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DENDROCHRONOLOGY AND WATER LEVELS AS INDICATORS OF RECENT CLIMATE CHANGE: GEORGIAN BAY, LAKE HURON (ONTARIO, CANADA)

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INTRODUCTION

As anthropogenic processes continue to contribute to global climate change, studies of past and current climates become increasingly important. Technology has given scientists the ability to use proxies for climate change (e.g., atmospheric CO_2, coral diversity) to determine past climate conditions. As climate fluctuates so do the levels of the oceans. As ice and snow build up on land and in glaciers during colder periods, sea levels fall. As temperatures rise, polar ice caps melt, glaciers retreat, and sea levels rise.

Dendrochronology can help identify major and subtle environmental events. Dendrochronology is the study of tree rings and is based on patterns of tree-ring growth. Characteristics such as ring width, color, and uniformity can indicate environmental changes and individual events such as forest fires or landslides. Tree cores can be taken from living or dead trees and compared to trees from the same region and time frame. Samples from trees that were growing at the same time can be matched based on a similar set of rings found in both samples. By matching up these signature ring patterns, dendrochronologists can extend the tree-core record back thousands of years. Because climate varies across different regions and factors that impact tree-ring growth can be quite different, a tree-ring chronology is only applicable to the local region.

Factors that influence tree-ring growth include rainfall, temperature, cloud cover, wind, soil properties, disease, and pollution. Through dendrochronology scientists aim to determine the impacts of each of these factors on the tree-ring record. Tree-ring data are more useful in locations with distinct seasons than in tropical regions where there is no single growing season. While many factors impact growth rates the main factor is climate, especially precipitation. A good growing season will consist of abundant rainfall, mild temperatures, and ample sunlight. These years are represented in the tree-core record as relatively thick tree rings. Tree rings are used in hydroclimatic studies to estimate precipitation and reconstruct past lake levels (Quinn and Sellinger, 2006). Soil properties tend not to change considerably from year to year in a given location, although they are highly variable from place to place.

The Georgian Bay, part of Lake Huron in Ontario, Canada (Diver, this volume, Fig. 2), is a geologically stable region where the tree-ring record is relatively well preserved and easy to interpret. Lake Huron connects to Lake Michigan via the Straits of Mackinac. Hydraulically, these three large bodies of freshwater act as one system (Bruxer and Southam, 2008). However, during the last ice age, glaciation in the area caused a large portion of the earth's crust to deform. Today the area experiences isostatic adjustment as the earth's crust rises in response to the retreat of the glaciers. Rates of isostatic rebound vary across the Great Lakes. The Georgian Bay has some of the highest rates of isostatic rebound in the area (Bruxer and Southam, 2008), which complicates evaluating water-level change in the area. Since the 1930's the Michigan-Huron basin has experienced low water levels in the 1930's, 1960's, and 2000's. Today, water levels are above average but are not at a historic high (Gronewold et al., 2013). Understanding how communities have responded to these water-level fluctuations is key for other coastal communities that must plan for future uncertain water levels.

METHODS

We used a stratified random sampling method to get a sample that is representative of the whole island. The size of the island determined the number of quadrats to be placed on that island. This sampling method is designed to be time-efficient and give a statistically accurate representation of each island (Diver, 2008), and has been used for the past twenty years. To determine sampling locations on each island the island was traced to scale. Five transect lines were placed along the island's long axis. Transect locations were based on a random number chart; however, they were stratified so that there was one transect within each fifth of the island's length.

A soil sample was collected at every site. Soil depth and GPS coordinates were recorded at the center of each quadrat. Within each ten-by-ten meter quadrat all trees (diameter at breast height greater than 10 cm) were measured and their species identified and recorded. All saplings (DBH between 2.5 and 10 cm) were identified and counted, but not measured. Seedlings (DBH less than 2.5 cm) were identified and counted within each one-by-one meter corner of the quadrat and at the center of the quadrat.

Skeleton plots were created of each individual core. Skeleton plots are used to compare tree-ring patterns across different core samples taken from trees in a given area. On such plots a longer dash represents a thinner ring relative to the rings around it (Fig.1). Groups of narrow tree rings, if found in multiple core samples that date to the same year, are indicative of poor growing conditions most likely due to a decrease in precipitation. Tree cores were collected from a variety of species and from a diverse size range. Emphasis, however, was given to larger healthy trees because they generally produce longer and higher-quality cores. Trees with rot at their center cannot yield useful dendrochronologic information and older trees provide more climate information. Tree cores were not collected at a specific interval, although several cores were collected on each island if possible.

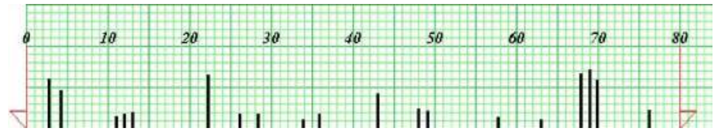

Figure 1. Skeleton plot of a tree that is 80 years old. The x-axis represents years: 0 is the year the tree was cored (2016) and 80 is the center of the tree. Vertical marks are made according to the relative narrowness of each ring. Dendrochronologists typically accentuate narrow rings because narrow rings are consistently expressed by most trees within a particular stand (Sheppard, 2014). Rings of average width merit no mark on the skeleton plot.

RESULTS

The Great Lakes have undergone many water-level fluctuations throughout the Quaternary. Climate change is responsible for water inputs due to the melting of glaciers or water removal from the system as polar ice caps grow during cold periods. Over the past sixteen years the water levels in the Lake Michigan-Huron system have fluctuated from about 175.7 to 176.6 m amsl (above mean sea level) (Fig. 2). Years 2015 and 2016 represent the highest water levels recorded during this time.

The effects of water level can be seen most noticeably in island area. Small changes in water level can have drastic impacts on island area. The islands studied show a decrease in area over the past fifteen years as portions of land above water during low-water years early in the study period became submerged in 2015 and 2016 (Fig. 3). Over the sixteen-year period that these islands have been studied water levels have varied but the net difference from 2001 to 2016 is about 0.7 m. Island-area change does not have a linear relationship with water-level change. Differences in water levels have a more dramatic effect on larger islands than on smaller islands (more surface area is lost per unit rise or fall). In addition the shape and slope of the island control exposed surface area. Water-level change is dependent on many variables including precipitation, groundwater, stream flow into the system, and stream flow out of the system. In this paper I focus on precipitation because those data are reflected in the dendrochronologic record and are related to climate change. Figure 4 shows the total precipitation for each year from 2001 to 2016.

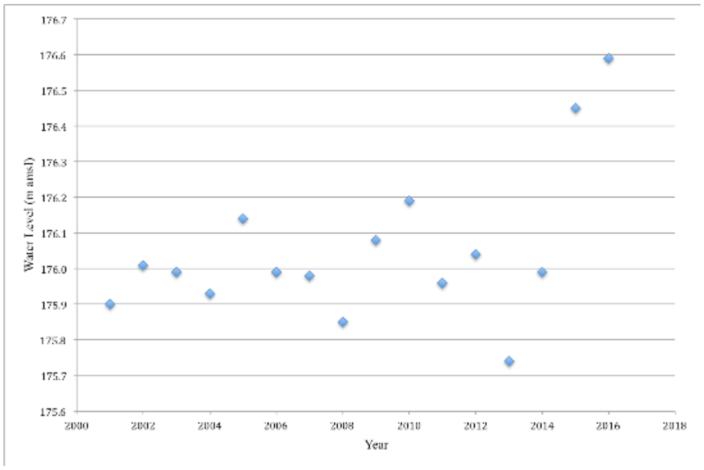

Figure 2. Yearly mean water level averaged from daily mean water level as recorded at Parry Sound, Ontario. (Data from Canadian Department of Fisheries and Oceans).

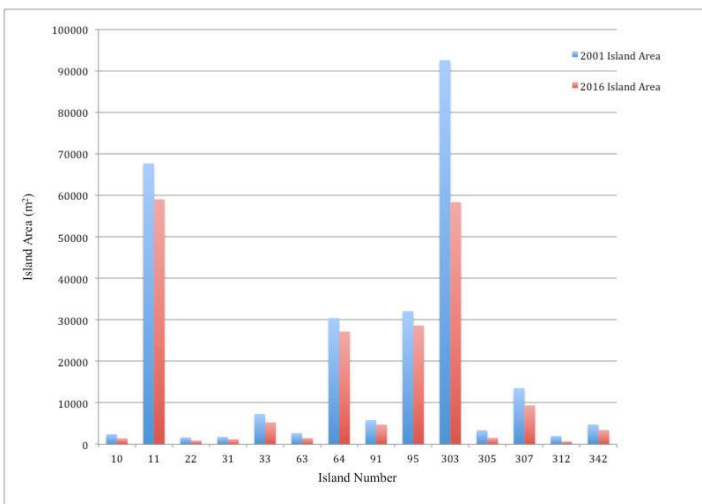

Figure 3. Comparison of island area in 2001 vs. 2016. (Data from Kim Diver, unpublished).

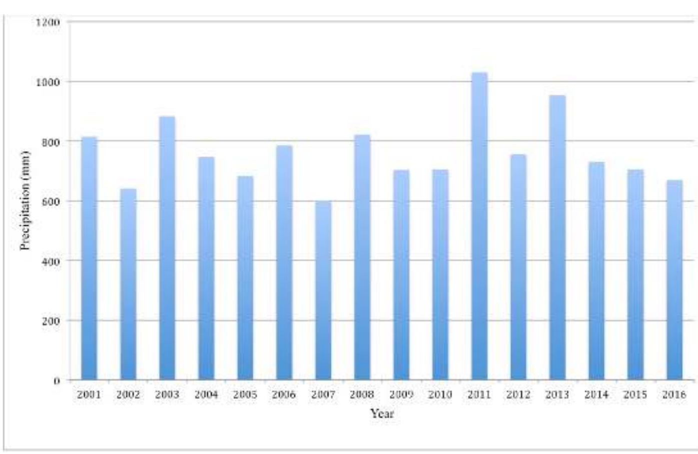

Figure 4. Annual precipitation from 2001 to 2016 in Georgian Bay, Ontario. (Data from Canadian Department of Fisheries and Oceans). Station Wiarton A, Ontario, is the closest precipitation measurement station to the field site.

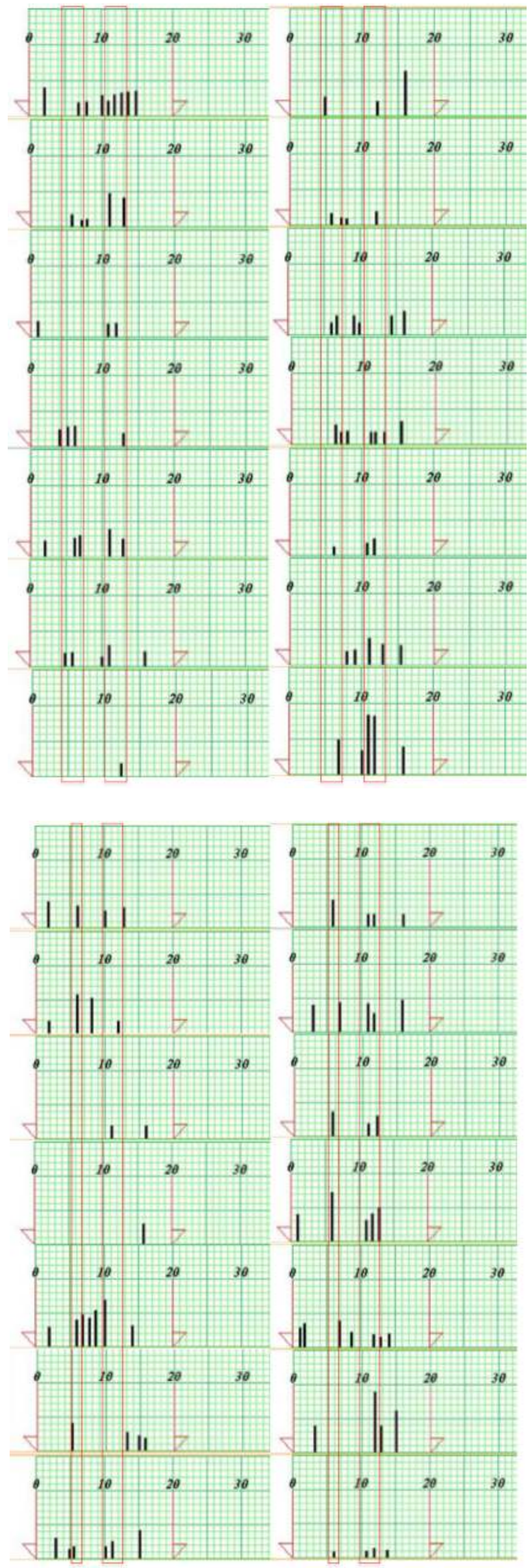

Figure 5. Skeleton plots of 28 tree cores collected in 2016. Data from the past sixteen years were plotted because island area data only extend back sixteen years. Red rectangles highlight years 2012 and 2007 when precipitation was below average. In these years the majority of tree cores show rings that are relatively narrow compared to average ring thickness.

The average annual precipitation was about 764 mm per year for the time period. In the tree-ring record, years with precipitation totals close to this should have ring thicknesses very similar to adjacent rings. Years with less than average precipitation totals should produce tree rings that are thinner than adjacent rings; such narrow widths are used by dendrochronologists to find patterns in the tree-ring record and interpret past climate events.

Skeleton plots of the tree cores that were collected in the field during 2016 yielded a pattern that suggest at least two distinct periods with little growth. These periods are thus represented by narrow tree rings, which probably reflect low precipitation levels. Narrow tree rings were found in 2007 and 2012. In 2007, 19 out of 28 (68%) tree cores had narrower rings; in 2012, 18 out of 28 (64%) had narrower than average rings.

DISCUSSION

The Lake Michigan-Huron water system is a vast freshwater system; lake levels are controlled by a number of variables including precipitation, groundwater flow into the lakes, winter water evaporation rates as influenced by ice cover, stream flow into and out of the lakes, and human interference such as dams. In this study I chose to focus on precipitation because that is the primary component of the water budget for the Michigan-Huron water system that is related to dendrochronology. All of the factors mentioned above control water levels in the Great Lakes; however, precipitation is the most variable as it is controlled directly by climate. Groundwater flow rates tend to be consistent and generally vary on local rather than regional scales (Eberts and George, 2000). Anthropogenic interference, such as large municipal wells or extensive groundwater pumping due to agriculture, can change groundwater flow patterns; however, on a scale as large as the Lake Huron-Michigan water basin, such effects are negligible.

Humans control stream flow into and out of the Great Lakes: when dams are built they effectively change the rate at which water enters or exits the system. However, because the system is so vast, dams and other water diversions do not affect long-term lake levels (Indiana DNR). Human interference does little to influence lake levels in the short term as well. Dams only help alleviate lake-level extremes during flood events. Further downstream in the Great Lakes water system, Niagara Falls acts as a control for all lakes except Lake Ontario because of the difference in elevation between the lakes upstream of Niagara Falls and Lake Ontario.

Another complication with this analysis of Great Lakes water levels are the effects of isostatic rebound from the last ice age. In the study region isostatic rebound rates are on the order of 27 cm per century (Neff and Nicholas, 2005). In this study only data from the past sixteen years are included; in that very short time scale isostatic rebound has caused the whole region to rise 4.32 cm. This is equivalent to a 4.32 cm drop in water level. As the area covered by the last glacial maximum rises due to the retreat of the glaciers, the water within that region will naturally flow to lower elevations and eventually to the ocean. The entire Great Lakes region was covered by the last glacial advance and as a result continues to rise as the crust and upper mantle adjust to a new equilibrium. The rise in Great Lakes water levels in recent years (Fig. 2) is therefore mitigated by the regional effects of isostatic rebound. Baedke and Thompson (2000) have made four relative curves of past lake levels as a function of isostatic rebound. All curves show similar fluctuations in lake levels but rates of uplift vary among different models and across the region. Clark et al. (2007) have suggested (in addition to varying rates of uplift) that a tilting of the whole region is a result of isostatic rebound. Similar to how the water level and orientation of the water surface in a bowl changes as the bowl is slowly tipped to one side, the Great Lakes have been subjected to varying degrees of tilting since the last ice age. This issue further complicates reconstructions of past Great Lakes water levels.

As expected when water levels rise there is a resulting loss of land area along the shores of these water bodies. The islands in the Georgian Bay are severely affected by small changes in water level. Figure 3 shows how each island was affected by the change in lake levels from 2001 to 2016. In this short time frame and with a 0.6 m change in lake level, all islands lost a significant portion of their area. Island 303 is an exception. When water levels were low as in 2001, the island was connected to an adjacent island through a low-lying bridge of land. When water levels are high enough to submerge that land bridge, one island becomes two islands; this accounts for the drastic drop in the area of island 303 from 2001 to 2016.

Perhaps the most dramatic result of this study is the rate of water-level rise over the past four years. Since 2013 water levels have gone from a low of 175.74 meters amsl to 176.59 in 2016. This almost one-meter rise in lake levels in only four years is very alarming especially because it doesn't agree with local precipitation data. Precipitation data for these years are just about average (Fig. 4), yet lake levels continue to rise at 21 cm per year. Gronewold et al. (2016) attribute this to above-average spring runoff and below-average evaporation as well as very high inflow rates from Lake Superior through the St. Mary's River.

CONCLUSION

This study shows the effects that changing water levels have on islands in the Georgian Bay. The use of dendrochronology to reconstruct past climactic change helps us quantify how severe climate change is. The tree-ring data tell us which years were particularly stressful for tree growth. These years match up well with years when there was below-average precipitation. Water-level changes, however, do not line up with fluctuations in precipitation. Precipitation totals have been about average for the past four years, yet water levels continue to rise to the highest levels recorded in the past sixteen years. As water levels rise, island area in the region shrinks. The area lost is a function of the size and slope of each island. Islands with low-relief shorelines are affected much more than islands with high-relief shorelines. Further research on the driving forces of water-level change in the Great Lakes, as well as a more complete dendrochronologic record, will yield more information on the relationship between climate and lake-level fluctuations. Understanding how climate change affects the health of the islands in the Georgian Bay is key to managing the entire Great Lakes system and making sure that human interference is not causing extreme rates of lake-level change.

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