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Eastern white cedar long-term dynamics in eastern Canada: Implications for restoration in the context of ecosystem-based management

Victor Danneyrolles [a,d,*], Sébastien Dupuis [a], Dominique Arseneault [a,d], Raphaële Terrail [a], Marie Leroyer [a], André de Römer [a], Gabriel Fortin [a], Yan Boucher [b,d], Jean-Claude Ruel [c,d]

[a] Chaire de Recherche sur la Forêt Habitée, Université du Québec à Rimouski, Rimouski, QC G5L 3A1, Canada
[b] Direction de la recherche forestière, Ministère des Ressources naturelles du Québec, 2700 Einstein, Quebec, QC G1P 3W8, Canada
[c] Département des sciences du bois et de la forêt, Université Laval, Québec, QC G1K 7P4, Canada
[d] Centre d'étude de la forêt (CEF), Pavillon des Sciences biologiques, 141 Président-Kennedy, Bureau SB-2987, Montréal, QC H2X 1Y4, Canada

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ABSTRACT

Eastern white cedar (*Thuja occidentalis* L.) has been identified as a target tree species for ecological restoration in northeastern North America. Insight into long-term population dynamics since preindustrial times is key to guiding restoration efforts. In this study, we used a large set of early land survey data to assess the status of eastern white cedar in preindustrial forests across a large area (78,000 km^2) of eastern Canada, and to evaluate subsequent population changes. In addition, we used early forest inventory data, which were available for a restricted portion of our study area, to assess the role of white cedar early dynamics in the success of its subsequent development. Our results show that the species was frequent (29.1%) and dominant (13%) in preindustrial forest landscapes. However, preindustrial frequency and dominance of white cedar displayed broad spatial variability, which suggests that several factors controlled its abundance. Following European settlement and logging, white cedar dominance and frequency decreased respectively by −6.2% and −12.1%, and these changes were also variable across the study area. Southern populations experienced the less pronounced decrease, and even a substantial increase in frequency in many areas that were affected by agricultural land abandonment. Northern populations experienced the largest decrease, especially on private lands. However, some northern areas locally experienced an increase in white cedar frequency and dominance due to partial natural and human disturbances (insect outbreaks, partial cutting). The presence of advanced regeneration at the time of partial disturbance is a key factor that allows white cedar to become dominant. These results help to identify areas with important needs and potential for restoration and support partial cutting systems with protection of advanced regeneration as a promising management practice for promoting white cedar.
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1. Introduction

A long-term ecological perspective is essential for planning ecosystem conservation and restoration (Higgs et al., 2014; Jackson and Hobbs, 2009; Willis et al., 2007). Forest historical baselines help identify target species and set quantitative objectives for restoration (Egan and Howell, 2001; Lindbladh et al., 2007). In northeastern North America, early land survey records have been widely used to reconstruct long-term changes in forest characteristics (Cogbill et al., 2002; Lorimer, 1977; Rhemtulla et al., 2009a; Tulowiecki and Larsen, 2015) and, thus, may provide key knowledge for the successful restoration of the target species.

Eastern white cedar (*Thuja occidentalis* L.) is a long-lived tree species that is native to the northeastern mixed and boreal forests of North America (Fig. 1). It is considered to be a fire-sensitive and very shade-tolerant, late-successional species (Hofmeyer et al., 2009; Johnston, 1990). This tree species exhibits strong plasticity regarding habitat characteristics, with an optimal growth on mesic uplands, but can also develop well in both poorly drained lowlands, limestone cliffs or acidic outcrops (Hofmeyer et al., 2009; Johnston, 1990). A decrease in white cedar populations since preindustrial times has been reported by several studies throughout its natural range, a trend that has been associated with past logging, as well as the sensitivity of the species to stand-replacing disturbance (fire, clear-cut; Aubé, 2008; Dupuis et al., 2011; Jackson

* Corresponding author at: Chaire de Recherche sur la Forêt Habitée, Université du Québec à Rimouski, Rimouski, QC G5L 3A1, Canada.
E-mail address: victor_dnr@hotmail.fr (V. Danneyrolles).

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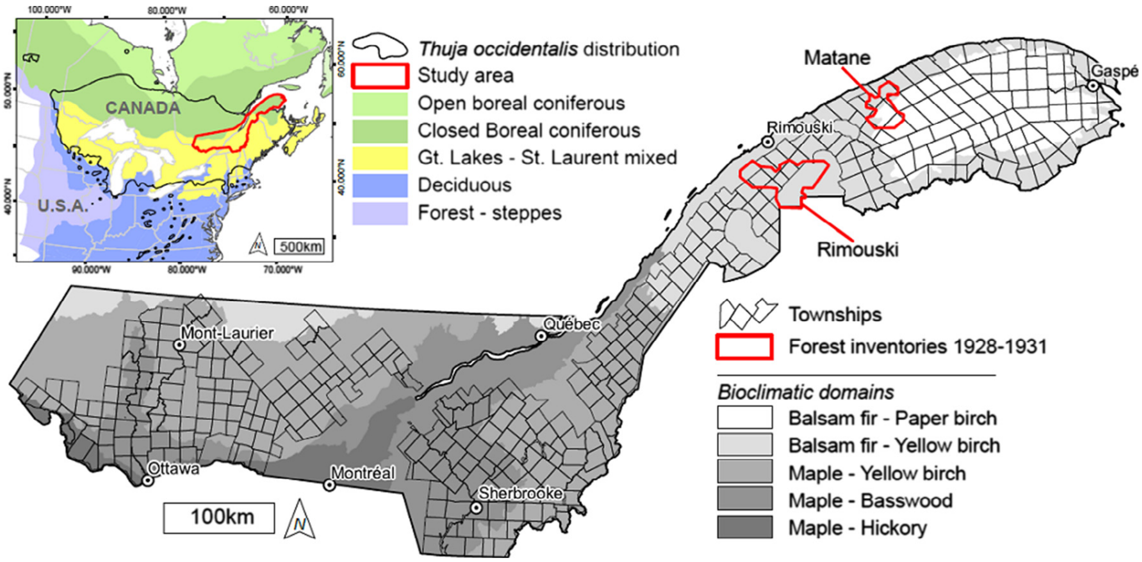

Fig. 1. Study area, location of historical land survey records and early forest inventories.

et al., 2000; Pinto et al., 2008) and to white-tailed deer (*Odocoileus virginianus*) browsing (Cornett et al., 2000; Heitzman et al., 1997; Rhemtulla et al., 2009b). White cedar is valued ecologically (e.g., old growth characteristics, wildlife habitat; Boulfroy et al., 2012; Grondin and Cimon, 2003), economically (mostly for specialized products such as shingles; Boulfroy et al., 2012) and spiritually by several First Nations (e.g., Danielsen, 2002). While these characteristics make white cedar an appropriate target species for restoration and ecosystem-based forest management in northeastern North America (Boulfroy et al., 2012; Grondin and Cimon, 2003; Horsley et al., 2003), challenges remain about how to achieve it. First, because compositional changes since the preindustrial era have not been spatially uniform (e.g., Danneyrolles et al., 2016a; Thompson et al., 2013), it is important to identify areas at the landscape-scale with important needs and potential for restoration (Bolliger et al., 2004; Zenner and Almendinger, 2012). Second, while partial cutting management is usually recommended to enhance white cedar growth and recruitment (e.g., Larouche et al., 2011; Ruel et al., 2014), white cedar may be outperformed by its competitors in absence of regeneration in treated stands (Hofmeyer et al., 2009, 2010). Thus, an in-depth understanding of white cedar population trends across space since the preindustrial era could greatly help to identify key factors that may guaranty restoration success.

In this study, we used an extensive set of early land survey data (1795–1940) to assess the abundance of white cedar in preindustrial forest landscapes of southern Quebec, and to evaluate population changes throughout this region. In addition, we used early forest inventory data (1928–1930) which were available for a restricted portion of our study area, to assess the importance of white cedar early dynamics (i.e., release as advanced regeneration) in the success of its long-term development. We discuss three general questions: (1) which factors controlled white cedar abundances in preindustrial forests? (2) Which factors have determined changes in white cedar populations? (3) What are the implications of our results for white cedar restoration?

2. Material and methods

2.1. Study area

The study area covers 78,000 km^2 in the southern part of Quebec, eastern Canada, and represents an east-west climate gradient that extends for more than 1000 km within the northern range of white cedar (Fig. 1). Forests in this region represent a transition between temperate mixedwood and boreal conifer-dominated forests (Rowe, 1972). They encompass five bioclimatic domains, according to the ecological land classification of Quebec (Robitaille and Saucier, 1998); Fig. 1). Mean annual temperature (1981–2010) ranges from 6.8 °C to −2.2 °C from south to north, while mean annual total precipitation ranges from 850 mm to 1000 mm moving from east to west. The region is characterized by sedimentary bedrock of the Appalachian Mountain Chain to the east and metamorphic bedrock of the Canadian Shield to the west, which are both covered by surface deposits of alteration and glacial origins (Robitaille and Saucier, 1998).

2.2. Early land-survey and forest inventories data

Early land-survey data were extracted from logbooks reporting the original survey of 366 townships between 1795 and 1940 (Fig. 1). In the Province of Quebec, public lands were divided into townships of about 16 km × 16 km, and further subdivided into parallel ranges that were 1.6-km wide. Surveys were conducted along the boundaries of the township and range lines, where surveyors also described forest composition (Dupuis et al., 2011). In this study, only observations that mentioned lists of taxa (e.g., "*pine, spruce, white birch and a few maples*") were retained, and were precisely georeferenced using historical and modern digital cadastral maps. Terrail et al., (2014) have compared these taxa lists with early forest inventories (1928–1931; see description below) available for a restricted portion of our study area (Fig. 1), and have shown that the position of taxa in the taxon list reflects their relative basal area. Thus, a rank was assigned to each taxon that was listed according to its position in the taxon list. Surveyors' observations also are divided into two geometric types: line descriptions and point observations. Observations were considered as linear segments when they clearly contained both a start and an end position along the range line, which were usually delineated by lot limit (about 260 m). Conversely, observations were considered as points when their position could be clearly located, but with no clear beginning or end along a range line, and were frequently distributed at each lot corners (about 260 m) or at every 10 chains (about 200 m). In order to incorporate these two types into the same database, a weight was assigned to each observation that represented the length of line observations and the mean spacing

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