Late-Holocene climate variability and ecosystem responses in Alaska inferred from high-resolution multiproxy sediment analyses at Grizzly Lake

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ABSTRACT

The late-Holocene shift from *Picea glauca* (white spruce) to *Picea mariana* (black spruce) forests marked the establishment of modern boreal forests in Alaska. To understand the patterns and drivers of this vegetational change and the associated late-Holocene environmental dynamics, we analyzed radiocarbon-dated sediments from Grizzly Lake for chironomids, diatoms, pollen, macrofossils, charcoal, element composition, particle size, and magnetic properties for the period 4100–1800 cal BP. Chironomid assemblages reveal two episodes of decreased July temperature, at ca. 3300–3150 (ca −1 °C) and 2900–2550 cal BP (ca −2 °C). These episodes coincided with climate change elsewhere in the Northern Hemisphere, atmospheric reorganization, and low solar activity. Diatom-inferred lake levels dropped by ca. 5 m at 3200 cal BP, suggesting dry conditions during the period 3200–1800 cal BP. *P. glauca* declined and *P. mariana* expanded at ca. 3200 cal BP; this vegetational change was linked to diatom-inferred low lake levels and thus decreased moisture availability. Forest cover declined at 3300–3100, 2800–2500 and 2300–2100 cal BP and soil erosion as inferred from increased values of Al, K, Si, Ti, and Ca intensified, when solar irradiance was low. Plant taxa adapted to disturbance and cold climate (e.g. *Alnus viridis*, shrub *Betula*, *Epilobium*) expanded during these periods of reduced forest cover. This open vegetation type was associated with high fire activity that peaked at 2800 cal BP, when climatic conditions were particularly cold and dry. Forest recovery lagged behind subsequent climate warming ($\leq$+3 °C) by ca. 75–225 years. Our multiproxy data set suggests that *P. glauca* was dominant under warm-moist climatic conditions, whereas *P. mariana* prevailed under cold-dry and warm-dry conditions. This pattern implies that climatic warming, as anticipated for this century, may promote *P. glauca* expansions, if moisture availability will be sufficiently high, while *P. mariana* may expand under dry conditions, possibly exacerbating climate impacts on the fire regime.

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1. Introduction

Long time series such as those provided by paleorecords offer the possibility to place recent and anticipated climate change and its impacts in the context of natural variability. Understanding long-term ecosystem variability is important to identify sensitivities, thresholds, and tipping points of ecosystem elements, such as vegetation or the fire regime (Willis and Birks, 2006). Because environmental changes are often nonlinear, abrupt state changes may occur when critical thresholds are crossed. Following such changes, the ecosystem may recover only slowly or not at all, with

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significant consequences for biodiversity and other ecosystem properties (Overpeck et al., 2003; Willis et al., 2010).

In Alaska, vegetation responses to Holocene climate change exhibited threshold effects, in some cases causing the displacement of plant community types, and in other cases provoking transient shifts including conversions from tundra into boreal forest and *vice versa* (Tinner et al., 2008). Such knowledge may be used as a baseline for conservation and management decisions regarding anticipated future vegetation shifts, but uncertainties in our understanding of patterns and drivers in ecological change often diminish the value of paleoecological evidence for global change assessments. For instance, the early-Holocene heliophilous *Populus* communities were displaced by white spruce (*Picea glauca*) forests about 10,000 years ago in central Alaska, and the latter were subsequently reduced by the mid to late-Holocene expansion of black spruce (*Picea mariana*) forests (e.g. Hu et al., 1996). Climate change, particularly increasing moisture, may have caused the early-Holocene rise of white spruce forests, but the mechanism of the black spruce expansion remains uncertain (Lloyd et al., 2006). High-resolution, multiproxy records for paleoecological and paleoclimatic reconstructions are necessary for disentangling the controlling factors of past ecosystem variability, and are thus crucial for improving the contribution of paleorecords to assess future climate-impact dynamics. Despite their importance, such records remain limited because of the exceptional labor and time intensity they entail.

We analyzed sediments of the period 4100–1800 cal BP from Grizzly Lake in south-central Alaska (Fig. 1) for a suite of complementary indicators of past climatic and ecological changes. Pollen, spore, and macrofossil assemblages were used to infer vegetation dynamics; microscopic and macroscopic charcoal to reconstruct past fire activity; chironomids to quantitatively derive mean July air temperature; diatoms to estimate past lake levels as a proxy for precipitation/evaporation; and magnetic, grain size, and elemental analyses to assess watershed soil erosion, slope stability, and ecosystem productivity. These analyses reached high to ultrahigh resolutions (ca. 50–1 yr/sample). We chose to focus on the period 4100–1800 cal BP because it encompasses marked changes in

climate and environments in our study region (e.g. Denton and Karlén, 1973; Calkin et al., 2001; Barclay et al., 2009; Clegg et al., 2010) and in other parts of the world (Chambers et al., 2007; Swindles et al., 2007). We concentrated on disentangling temperature and moisture responses, and elucidating vegetation responses to climate and disturbance (e.g. fire, erosion). Our results offer new information on the Holocene establishment of boreal forests dominated by black spruce.

2. Study site

Grizzly Lake (62°42′38″ N, 144°11′57″ W) is located in south-central Alaska at an altitude of 720 m a.s.l. (Fig. 1), with a surface area of ca. 11 ha and a maximum water depth of ca. 8 m. The lake is a topographically closed basin with no major inlet and outlet and is surrounded by boreal forests. *P. mariana* dominates the forests in the plains south of the lake, while *P. glauca* is common on the slopes north of the lake, forming treeline at ca. 900–1000 m a.s.l. Above timberline *Alnus viridis* (green alder) thickets grow up to about 1100 m a.s.l. Additional site information is available in Tinner et al. (2006, 2008).

3. Material and methods

3.1. Coring, sediments and dating

Parallel sediment cores (including GYA, GYE, and GYF, see Table 1) were taken with a Livingstone piston corer (Wright et al., 1984) from the deepest point of the lake. The cores were correlated with lithostratigraphy, with an average precision of ca. 1 cm. The sediment was described following the Troels-Smith scheme (Aaby and Berglund, 1986). Four AMS (Accelerated Mass Spectrometry) ^{14}C ages on terrestrial plant macrofossils were obtained from the Grizzly Lake sediments spanning the time interval of interest (Table 1). The ^{14}C ages were recalibrated with the program Calib version 7.0.2 (Reimer et al., 2013) for comparison with the original chronology using Calib version 5.01, as presented in Tinner et al. (2006). Subsamples for the different proxies were collected on
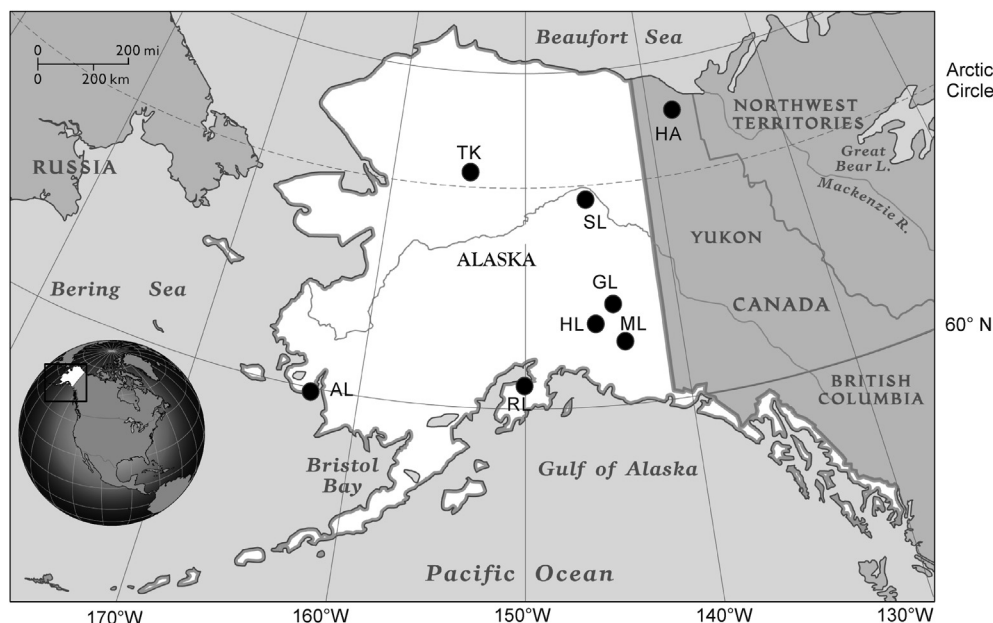

Fig. 1. Map of Alaska showing the location of Grizzly Lake and other important study sites. GL = Grizzly Lake, AL = Arolik Lake, HA = Hanging Lake, HL = Hudson Lake, ML = Moose Lake, RL = Rainbow Lake, SL = Screaming Lynx Lake, TK = Takahula Lake.