Quaternary Science Reviews 75 (2013) 169–180

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Climatic change causes abrupt changes in forest composition, inferred from a high-resolution pollen record, southwestern Quebec, Canada

Nathalie Paquette, Konrad Gajewski*

Laboratory for Paleoclimatology and Climatology, Department of Geography, University of Ottawa, Ottawa, ON K1N 6N5, Canada

ARTICLE INFO

Article history:
Received 12 September 2012
Received in revised form
30 May 2013
Accepted 12 June 2013
Available online 15 July 2013

Keywords:
Varves
Quebec
Holocene
Pollen
Forest dynamics
Paleoclimate reconstruction
Charcoal
Eastern deciduous forest
Lake sediments

ABSTRACT

A pollen profile from a lake with varved sediments sampled at continuous 10-year intervals and spanning the past 1000 years was analyzed to understand the effects of climate change and anthropogenic activity on forests in southwestern Quebec. Pollen assemblages were dominated by arboreal taxa, primarily *Pinus*, *Tsuga*, *Betula* and *Fagus*. Between 990 and 1560 AD, pollen accumulation rates and percentages of hardwoods (*Betula*, *Fagus*, *Acer*, *Ulmus*, *Tilia*) and *Tsuga* were relatively high. At 1560 AD, PARs of many hardwood taxa (*Fagus*, *Acer*, *Betula*, *Fraxinus*, *Ulmus*) and *Tsuga* abruptly decreased, some remaining low for the remainder of the record (*Tsuga*, *Fagus*, *Acer*), but others increasing after 50 years (*Betula*, *Fraxinus*). An increase in non-arboreal pollen between 1810 and 2010 AD was caused by European settlement of the area. The transition in the pollen assemblages beginning at 1560 AD and a climate reconstruction based on these data shows an abrupt climate cooling had a significant impact on the pollen accumulation rates of the region within a couple of decades. A synthesis of this record with other high-resolution and well-dated pollen data from the conifer-hardwood forest of eastern North America shows consistent results across the whole area, indicating that very-high resolution pollen data can provide insight into multi-decadal climate variability and its impact on forest vegetation.

1. Introduction

Ecological studies are documenting impacts of global warming on ecosystems around the world, such as range extensions of species into new areas. In the deciduous forest of eastern North America, as well as elsewhere in the world, discerning present-day climate impacts on the vegetation is complicated by the changes in the forest over the past centuries caused by human activities, such as succession after farm abandonment. Many studies have shown the impact of European (e.g. Whitney, 1994) or Native American (e.g. McAndrews and Boyko-Diakonow, 1989; Bunting et al., 1998; Munõz and Gajewski, 2010) activities on the forest composition. In addition, climate variability of the past few millennia has impacted the forests, although details about vegetation–climate interactions at decadal to century scales are not well understood. For example, Gajewski (1987), Finkelstein et al. (2005) and Houle et al. (2012) showed that recent changes in the composition of the conifer-hardwood forests of eastern North America, previously attributed to land-use changes associated with agriculture or to pollution, were actually initiated centuries before the European settlement of the area, and could be associated with late Holocene climate variability, such as the Little Ice Age (~AD 1450–1850) and Medieval Warm Period (~AD 800–1200). However, only few studies have had the necessary temporal resolution to provide insight into decadal to century-scale climate variability and its impact on the forests of eastern North America (e.g. Swain, 1973, 1978; Gajewski et al., 1985, 1987; McAndrews and Boyko-Diakonow, 1989; Fuller, 1997; Booth et al., 2012; Houle et al., 2012). At much longer time-scales, the postglacial environmental history of North America has been extensively studied (Anderson, 1985; Ritchie, 1987), documenting the migration of the major tree taxa following deglaciation and their response to long-term climate changes over the Holocene (Bryant and Holloway, 1985; Wright et al., 1993; Williams et al., 2004).

The purpose of this study is to investigate the history of climate, vegetation changes and fire occurrence during the last 1000 years in the Gatineau Hills of southwestern Quebec, using annually-laminated sediments from a small lake. The presence of varved sediments (annual laminations) provides an opportunity to examine changes in vegetation and fire occurrence at continuous intervals, thereby providing multi-decadal to centennial-scale information about the timing of fluctuations in the pollen and

* Corresponding author. Tel.: +1 613 562 5800x1057.
E-mail address: gajewski@uottawa.ca (K. Gajewski).

0277-3791/$ – see front matter
http://dx.doi.org/10.1016/j.quascirev.2013.06.007

charcoal record. The presence of varves also permits the more accurate estimation of pollen accumulation rates (PAR), as individual pollen samples are accurately and independently dated. The relationship between climate, vegetation and fire is investigated, and climate is reconstructed at multi-decadal scales. The project can answer several questions: To what extent have climate variations of the past millennium affected the vegetation in southwestern Quebec? Can we see the impact late Holocene climate variability on the terrestrial ecosystems of the region? If so, how have these climate changes affected the forest composition as well as fire occurrence? How has human settlement impacted vegetation communities and fire occurrence in the last 200 years? Can these data provide new insight into climate variability of the past 1000 years?

The study area is located on the boundary between the St-Lawrence Lowlands and the Laurentian Highlands of the Precambrian shield (Braun, 1950; Mott and Camfield, 1969). The Laurentian Highlands are characterized by rolling hills 100 m or more above uneven valleys (Mott and Farley-Gill, 1981). The mixed forest in south-western Quebec is the transition zone between the boreal forest to the north and the deciduous forest to the south (Braun, 1950; Ritchie, 1987; Burns and Honkala, 1990; Richard, 1993).

Lac Noir (45°46′31.91″N, 75° 8′6.23″W, 176 m a.s.l.) is located 60 km north–east of Ottawa (Fig. 1). It is a small lake of about 10 ha (Ministère de l'Environnement du Québec, 1991), with a maximum depth of 16.2 m. The lake is next to a steep hillside (400 m a.s.l) to the west and some agricultural land in the valley of La Petite Nation within a kilometer to the east. There are two summer cabins on the lake but otherwise there is no other land use presently on the shore. In June 2012, the top of the water column was saturated (dissolved oxygen (DO) = 96%), whereas the bottom of the lake near the coring site was anoxic (DO = 3%). Lake water pH was 8.2 at the surface and 6.9 at the bottom, and specific conductance was 72 μS at the surface and 58 μS between 6 and 10 m, indicating a low concentration of dissolved ions in the water column.

2. Methods

Three cores were collected from the deepest part (16 m) of Lac Noir using a freezer corer (Shapiro, 1958). The cores were clearly laminated along the entire length, with distinct marker layers observed in each of the cores that were used for cross-dating (Fritts, 1976). A pin was inserted in the sediments at every 10 couplets (10 years) independently in each of the three cores and the sequences then cross-dated. The distance between pins (i.e., the 10-year segments) was measured on each core using a Mini-scale and System Encoder connected to an Acurite III digital counter with a precision of 0.001 mm.

One-cc of sediment was taken using a calibrated brass sampler at continuous 10 year increments from one of the cores and was processed to extract the pollen using standard methods (Faegri et al., 1989), including HCl, KOH, acetolysis, and HF treatments and storage in Si oil. Two *Lycopodium* spore tablets were added to each sample to calculate pollen concentrations; since each sample comprised 10-years of deposition as measured from the varves, pollen accumulation rates (PAR) could be computed (Stockmarr, 1971; Faegri et al., 1989). An average of 510 grains was counted for each subsample. Pollen percentages were computed using a sum of tree and shrub pollen (AP), non-arboreal pollen (NAP) and spores.

Micro-charcoal was counted and measured on the pollen slides (Whitlock and Larsen, 2002). Particles were classified into 4 size classes (1: $218.75 \le x < 437.5$ μm^2, 2: $437.5 \le x < 875$ μm^2, 3: $875 \le x < 1750$ μm^2 and 4: $\ge$1750) and total area summed (Whitlock and Larsen, 2002). A grid in the imaging software *NIS*-Elements version 3.0 was used to classify the particles. Loss-on-ignition (LOI) was conducted at 10 year intervals using the varves as the sampling intervals (Heiri et al., 2001).

Another sediment core (94 cm) was retrieved, using a 5-cm diameter clear plastic tube fitted with a piston and lowered to the sediment using drive rods (Wright, 1967). The first 30 cm were

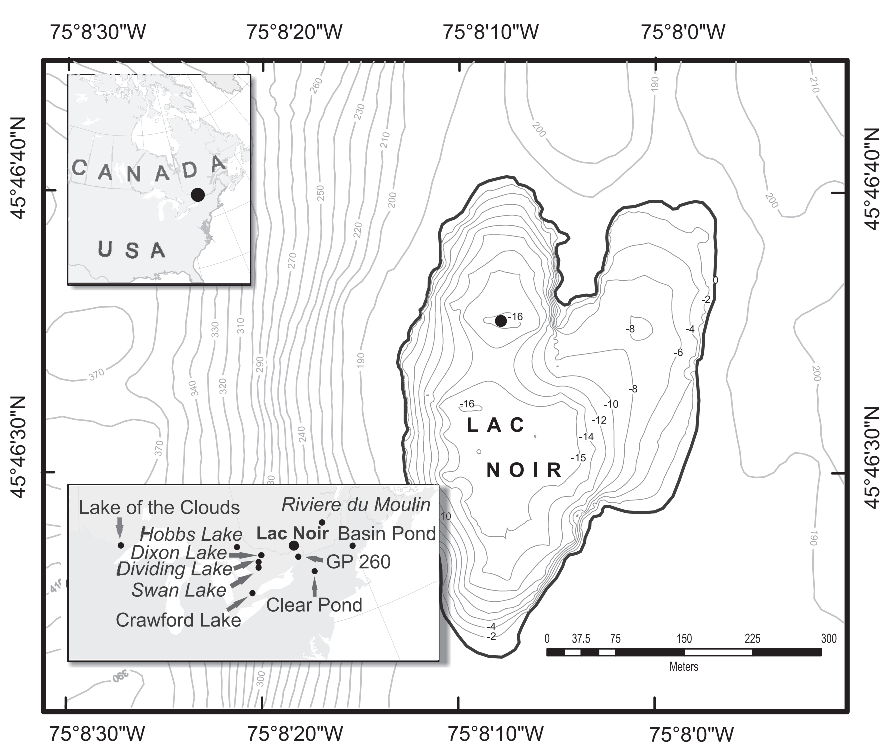

Fig. 1. Location of Lac Noir in southwestern Quebec with contour intervals and coordinates. The dot represents the coring location at a depth of 16.2 m. Inset map shows location of study area relative to North America. Second bottom inset map shows sites plotted in Fig. 8 and Lac Noir in bold, tree-ring sites in italics and PDSI Grid Point 260.