the most prominent vegetation types from the REVEALS-transformed pollen data, interpolated to match the median temporal resolution of the displayed charcoal data and with zone separations from cluster analysis (applied to interpolated data)

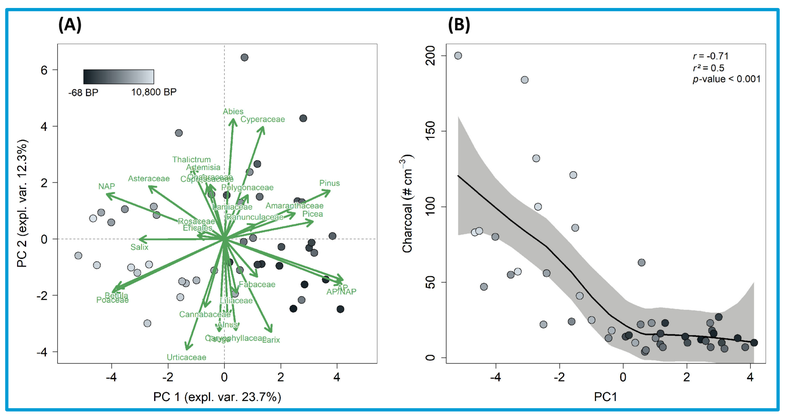

Figure 4 (left):
(A): Principal component analysis (PCA) of REVEALS-transformed pollen types. PC1 differentiates between Early Holocene open woodlands (negative values) and Late Holocene, dense larch forest (positive values). **(B):** Scatterplot and correlation of macroscopic charcoal concentration and principal component 1 (PC1) of the PCA, with locally estimated scatterplot smoothing (LOESS)

Early Holocene state	Late Holocene state	
High	Low	**Amount biomass burnt**
Open woodlands	Dense forest	**Forest structure**
Larix/Betula + Populus	*Larix + Picea/Pinus/Betula*	**Forest composition**
More Poaceae, fireweed	More Cyperaceae	**Grassland composition**
Warmer	Colder	**Temperature**

The **„open woodland-fire feedback“** hypothesis:
Increased tree mortality may push the forest towards its Early Holocene state

Fires / Extreme weather / Insects

Outlook

- Considering an **anticipated increase in tree mortality**, potentially leading to sparser tree populations, our results point towards a possible **positive feedback on currently intensifying fire regimes in Central Yakutia**
- The presence of a dense larch forest might be still **mediating the true extent of the climate-induced fire regime intensification** observed during the last decade
- **Ecological modelling** should test and constrain this “open woodland-fire feedback” hypothesis, whereas **spatially extended paleoenvironmental information** could tell whether the suggested feedback at Lake Satagay applies to regional or ecosystem-wide scales. Will changes happen gradually or display tipping point-like behavior?

http://qrcc.me/rc4mq3CC

Additional figures

References: **[1]:** Glückler et al. (2021): Wildfire history of the boreal forest of south-western Yakutia (Siberia) over the last two millennia documented by a lake-sediment charcoal record. BG; **[2]:** Sugita (2007): Theory of quantitative reconstruction of vegetation I: pollen from large sites REVEALS regional vegetation composition. The Holocene; **[3]:** Theuerkauf et al. (2016): A matter of dispersal: REVEALSinR introduces state-of-the-art dispersal models to quantitative vegetation reconstruction. Veget Hist Archaeobot; **[4]:** Power et al. (2010): Fire history and the Global Charcoal Database: A new tool for hypothesis testing and data exploration. PPP; **[5]:** Kruse et al. (2021): SiDroForest: Orthomosaics, SfM point clouds and products from aerial image data of expedition vegetation plots in 2018 in Central Yakutia and Chukotka, Siberia. PANGAEA; **[6]:** van Geffen et al. (2021): SiDroForest: A comprehensive forest inventory of Siberian boreal forest investigations including drone-based point clouds, individually labelled trees, synthetically generated tree crowns and Sentinel-2 labelled image patches. ESSD Discussions [Prepr.]; **[7]:** Geng et al., 2022 [Subm.]; **[8]:** He (2011): Simulating transient climate evolution of the last deglaciation with CCSM3 [Diss.]

Let‘s keep in touch!

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