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Assessing the effects of climate change and land use on northern Labrador forest stands based on paleoecological data

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A B S T R A C T

We reconstructed the late Holocene vegetation of the Nain region (northern Labrador, northeastern Canada) in order to assess the influence of climate and historic land use on past shifts in forest composition. Chronostratigraphy was used in combination with macrofossil and pollen data from monoliths sampled from four peatlands. Paleoecological reconstructions produced a vegetation history spanning 4900 years for the Nain region that is largely concordant with other studies in Labrador. An initial open forest tundra phase was followed by an increase in tree cover at around 2800 cal yr BP. Paludification began ~200 cal yr BP. A decline in *Picea* and its subsequent disappearance from most of the sites occurred ~170 cal yr BP (AD 1780) in a period of relatively mild conditions during the Little Ice Age. This event was followed by the establishment of *Larix laricina* in the region. Local anthropogenic factors are likely responsible for these later developments, as they were not observed in other regional studies. The period around AD 1780 corresponds to the establishment of the Moravian missionaries on the Labrador coast, which increased the need for fuel and lumber. We conclude that changes in land use are reflected in the patterns of vegetation and hydrological change at the study sites.

Introduction

Paleoecological studies provide an important long-term perspective that may be useful for assessing contemporary ecological structures, patterns, and processes (Birks, 1996; Swetnam et al., 1999; Willis and Birks, 2006; Willis et al., 2007; Josefsson et al., 2010; Lindbladh et al., 2013). When combined with historical records such as archives, oral histories and archaeological data, paleoecological proxies can contribute to our understanding of how the natural landscape was shaped by human land use (and vice-versa) at decadal, centennial, and millennial scales (Gaillard et al., 1992; Neil et al., 2014).

Significant climate change events took place during the late Holocene in the eastern Arctic and Subarctic regions of Canada. The "Little Ice Age" (LIA) spanned the 14th to 19th centuries and is considered to be a defining climatic feature of that period. Data from the GISP2 and GRIP ice core projects and dendroclimatic reconstructions indicate that this period was characterised by high climate variability rather than intense and sustained cooling (Dansgaard et al., 1993; D'Arrigo and Jacoby, 1993; Mayewski et al., 1994; Meese et al., 1994; MacDonald, 2009). There were two main periods of cold climate during the LIA: the first occurred in the mid-17th century and lasted until the 1730s and the second occurred from 1815 to the 1870s (Overpeck et al., 1997; Barlow, 2001; D'Arrigo et al., 2003). In Labrador, late Holocene climate variability triggered significant shifts in key environmental systems, most notably the extent and duration of seasonal sea ice and the distribution and structure of plant communities (Newell, 1990; D'Arrigo et al., 2003).

Concurrent with the climate variability associated with the LIA, the late 18th century was also marked by the settlement of Europeans in northern Labrador (Brice-Bennett, 1977). The establishment of permanent Moravian missions in Nain and elsewhere in coastal Labrador had a significant impact on Inuit land use patterns and Inuit society in general (Brice-Bennett, 1977; Kaplan, 2012). For example, Moravian influence led to the use of above-ground houses made of locally harvested wood by the late 19th century rather than the Inuit traditional sod winter houses. Furthermore, these poorly insulated log and plank houses were heated with wood-burning stoves, which would have further increased wood cutting activity

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in the region. The Inuit also traded wood with the Moravians for their heating needs (Brice-Bennett, 1981; Lemus-Lauzon et al., 2012). This rapid and significant increase in local wood harvesting would have altered the subarctic forest stands of the Nain region. However, very little is known about the effects of such human activities on the broader forest landscape.

At our study sites in the Nain region (Nunatsiavut, Labrador), paleoecological reconstructions were used to link regional vegetation history to historical patterns of forest use in the context of climate variation and socio-economic change. In particular, chronostratigraphy was combined with macrofossil and pollen data from peat monoliths sampled in four peatlands. Our primary objectives were: 1) to establish a high-resolution paleoecological reconstruction of local and regional ecosystem dynamics during the late Holocene (with a focus on the period from AD 1700 to the present day), and 2) to document the impact of human land use on forests in the region during the same period.

Study region and sites

The study area is located in northeastern Canada and is part of the Nain coast ecodistrict (Notzl and Riley, 2013) (Fig. 1). Nain (56° 32.501′N; 61° 41.816′W) is an Inuit coastal community in northern Labrador. The region is part of the discontinuous permafrost zone (Brown et al., 2001) and lies on the Precambrian Shield, which is characterized by metamorphic gneiss bedrock and igneous anorthosite outcrops. The region was covered by the Laurentide Ice Sheet during the last glaciation until 8500 cal yr BP (Dyke, 2004). The Labrador Sea submerged the land to an altitude of approximately 70 m (Clark and Fitzhugh, 1990). The coastal landscape is characterized by glacial fiords, an extensive island archipelago and a mountain range that runs parallel to the coast (with summits of 750–1200 m).

The Labrador coast is a transition zone between arctic and subarctic climate regions. The climate is strongly influenced by atmospheric and oceanic circulation patterns, in particular the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), and the El Niño-Southern Oscillation (Gustajtis, 1979; Newell, 1990; Way and Viau, 2014). The conjunction of these systems creates high levels of precipitation and multi-scale climate variability in the region (D'Arrigo et al., 2003; Way and Viau, 2014). The annual mean temperature is −3 °C and the annual mean precipitation is 893 mm, with more than 50% falling as snow (Environment Canada, 2015).

The study area is located ~100 km south of the northern margin of the contemporary boreal forest-tundra ecotone (Payette, 1983). The tree line is at Napaktok Bay, although isolated *Picea* (spruce) stands are found farther north to the interior of the Hebron region, and a handful of small (<0.5 ha) *Populus balsamifera* (balsam poplar) groves are present as far north as Saglek Fiord (Fig. 1) (Elliot and Short, 1979; Payette, 2007). Closed canopy forests grow in the floor of the valley, where soil conditions are favourable and the environment is more protected. Dominant tree species are black spruce (*Picea mariana* [Mill.] B.S.P.), white spruce (*Picea glauca* [Moench] Voss), and eastern larch (*Larix laricina* [Du Roi] K. Koch). Black spruce is also found at higher altitudes and in exposed coastal areas in the form of krummholz (stunted) trees (Payette, 1983). Shrub vegetation is represented by berry heaths (notably *Empetrum nigrum* and *Vaccinium* sp.), dwarf birch (*Betula glandulosa*), Labrador tea (*Rhododendron groenlandicum*, *R. tomentosum*), alder (*Alnus* sp.), and various willows (*Salix* sp.).

Archaeological research has documented a continuous aboriginal presence in Labrador since about 7000 cal yr BP (Hood, 2008). The Thule, who were the direct ancestors of the Inuit, arrived in Labrador between the late 13th and 15th centuries and established winter camps in the outer coastal zone in proximity to the open ocean (Kaplan, 1983; Fitzhugh and Lamb, 1985). Permanent contact with Europeans began in the late 18th century when Moravian missionaries established several settlements along the coast, including one at Nain in 1771. By the 1950s, all of the inhabitants of communities to the north of Nain and the smaller neighbouring settlements were relocated by the government (except for Killinek, which was closed in the late 1970s). Today, Nain is the largest community of Nunatsiavut, the Inuit territories of Labrador. It has a population of approximately 1200, of whom 90% are Inuit (Statistics Canada, 2011).

Following extensive surveys in the Nain region, four peatlands were selected and sampled for paleoecological analysis: Nain1, Nain2, KAM, and WB (Fig. 1 and Table 1). The sites were chosen for their accessibility, their location near a permanent human settlement of some importance, and the presence of >30 cm of peat accumulation. Nain1 and Nain2 are both located in the vicinity of Nain in two parallel valleys bordering the community. The KAM site is located in the Voisey's Bay area approximately 30 km south of Nain in a former small settlement known as Kammâsuk. The WB peatland is in Webb's Bay, which is another small historic settlement located about 30 km north of Nain. The two outlying sites (KAM and WB) represent a contrast with the Nain sites because the scale and duration of land use there was limited because they were occupied for a shorter time. All of these sites were minerotrophic peatlands in which the contemporary vegetation includes sedges (*Carex* sp., *Eriopohorum* sp.) brown mosses, *Sphagnum*, and shrubs (Ericaceae, *Betula glandulosa*). Many larch trees and saplings grow within the peatlands and around the edges, while black spruce has a more limited presence (see Fig. 2).

Methods

The four peatlands were sampled during the summers of 2010 and 2011. In total, four monoliths were excavated down to the level of the mineral substrate using a shovel (one per site, ranging between 28 cm and 64 cm thick). The stratigraphy of the peat was documented and each monolith was cut into sections that were wrapped in foil and plastic bags for transportation to the laboratory. To avoid contamination, each section was cleaned in the laboratory by removing a layer approximately 1 cm thick from the external surface. The on-site vegetation was also inventoried and the main taxa were identified.

Macrofossil analysis was conducted following the protocol outlined by Bhiry and Filion (2001). Each 1 cm thick slice contained 25 cm^3 of organic sediment. Sediments were treated with a weak 5% aqueous KOH solution and boiled for a few minutes to deflocculate. The material was then wet-screened through a series of sieves (850, 425, and 180 μm meshes).

Given that our research was focused on a specific historical period (1700-present day), we analysed the upper part of the monoliths either in a continuous manner, that is every cm, or at 2 cm intervals. Thus, for the Nain1 monolith, we used the following intervals: 1 cm at the top section (0–16 cm), 2 cm in the top-middle section (17–32 cm) and 4 cm at the lower half section (32–64 cm). For the Nain2 monolith, the intervals were 2 cm between 0 and 16 cm and 4 cm between 16 and 35 cm; for KAM, the intervals were every cm between 14 and 21 cm and 2 cm from 22 to 40 (0–14 cm consists of present day vegetation); and for WB, the analysis intervals were every cm between 7 and 15 cm and 2 cm from 15 to 30 cm (0–7 cm consists of present day vegetation).

Macrofossils were identified under a binocular microscope at magnifications between 4× and 40×. Bryophytes present in the organic matrix were identified and their respective percentages were calculated relative to the total volume of the section (25 cm^3). The remains of vascular plants and aquatic invertebrates were