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A DENDROCHRONOLOGICAL RECORD OF TWENTIETH CENTURY WATER LEVELS IN GEORGIAN BAY, ONTARIO, CANADA

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INTRODUCTION

Dendrological studies provide a proxy for local and regional Holocene climate inferences. Annual tree ring growth is a combination of multiple climatic factors such as precipitation and temperature. In forests adjacent to large lakes, dendrochronological records also relate to high and low level lake stands. Further, these histories help us understand the effects of climate change on insular forests and may help us predict future impacts on insular forests in relation to changing climates.

The purpose of this study is to examine whether the annual growth of trees in an insular forest can be correlated with the timing of high and low level lake stands. The response of trees to the historical climate records, such as lake levels, can be used to better understand the response that insular forests may have to a changing climate. Previous dendrohydrology studies have shown that there is a strong correlation between stream height and lake levels with annual ring growth (Cook and Jacoby 1983; Stockton and Fritts, 1973). Here I present new dendrochronological data from insular forests on small islands in The Massasauga Provincial Park, along the eastern shore of Georgian Bay (Ontario, Canada). I present preliminary data on two new tree-ring chronologies of Pinus strobus (1777-2015) and Tsuga canadensis (1891-2015).

METHODS

The Massasauga Provincial Park is located along the eastern shore of the Georgian Bay (Lake Huron) (see Diver, 2017 for figure). The islands located in this area of the Georgian Bay form a dense archipelago, creating insular patches of forest. The islands in the park range from 0.0002 km^2 to larger than 0.6 km^2 (Diver, 2004). The islands are generally flat, ranging to a maximum of 50 meters above the lake level (Diver, 2004). Between the islands, the water depth is quite variable, ranging from less than a meter between some, to over 30 meters. Water levels in the region fluctuate between 175 m and 178 m, with a yearly average of 177.5 m (Bishop, 1990). With the water levels of Lake Huron reaching record lows in recent years, it is possible that some of islands may connect to their neighbors, which has occurred in previous years. Diver (2004) presents a large database of tree cores from this region across a span of 15 years.

Tree cores of 56 trees were obtained during four separate field seasons (2000, 2001, 2011, and 2016), and obtained from 15 islands in The Massasauga Provincial Park. I present data from both hemlock and white pine trees (Table 1). The area of these islands ranges from 0.001 km^2 to 0.15 km^2, with six very small islands, six small islands, three medium islands, and one large island. Very small is defined as the area being under 0.01 km^2, small from 0.01 km^2 to 0.05 km^2, medium from >0.05km^2 to 0.1 km^2, and large from >0.1 km^2 to 0.5 km^2 (Diver 2004). Six of these islands were outer islands, defined as having “some fraction of open water horizon” (Diver 2004), with the rest being inner where “the horizon of inner islands is terrestrial from every vantage point” (Diver, 2004). The ages of cored trees ranged considerably with the oldest tree being 239 years old when cored and the youngest being 8 years old when cored. Most of the white pines date back to the late 19th century and early 20th century, and a majority of the hemlocks date back

Table 1: Data from islands and cored trees included in this study

Island	Type	Area (km sq.)	Hemlocks Sampled	White Pine Sampled
91	Very Small Inner	0.004		4
33	Very Small Outer	0.0053		1
83	Very Small Inner	0.0065		3
94	Small Inner	0.0238	4	1
5	Large Inner	0.1538	1	1
95	Small Inner	0.0296	12	4
66	Medium Outer	0.0526		6
31	Very Small Outer	0.0012		2
71	Small Inner	0.0174	2	5
11	Medium Inner	0.0688		3
10	Very Small Inner	0.002		1
12	Very Small Inner	0.0025		1
64	Small Outer	0.0275		2
22	Very Small Inner	0.001		1
303	Medium Inner	0.0604		1

to the early 20th century. Due to logging in the region at the turn of the 20th century, few trees exist with a longer chronology than used in this study. (Larson and Rawling, 2015) The diameter at breast height (DBH) of trees in the study area ranged from 10 cm to just under 60 cm. Trees that have a DBH <10 cm are considered saplings or seedlings and were not cored for this study. Due to varying growth factors among the islands sampled, the diameter at breast height is not necessarily an indicator of the age of the tree sampled. For example a 33 year old tree had a DBH of 22.7, while a 117 year old tree had a DBH 19.5 cm.

Kim Diver and colleagues collected the tree cores during the summers of 2000, 2001, 2011, and 2016 using an increment borer 1.5 meters from the base of the tree. For each tree, they also recorded the DBH, species, and location of each tree. The tree cores were collected using a random sampling method across multiple inner and outer islands of the Massasauga Provincial Park. Once cored, the cores were stored in straws. Back at Wesleyan University, the straws were opened to allow for the cores to dry. Once dry, they were mounted and glued onto wood mounts. (Figure 1) The cores were sanded using a sanding belt to allow for the rings to be seen and thus be measured.

Figure 1. Core of a hemlock that was cored in 2016. As this core did not have any rot, or breakage of the core, it is included in the dataset. The star, of the left end of the core, indicates the bark side. This side is also the youngest part of the tree.

In order to measure the annual ring growth, the cores from all four field years were scanned as digital images. Using ImageJ (National Institutes of Health), I conducted the ring width measurements by measuring perpendicular to each ring boundary. These measurements included both the early and late growth (i.e. the light and dark layers) in one measurement to provide the annual ring growth used for analysis. I compiled these measurements in Excel and then converted the Excel files into Tuscan format using the Dendrochronology Program Library (DPL) CASE and FMT in order to be read by the DPL's COFECHA (Grissino-Mayer, 2016).

I then used COFECHA to verify the measurements, check for growth outliers, and find the correlation between the growth of trees of the same species on different islands (Grissino-Mayer, 2016; Speer, 2013). As some of the cores had experienced rot and other factors that led to missing parts of the core, I omitted data from these cores as I could not determine how many years were missing (Figure 2). This allows for a stronger correlation between the selected cores, and provides a better proxy for climatic factors such as the timing of high and low levels of Lake Huron.

Figure 2. Due to breakage in the core of this white pine, likely the result of rot, the annual ring growth could not be determined. This core, and others like it, are not included in the data set.

RESULTS

The 19 hemlocks cored during the four field years produced a record from 1777-2015, and the 35 white pines produced a record from 1891-2015. Cross-dating within COFECHA shows that there is not a significant correlation within each species of trees across the islands. The series intercorrelation is the common stand-level signal that is expressed by each core when it is compared to the master chronology. Mean sensitivity is the year-to-year variability. The series intercorrelation for the white pines was 0.153, with a mean sensitivity of 0.404. For the hemlocks, the series intercorrelation was 0.233, and a mean sensitivity of 0.357.

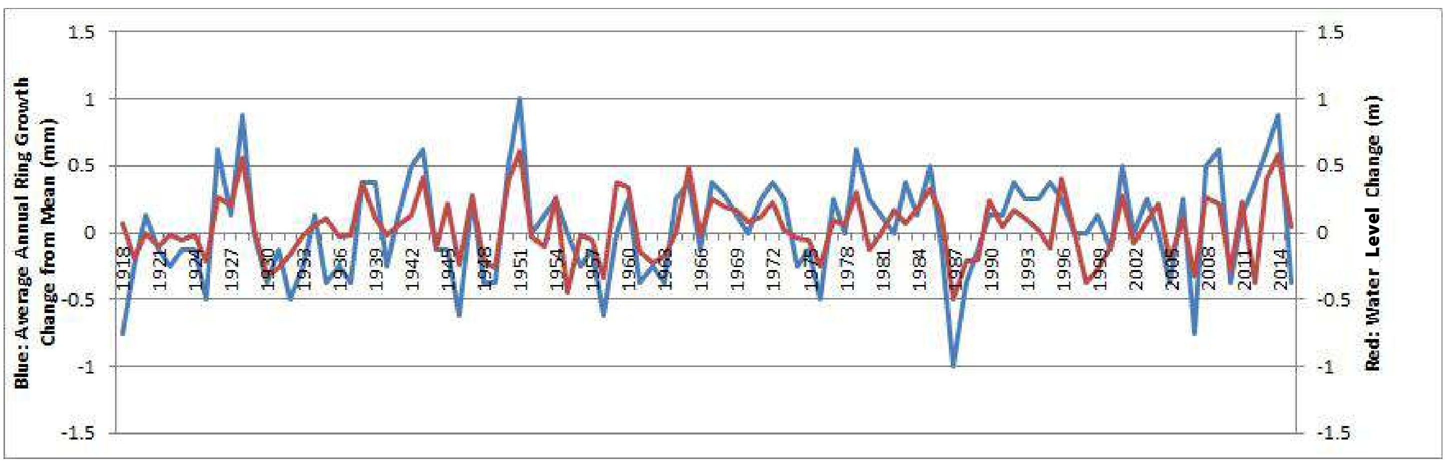

Figure 3. The average annual growth of both white pine and hemlock averaged together compared to the yearly change in the lake level. A strong correlation between the annual growth of the trees and the yearly change in the lake levels exists.

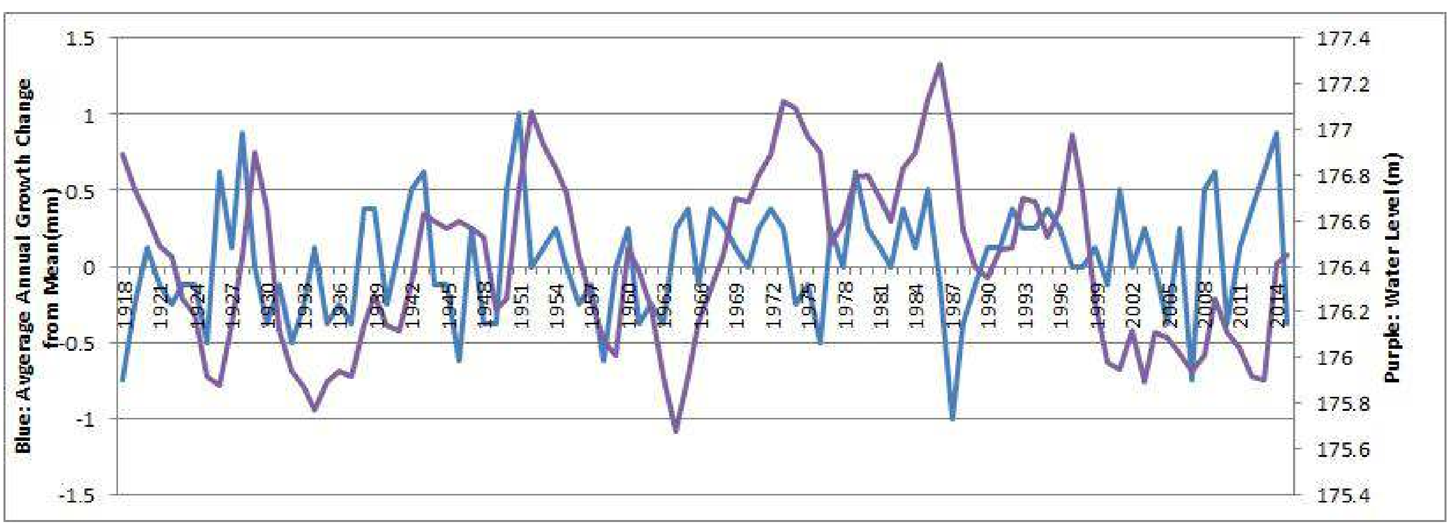

Figure 4. The average annual growth of both white pine and hemlock averaged together compared to the overall lake level. A strong correlation between the annual growth of the trees and the level of Lake Huron.

While there is not a strong series intercorrelation for either species, the annual ring growth does strongly correlate with the fluctuating lake level of Lake Huron's Georgian Bay. When we compare the average annual ring growth with the yearly change in lake level, there is a strong correlation of 0.73 between the tree growth and the water levels of Lake Huron (Figures 3 and 4). Overall, annual growth of the trees appears to be an accurate proxy for the change in the lake level even though there is poor intercorrelation. In years when the yearly water level increased by 0.5 meters (for example 1928, 1951, 2004), the annual growth increase to close to 1 standard deviation above the average. The same is true for when the yearly water level decreased by 0.5 meters (for example 1987), the annual growth decrease is 1 standard deviation below the annual growth average. There were some years where the tree growth was not responsive to the change in lake levels. For six of the years, the annual growth was above the average; however, the lake level had decreased since the previous year's level (1953, 1964, 1980, 1995, 1999, 2012). Also, five years the lake level increased and the annual growth was below the average (1918, 1935, 1945, 1986, 2015).

DISCUSSION AND CONCLUSION

While there is poor intercorrelation for either species, there is a strong correlation with the lake level. Some reasons for the poor intercorrelation are likely that both complacent and sensitive trees were sampled. Complacent trees do not provide sufficient variability that could be used for crossdating. Poor nutrient availability on sections of the islands can also limit the growth, and thus the limiting factor would be nutrient availability and not the lake level, but we do not have this data.

It is also interesting to note that the years where the annual growth data correlate poorly with lake levels are generally quite recent (since 1990). This could be the result of other climatic factors such as temperature and evaporation rates, as from January 2013-December 2014 Lake Huron rose at the highest rate ever for a 2 year period. This period also had below average air temperature for the region, and extensive ice cover leading to a below average evaporation rates (Gronewold et al., 2016). Below average temperature of the region can limit the annual growth as tree growth is highly responsive to climatic changes. This historic low level is seen in Figure 4, and it further shows that during the years of 2011 and 2014, the annual growth was both above the mean, and rebounding from a below-average growth span from 2009 to 2011.

Another consideration is that the limiting factor for tree growth may vary between the sampled locations. Due to the limiting factors being different among cores and possibly years, there would be little correlation between the cores. In order to study the most significant limiting factor, multiple trees from each limiting factor on each island should be compared to the same limiting factor on the same type of island, i.e. trees along the shoreline of very small outer islands. There is an insufficient number of usable cores from the current data set to run such an analysis.

For much of the 20th century, the tree ring data has a poor intercorrelation between the species but constitutes an excellent proxy for lake levels. But the more recent data suggests that this proxy may not be as strong when other shifts in climatic factors are present. Starting in 2005, there is an oscillating pattern between below average growth and above average growth. The annual growth drops considerably below average, and within one to two years, spikes considerably above the mean annual growth. While water level change did correlate with the change in growth, it does not spike in the way that the growth does. This reaction may imply that there are other climatic factors that affected the growth during these years more than the lake levels. As Figure 4 shows, within the past 20 years, the lake level has been much lower overall than the average of this record, which is 176.4 m. There was also a slow overall increase in water levels up to the early 1980s, and then a slow overall decrease until 1990 where the water level leveled off at the new low. However, the annual growth did not level off at a below average growth, but continued to vary between growth above and below the mean. While the overall water level reached a below-average state in 1990 (Figure 4), and stayed there until 2014, the change in water level did rise and drop below the average, as seen in Figure 3 in the same way that the growth of the trees both rose and dropped during this period.

Overall, our study suggests that there is a strong correlation in the annual growth in insular forests and high and low level lake stands. For areas where little or no record exists of lake levels, the annual ring record can provide an accurate proxy for water levels in large lake systems.

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