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Research paper

Forest dynamics in relation to multi-decadal late-Holocene climatic variability, eastern Ontario, Canada

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ABSTRACT

Pollen profiles from two lakes, Tawny Pond (44°48′59″N, 77°10′54″W, 276 m) and Stoll Lake (44°58′16″N, 77°17′22″W,303 m) in Addington Highlands, eastern Ontario, Canada were analyzed to determine the effects of late-Holocene climate change and European settlement on eastern Ontario's forests. Both lakes were analyzed at high temporal resolution and record vegetation dynamics over the last 1000 years. Throughout the past 1000 years, *Pinus*, *Tsuga*, *Betula*, *Quercus*, *Acer* and *Fagus* were the dominant taxa in the pollen record. From 950–1550 AD the forest was dominated by *Tsuga*, *Fagus* and *Acer*. Between 1550 and 1730 AD *Pinus* and boreal tree species became more abundant and/or had increased relative pollen production. Low pollen influx to the sediment, high values of *Pinus* and relatively low values of *Tsuga* and hardwoods between 1730 and 1870 AD suggest colder temperatures. Since 1870 AD, herbaceous plants (weeds) increased in abundance, whereas softwoods decreased and hardwoods increased, due to landscape changes associated with European settlement. A comparison of the temperature reconstruction based on the pollen assemblages and the Toronto and Ottawa climate records shows a close correspondence, suggesting pollen records can record decadal-scale climate fluctuations.

1. Introduction

Naturally-occurring changes in forest cover result from changes in regional and local scale climatic conditions across relatively short (10^1–10^2 years) and long (>10^3 years) time periods. Studies of the paleoecology of eastern North America have noted large-scale biome changes and the northward expansion of plants in relation to post-glacial climate warming (Bernabo and Webb, 1977; Prentice et al., 1991; Overpeck et al., 1992; Jackson et al., 2000). These studies were primarily concerned with millennial-scale climate changes and lack the temporal resolution to observe multi-decadal and century-scale climate and vegetation variability. Recent paleoecological studies have focused on late-Holocene changes in vegetation composition in eastern North America (e.g., Gajewski, 1987; McAndrews and Boyko-Diakonow, 1989; Fuller, 1997; St. Jacques et al., 2008; Paquette and Gajewski, 2013; Lafontaine-Boyer and Gajewski, 2015). These studies use high temporal-resolution pollen records to observe the effect of multi-decadal and century-scale climate variability on vegetation. Other studies have shown how land use activities of Native Americans (Doolittle, 1992; Munoz and Gajewski, 2010) and European settlers (Fuller et al., 1998) influenced the natural dynamics of forest response to climate.

During the past millennium generally warm conditions were recorded widely between 800 and 1100 AD (Medieval Warm Period, MWP) and cool conditions between AD 1600 and 1850 (Little Ice Age, LIA), although the timing and nature of these regimes varies between regions (PAGES 2k Consortium, 2013). In the Great Lakes region of North America (Fig. 1), a transition from warm to cooler conditions has been noted during the period from 1200–1500 AD, although the timing varies from site to site. There is a question about the hydro-climate in this region during the past 1000 years: during the Medieval Warm Period droughts have been shown toward the west and from sites to the south of the study area, but in some areas this time was relatively wet (Gajewski, 1987; Campbell and McAndrews, 1991; Fuller et al., 1998; Pederson et al., 2005; St. Jacques et al., 2008; Laird et al., 2012; Booth et al., 2012; Paquette and Gajewski, 2013; Lafontaine-Boyer and Gajewski, 2015). Nevertheless, although most sites sampled at sufficient temporal resolution record these two climate regimes; more detail about the temporal evolution and the spatial extend are needed.

This study uses fossil pollen records from two lakes in eastern Ontario to examine vegetation and climate dynamics during the last 1000 years. Tawny Pond and Stoll Lake are located in Addington Highlands Township, eastern Ontario, Canada (Fig. 1). The principal objective of this study is to document forest change in Addington Highlands and surrounding region in relation to multi-decadal and century-scale climate variability and land-use changes, including the MWP, the LIA and European settlement. This location is of considerable ecological interest, given that it is at the headwaters of three important river systems and a tributary of a fourth.

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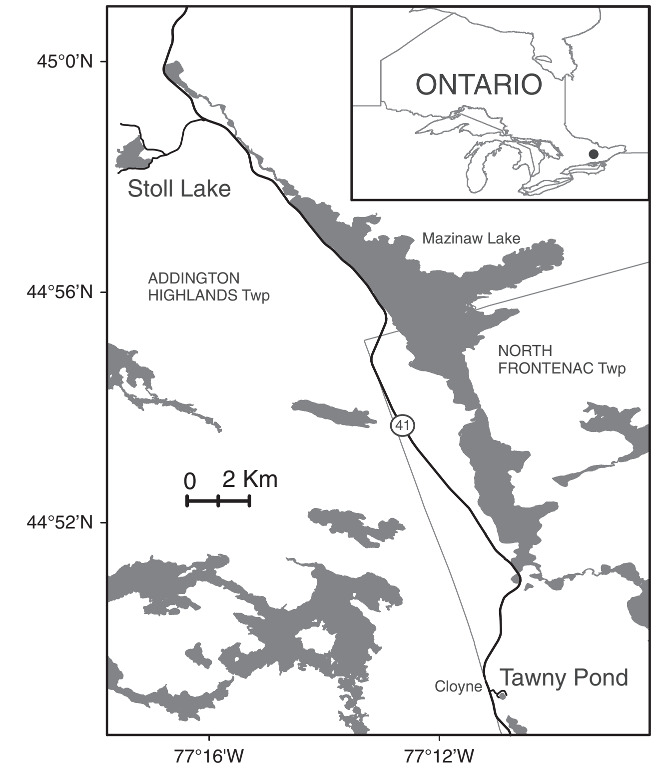

Fig. 1. Location of Tawny Pond and Stoll Lake in Addington Highlands Township, eastern Ontario. Small lakes have been removed, and only major roads are shown.

The study area is a rugged upland region near the northern edge of the Eastern Great Lakes Lowland Forest Region that has been heavily glaciated, characterized by large areas of exposed gneiss and granite bedrock; thin, acidic soils; and, a high density of wetlands, lakes and rivers (Gillespie et al., 1963; McLeman, 2008, 2010). Cold-tolerant softwoods dominate present-day forests in this region (Rowe, 1972). In the study area there is a high degree of heterogeneity on the ground, with the composition of forest stands varying over short distances depending on aspect, soil availability, and soil moisture. Tawny Pond (44°48′59″N, 77°10′54″W, 276 m) is a few hundred meters from the village of Cloyne, and is bounded by a small number of cottages and permanent homes on its western shore, with secondary mixed forest on its remaining sides. Stoll Lake (44°58′16″N, 77°17′22″W, 303 m) is 18 km farther north, in a secondary forest stand that is currently being logged using sustainable harvesting methods. In the first half of the 20th century the Sawyer-Stoll Lumber Company maintained a sawmill and settlement for its workers on the lake's eastern shore (Campbell, 2000), but there are today no year-round habitations or seasonal residences on this lake. Tawny Pond has a ~2 ha surface area so the pollen source area is mainly local whereas Stoll Lake, with its larger surface area (~37 ha), is believed to be accumulating more regional pollen (Jacobson and Bradshaw, 1981; Bunting et al., 2004). High temporal-resolution pollen analysis of these two sites is therefore assumed to provide both local and regional representations of the forest through time.

The study area has a generally sparse human population today of 1.9 people per square kilometer, based on 2532 year round residents of Addington Highlands (Statistics Canada, 2011). The overall population and the population density have changed little since 1900 (McLeman, 2010). The region's poor soils made it one of the last parts of southern Ontario to be settled by non-Native peoples. European settlement began after the first survey in 1854 AD, and by 1870 AD a large-scale lumber industry had developed (Campbell, 2000; Axford et al., 2008). Late 19th and early 20th century forestry practices in the region involved wholesale clear-cutting of the forest, with cut logs being rafted down river to the Ottawa River valley for processing and onward export to Canadian urban centers, the US, and Europe (Kennedy, 1970; Armstrong, 1976; Campbell, 2000). Through grants of land, governments encouraged settlers to clear forests and wetlands along roads and establish small farms, but with the exception of small pockets with reasonable soils, few of these have survived. The adoption of active forest management and sustainable harvesting practices in recent decades have resulted in a healthy, diverse, and increasingly mature secondary forest across most of the study region. Small-scale forestry by family operated companies continues to this day, but the mainstays of the local economy are now outdoor recreation and the provision of goods and services (McLeman, 2010).

2. Methods

Lake sediment cores (5 cm diameter) were taken from Tawny Pond and Stoll Lake in the spring and fall of 2011 using a modified Livingstone piston corer (Wright et al., 1984). Replicate cores of different lengths were obtained from Tawny Pond, and correlated using the loss-on-ignition (LOI) curves. The uppermost unconsolidated sediments of the cores were extruded at 0.5 cm intervals and stored in plastic bags. The deeper consolidated sediments were extruded and wrapped in plastic film and aluminum foil and stored at 4 °C.

Wet samples from the uppermost sediment were sent to Flett Research for ^{210}Pb dating. Organic matter (e.g., charcoal, plant material) picked from the sediment was sent to Beta Analytic for ^{14}C dating. Loss on ignition was conducted at 1 cm intervals on all cores (Heiri et al., 2001) by igniting dry sediment for 4 h at 550 °C and 2 h at 950 °C to estimate organic and carbonate content respectively.

Sediment was subsampled for pollen analysis at 0.5 cm–1 cm intervals at Tawny Pond and 1 cm–2 cm intervals at Stoll Lake. Samples of 1 cm^3 were processed using standard methods of preparation (Faegri and Iverson, 1989), including treatment in HCl, KOH, HF and acetolysis, before being stored in Si oil. Two *Lycopodium* spore tablets (batch number 938934) were added to the sediment at the beginning of preparation to enable computation of pollen and charcoal concentrations (Faegri and Iverson, 1989). Pollen were identified and counted under a magnification of 400× and 1000× for critical identification. Fossil pollen grains were compared with reference material and standard texts to aid in identification (Faegri and Iverson, 1989; McAndrews et al., 1973; Moore et al., 1991). At least 500 pollen grains were counted for each sample. The pollen data are expressed as percentages of the total pollen count, excluding pollen of aquatic plants.

Microscopic charcoal was tallied for each sample using the size-class method (Waddington, 1969; Whitlock and Larsen, 2001) with a gridded eyepiece. The geometric mean of each size class was used to determine the total area of charcoal on each slide.

A principal components analysis of the major tree and herbaceous taxa was used to summarize the pollen data. The pollen assemblages of both Tawny Pond and Stoll Lake were analyzed together to enable comparison of the data between the lakes.

Mean summer (June, July, August) temperature and total summer precipitation were reconstructed using the Modern Analogue Technique (MAT) (Sawada, 2006) and version 1.8 of the North American Modern Pollen Database (Whitmore et al., 2005). Modern pollen data spanning the Eastern Deciduous Forest biome between 50 and 100°W longitude and 20–50°N latitude were extracted as potential candidates for modern analogues. The average of the 3 closest analogues and a squared chord distance dissimilarity coefficient (Williams and Shuman, 2008) was used to compute the reconstructed climate variables. A pollen sum of 24 arboreal pollen taxa was used for the reconstruction, including *Pinus*, *Picea*, *Abies*, Cupressaceae, *Larix*, *Tsuga*, *Betula*, *Quercus*, *Fraxinus*, *Populus*, *Ulmus*, *Ostrya/Carpinus*, *Acer*, *Fagus*, *Carya*, *Juglans*, *Tilia*, *Platanus*, *Castanea*, *Celtis*, *Corylus*, *Alnus*, *Salix* and *Myrica* (Paquette and Gajewski, 2013). These reconstructions were then compared with weather station data from Toronto and Ottawa, stations that are located to the southwest and east of the study area