Palaeogeography, Palaeoclimatology, Palaeoecology 423 (2015) 91–101

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

# Assessing tree-ring carbon and oxygen stable isotopes for climate reconstruction in the Canadian northeastern boreal forest

Christian Bégin [a,*], Mathieu Gingras [b,1], Martine M. Savard [a], Joëlle Marion [a], Antoine Nicault [c], Yves Bégin [b]

[a] Geological Survey of Canada, Natural Resources Canada, 490 rue de la Couronne, Quebec, QC G1K 9A9, Canada
[b] Institut national de la recherche scientifique (INRS-ETE), 490 rue de la Couronne, Quebec, QC G1K 9A9, Canada
[c] Université Aix-Marseille (AMU)-ECCOREV (FR 3098), Europôle Méditerranéen de l'Arbois, Avenue Louis Philibert, BP 80, 13545 Aix en Provence, Cedex 4, France

ARTICLE INFO

*Article history:*
Received 9 January 2014
Received in revised form 13 January 2015
Accepted 26 January 2015
Available online 4 February 2015

*Keywords:*
Black spruce
Stable isotopes
Tree-rings
Dendroclimatology
Boreal forest

ABSTRACT

In this study, we analyzed stable isotopes of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) of five black spruce (*Picea mariana* (Mill.) BSP) trees growing in the Québec boreal forest. We then produced the first dendroisotopic series covering the last two centuries (1800–2003) for this region where climatic records are particularly scarce and of short duration. Our aim was to evaluate the isotope sensitivity to climate and their potential as proxies for past climate conditions. The $\delta^{18}O$ results show a strong coherence between all trees indicating that these values express a homogenous response at the site scale. For the $\delta^{13}C$ series, slight inter-tree differences suggest the influence of micro-site conditions. Isotopic values were compared to climatic data for the period 1944–2003. These statistical analyses indicate that the $\delta^{13}C$ and $\delta^{18}O$ ratios are directly influenced by summer maximum temperatures but also correlate with parameters that integrate temperatures and moisture status. In all cases, the climate effects on $\delta^{13}C$ values are weaker than the ones recorded by the $\delta^{18}O$ series. Moreover, because the $\delta^{18}O$ and $\delta^{13}C$ values are sensitive to climatic variables that are linked and commonly associated in typical subarctic climate ambiances (warm-dry, cold-wet), the patterns of their joint response show stronger correlations with climatic parameters. Then, a temperature reconstruction was developed based on a regression model that calibrates the combined $\delta^{13}C$ and $\delta^{18}O$ series against summer maximum temperature (TmaxJJA). The reconstructed summer temperatures indicates that the first half of the 19th century was the coldest period in the past 200 years and that a steadily change throughout milder conditions started in the early 1940's. These trends are consistent with other reconstructed values from independent proxies available for the same region. This research confirms that C and O dendroisotopic series of black spruce trees in high latitudes can document adequately past climatic conditions.



## 1. Introduction

Climate change and particularly future modifications of water and temperature regimes are among the major issues of the 21st century. A thorough knowledge of past climatic conditions is needed to better understand the natural variability of climate and allow an evaluation of future climatic conditions. To compensate for the short coverage of instrumental data, various natural archives sensitive to climatic variations are used to reconstruct climatic conditions at different time scales beyond the period covered by instrumental measurements. Among the most used natural archives are ice cores, peat deposits, marine and lake sediments and their microfossils, corals, and tree-ring series. These natural archives reveal different information, sometimes complementary, but often limited by their spatial distribution or relatively coarse temporal resolution. For these reasons, tree-ring series are among the most used natural indicators as they offer an annually resolved record, even seasonal, and a wide distribution on most continents and in several natural environments.

Within the range of tree-ring indicators, isotopic characteristics offer the advantage of being controlled by relatively simple and well-known physiological mechanisms, in comparison to the more frequently used growth parameters based on cambial growth such as ring width and ring density (McCarroll and Loader, 2004). Moreover, change of tree geometry with age induces a decreasing trend in ring width patterns that has to be removed by statistical detrending techniques prior to inferring any climate signal. Depending on the detrending model, the standardization of data often has the undesirable effect of removing mid- and long-term climate signals in tree-ring series. Generally, there is no long-term trend related to tree aging in isotopic series (Young et al., 2011). Only the firsts 20–30 years at the beginning of the series are usually removed to avoid the so-called juvenile effect (Gagen et al., 2007).

* Corresponding author. Tel.: +1 418 654 2648.
*E-mail addresses:* cbegin@nrcan.gc.ca (C. Bégin), mathieu.gingras@lacoop.coop (M. Gingras), msavard@nrcan.gc.ca (M.M. Savard), jmarion@nrcan.gc.ca (J. Marion), nicault@eccorev.fr (A. Nicault), Yves.Begin@ete.inrs.ca (Y. Bégin).
[1] Present address: La Coop fédérée, 9001, boul. de l'Acadie, bureau 200, Montréal, QC H4N 3H7, Canada.

http://dx.doi.org/10.1016/j.palaeo.2015.01.021
0031-0182/

On the other hand, in the dendroisotopic approach, each tree studied requires a considerable analytical effort compared to traditional tree-ring analyses. However, dendroisotopic analysis generally requires a smaller number of trees than the traditional tree-ring approach to obtain a satisfactory signal-to-noise ratio.

Several studies have shown that tree-ring stable isotope ratios of carbon ($^{13}C/^{12}C$, noted $\delta^{13}C$) and oxygen ($^{18}O/^{16}O$, noted $\delta^{18}O$) are sensitive to climatic conditions which result in fractionation prior to cellulose synthesis (McCarroll and Loader, 2004; Loader et al., 2007; Tardif et al., 2008; Seftigen et al., 2011). Tree-ring isotopes, generally in cellulose (see further), are thus potentially useful to reconstruct past climatic conditions with high temporal resolution (Waterhouse et al., 2000; Barbour et al., 2002; Raffalli-Delerce et al., 2004; Danis et al., 2006; Young et al., 2010; Szymczak et al., 2012; Porter et al., 2013).

Northeastern Canada is characterized by a very well developed hydrographic network, a heritage of the last glaciation, which constitutes a unique freshwater reserve. For this reason, more than 80% of Québec hydroelectric power has been developed in this region (Consortium Ouranos, 2007). Knowledge of the hydroclimatic conditions of this vast territory is based on a restricted number of weather and hydrological stations. Moreover, the instrumental climatic monitoring has generally been of short duration, offering a limited period for calibration of prediction models (approximately 40 to 50 years depending on the climatic variable). It thus appears important to extend the climatic series in order to better understand the natural variations of the regional climate and to optimize the calibration of hydroclimatic models, allowing the prediction of future trends for the Québec–Labrador peninsula.

The main objectives of this research are to produce black spruce (*Picea mariana* (Mill.) BSP) tree-ring dendroisotopic series representative of the upstream area of La Grande River basin, and evaluate their potential as proxies for reconstructing climatic conditions over the last two centuries. From a methodological point of view, the study will also allow us to assess if it is necessary to extract cellulose from wood subsamples. This extraction is generally judged essential because of the possibility of creating artificial isotopic variations related to the different proportions of wood components, each having its own isotopic ratio (Saurer et al., 1997a; Ferrio and Voltas, 2005) or of losing climate information (Borella et al, 1999). However, several studies have suggested that in cases whole wood analyses may provide reliable isotopic series (Verheyden et al., 2005; Harlow et al., 2006). It seems therefore relevant to verify if, for this species, cellulose extraction is required or if isotopic values of total wood are adequate for paleoclimatic investigations in the context of northeastern Canada.

## 2. Study area and site selection

The study area is located in the center of Quebec–Labrador peninsula (Canada) (Fig. 1). The area sits on the Precambrian shield which is composed of granitic and gneissic rocks; the relief consists of low altitude plateaus ≈ 200–400 m.a.s.l. The dominant landforms have been inherited from the last glaciation; they are drumlins and rocky hills covered by a layer of ablation till (Payette et al., 1989). The region is located in the northern part of the boreal forest biome occupied for the most part by the bioclimatic domain of the spruce–lichen forest (Ministère des ressources naturelles du Québec, 2003) and of the spruce–moss forest in less well drained sectors (Payette et al, 1989). The dominant tree species is black spruce, however jack pine (*Pinus banksiana* Lamb.) stands are frequent in fire-prone areas.

The area has a subarctic climate (Gouvernement du Québec, 2013). At the regional scale, the average annual temperature from 1944 to 2010 is approximately −4 °C and the average annual precipitation amounts to approximately 750 mm, of which 40% falls as snow.

The study site is located at the eastern edge of Lake Hurault (54°15′ 00″ N, 70° 46′12″ W, Fig. 1), ~460 km to the east of Radisson near the head reservoir (Caniapiscau) in the upstream area of La Grande hydroelectric complex. The study site occupies the western slope of a hill covered with relatively well-drained till where a Brunisol type soil has developed. Zones covered with till are unevenly distributed within the site causing heterogeneous edaphic conditions. The surface is colonised

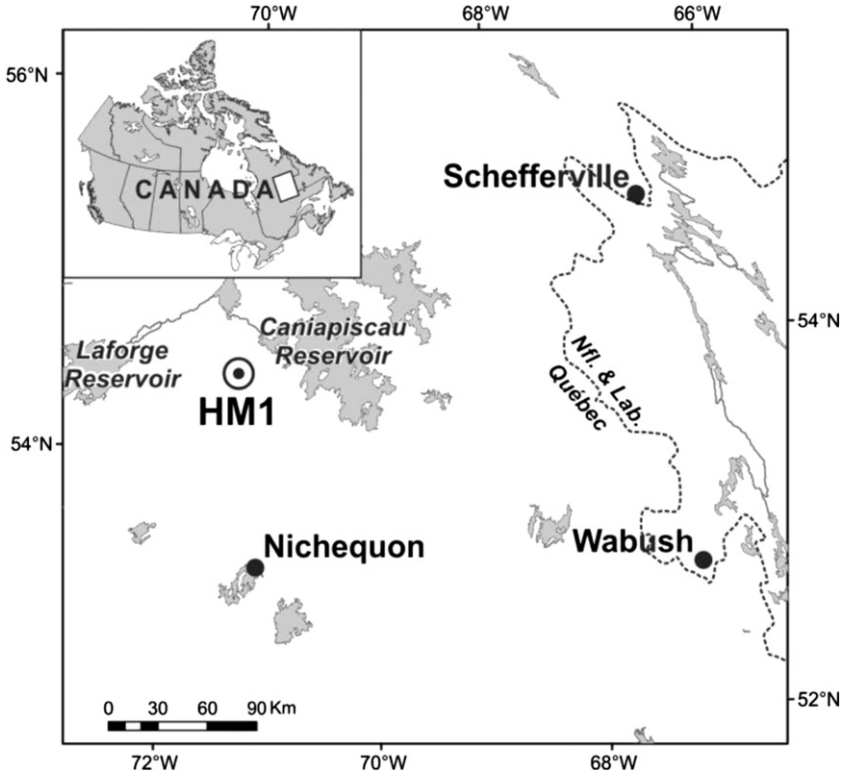


**Fig. 1.** Location map showing the study site (open circle) and the weather stations (black dots).