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Recent and Holocene climate change controls on vegetation and carbon accumulation in Alaskan coastal muskegs

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ABSTRACT

Pollen, spore, macrofossil and carbon data from a peatland near Cordova, Alaska, reveal insights into the climate–vegetation–carbon interactions from the initiation of the Holocene, c. the last 11.5 ka, to the present (1 ka = 1000 calibrated years before present where 0 = 1950 CE). The Holocene period is characterized by early deposition of gyttja in a pond environment with aquatics such as *Nuphar polysepalum* and *Potamogeton*, and a significant regional presence of *Alnus crispa* subsp. *sinuata*. Carbon accumulation (50 g/m^2/a) was high for a short interval in the early Holocene when *Sphagnum* peat accumulated, but was followed by a major decline to 13 g/m^2/a from 7 to 3.7 ka when Cyperaceae and ericads such as *Rhododendron* (formerly *Ledum*) *groenlandicum* expanded. This shift to sedge growth is representative of many peatlands throughout the south-central region of Alaska, and indicates a drier, more evaporative environment with a large decline in carbon storage. The subsequent return to *Sphagnum* peat after 4 ka in the Neoglacial represents a widespread shift to moister, cooler conditions, which favored a resurgence of ericads, such as *Andromeda polifolia*, and increased carbon accumulation rate. The sustained *Alnus* expansion visible in the top 10 cm of the peat profile is correlative with glacial retreat and warming of the region in the last century, and suggests this colonization will continue as temperature increases and ice melts.

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1. Introduction

Peatlands store up to one third of the global soil carbon (C) pool, are abundant at high latitudes where climate change is strongly felt, and are particularly sensitive to climate shifts (Gorham, 1991; MacDonald et al., 2006). Quantifying future shifts in C sequestration as climate warms is challenging because warmer temperatures foster both increased production and decomposition (Gorham, 1991). However, not surprisingly, biota has been shown to play a decisive role in controlling peatland C dynamics at the species, community, and ecosystem levels (Kuiper et al., 2014). Thus, exploring the relationship between carbon accumulation rate (CAR), the net storage after production and decomposition, and

detailed vegetational shifts that cause these peatland C storage changes can help us to predict future carbon stores as climate-driven vegetational shifts occur. In particular, Alaska is projected to have increased precipitation in a warming world (Christensen et al., 2007), and the maritime south-central coast is a region that today already receives abundant moisture, providing a key analog as a region warmer and wetter than much of the rest of the boreal and Arctic zones. This region is also of interest because it has active glacial recession (Wiles et al., 2014), and represents a spatial gap in our southern coastal study of peatland paleovegetation and carbon (Peteet, 1986, 1991; Peteet and Mann, 1994; Jones et al., 2014; Nichols et al., 2014). In addition, the AMS C-14 dates on *Picea* and *Tsuga* macrofossils provide a robust record of conifer migration northward in a changing Holocene climate.

Paleoecological studies in maritime coastal Alaska take advantage of abundant peatlands. The Algonquins first referred to these peatlands as "muskeg," a term used extensively by Rigg (1914), Dachnowski-Stokes (1941), and Heusser (1960). These soligenous,

topogenous, and ombrogenous muskegs are adjacent to active glaciers, where processes of active glacial advance and retreat occur on human timescales (Tarr and Martin, 1914). Previous pollen and spore studies along this coastline provide a stratigraphic archive of vegetational shifts resulting from both climate change and tree migration (Heusser, 1960, 1983; Heusser et al., 1985; Peteet, 1986, 1991). Macrofossils provide detailed, site-specific records of *in situ* response to moisture that can be reliably dated and then compared with nearby lake and peatland records (Peteet, 1986, 1991).

For Corser Bog, south-central Alaska, Nichols et al. (2014) produced an independent record of hydroclimate and temperature change using the distributions and hydrogen isotope ratios of leaf wax biomarkers and the distributions of branched glycerol dialkyl glycerol tetraether lipids (brGDGTs). We found that relative changes in reconstructed temperature in the peatland are broadly correlative with changes in glacial ice extent documented for south-central Alaska. We also examined the role of carbon storage with change in peat type in Corser Bog, and found a marked increase in carbon storage when *Sphagnum* peat was present compared to sedge peat. However, more detailed vegetational history was lacking. Pollen, spores, and macrofossil identification here will reveal detailed vegetation shifts and attendant climatic inferences, which we can then compare to those made from organic geochemical data.

2. Study site

The Copper River Delta is one of the largest coastal wetlands on the Pacific coast, extending some 200 km from Hinchinbrook to Kayak Island in southeast Alaska. Sandwiched between the Delta and the Chugach Mountains, Corser Bog (Fig. 1) at 42 m asl is located in the gently sloping peatland area between Cabin Lake and Corser Lake, about 21 km east of the town of Cordova, AK. Today the peatlands are very open landscapes, dominated by *Sphagnum* moss, *Carex*, *Andromeda polifolia*, *Gentiana douglasiana*, and surrounded by the three dominant conifers − *Picea sitchensis*, *Tsuga heterophylla*, and *Tsuga mertensiana*.

Underlying the peatlands are Paleogene sedimentary rocks (Winkler and Plafker, 1993). The entire area endures repeated subsidence and uplift (Plafker et al., 1993) and was uplifted 2 m during the 1964 earthquake (Plafker, 1969). This extremely dynamic tectonic regime presents an unusual background for the vegetational and climate history of the region, as it is possible that rapid uplift of the coast might provide colonization territory for vegetational pioneers such as ferns, *Alnus viridis* subsp. *sinuata* (formerly *Alnus crispa*), and migrating conifers.

Climate of the region is maritime, with moderate temperatures (avg. 3.5 °C with −4.1 °C in January and 12.5 °C in July) and abundant precipitation in the form of rain (2.3 m) and snow (3 m) according to records from the nearby Cordova airport (Leslie, 1989; usclimatedata.com). Precipitation falls throughout the year, but September and October usually record peak values.

The modern vegetation is comprised of coastal conifers (*Picea sitchensis* (sitka spruce), *Tsuga heterophylla* (western hemlock), and *Tsuga mertensiana* (mountain hemlock) along with blanket muskeg. *Picea sitchensis* is largely coastal, *Tsuga heterophylla* prefers more organic soils, and *Tsuga mertensiana* thrives mostly farther from the coast and at timberline, with extensive growth of ferns, such as *Athyrium filix-femina* subsp. *cyclosorum,* in avalanche tracks (Heusser, 1960). A study of early successional dynamics by Lutz (1930) documents the rapid invasion of *A. crispa* var. *sinuata* along with *P. sitchensis* and *T. mertensiana* on the Sheridan glacier outwash. He mentions *Lupinus* and *Equisetum* along with mosses as early colonizers. Cooper (1942) provides a complete account of the

forelands of nearby Prince William Sound. Muskeg is interspersed there with shallow lakes and conifer forest, and the muskeg flora is comprised of *Sphagnum* moss as well as herbs such as *Scirpus caespitosus, Carex pauciflora, Cornus canadensis, Geum calthifolium, Empetrum nigrum, A. polifolia, Oxycoccus microcarpus,* and *Drosera rotundifolia.* Hollows in the muskeg support a few aquatics and emergents, such as *Nuphar polysepalum* (water lily) and *Myrica gale* var. *tomentosa.* Alpine tundra extends over a large part of the district between timberline and the glaciers, and strand-dune communities are continuous along the coast.

3. Methods

Two cores were extracted from the Corser peatland with a 10-cm diameter, tripod-mounted modified Livingstone piston corer in five successive drives for each. They were wrapped in plastic food wrap and aluminum foil, refrigerated, and stored at Lamont Doherty Earth Observatory (LDEO). Core B, 3.72 m in depth, was chosen for analysis. Core A showed similar stratigraphy, but was approximately 0.5 m shorter. The core was split and imaged in the LDEO respository with a Geotek linescan camera, and samples taken for loss-on-ignition (LOI) at 2-cm intervals throughout, dried at 100 °C to estimate moisture content and then burned at 550 °C for 2 h using standard procedures (Dean, 1974). LOI and bulk density measurements were multiplied to calculate ash-free bulk density. Carbon content was calculated from the ash-free bulk density by multiplying by 0.423 in *Sphagnum* peat and 0.511 in sedge peat (Loisel et al., 2014).

Samples for pollen and spore analysis (1 cm³) were taken every 1 (upper 10 cm), 5 or 10 cm throughout the core, and extraction followed a modified Faegri and Iverson (1989) methodology involving KOH, acetolysis, ethanol and tertiary butyl alcohol washes, and immersion in silicone oil. 1 tablet of marker *Lycopodium* spores (x = 10,679) was added to each sample. Identification was performed at 400X magnification with a minimum of 300 terrestrial pollen grain counts. Fossil spores were counted in addition to the 300 pollen grain sum, and spores are plotted as percentage of the pollen and spore sum. All grains were identified using the LDEO modern reference collection from south-central Alaska as well as published pollen references (Hebda, 1979; Faegri and Iverson, 1989). Contiguous macrofossil samples were selected every 5 cm or 10 cm (20 cc), wet-sieved using screens of 125 and 500 microns, and the residue picked in water at magnification of 20-60X. Reference material from Alaska, including an extensive seed collection, aided identification. All pollen and macrofossil data were plotted in Tiliagraph (Grimm, 1992).

Statistical analyses were performed using the R statistical computing environment (R Core Team, 2014). To reduce the dimensionality of the paleoecological data and define groups of similar samples, principal components analysis by singular value decomposition was performed on the pollen and spore dataset using the function prcomp(). A hierarchical cluster analysis by Ward's method was also performed on a Euclidean distance matrix of the pollen and spore data using the functions dist() and hclust(). We chose this method of clustering our data rather than the traditional, incremental sum-of-squares, depth-constrained method (Grimm, 1992). Our goal was not necessarily to identify shifts in vegetation composition alone, but to group similar samples together, irrespective of their stratigraphic position. Our analysis thus looks for similarities rather than differences. The ecological implication of using this method is that we do not assume that the vegetational assemblage always changes to a new state and we allow the system to shift back to a vegetational assemblage whether or not that assemblage had previously occupied the site.