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DENDROCHRONOLOGICAL ANALYSIS OF INSULAR FOREST STANDS IN RELATION TO CLIMATE AND WATER-LEVEL FLUCTUATIONS IN THE GREAT LAKES

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INTRODUCTION

Global and regional environmental change has resulted in water-level changes in the world's oceans and large lakes. Examination of the dynamic terrestrial-aquatic interface in the Great Lakes is pertinent to many of the conservation and policy issues in the region today. The Great Lakes have a history of water-level fluctuations. The Great Lakes contain the world's largest collection of freshwater islands (Vigmostad 1999). The majority of these islands form dense archipelagos in the Canadian waters of Lake Huron's Georgian Bay (Ontario). Little is known regarding the role of feedbacks between climate patterns, coastline geomorphology, and shoreline vegetation on species richness patterns on islands. This project combined dendrochronological analyses, spatial analyses, soil analyses, and ecological analyses to examine the interplay of regional climate, water levels, soils, and forest dynamics on plant species richness and composition patterns within the Ontario Ministry of Natural Resources' The Massasauga Provincial Park. Project objectives included: (1) tree-ring reconstructions of recent climate history in the study area (L. Bournival and M. Kelly); (2) soil characterization comparisons between recently emerged and established substrates (E. Steinfeld); and (3) spatiotemporal forest dynamics (not investigated by a Keck student). The research objectives were analyzed in relation to vegetation surveys of plant species richness to shed light on the applicability of the prevailing model of island biogeography (Equilibrium Model of Island Biogeography; MacArthur & Wilson 1967) in areas with fluctuating water levels. Previous studies in The Massasauga show that island area, island shape, and island isolation are the main drivers of the diversity of plant species on islands within the archipelago (Diver 2004, 2008). The project utilizes multifaceted approaches not hitherto studied within the scope of island biogeography theory and may contribute to a contemporary theory of island biogeography.

STUDY AREA

The islands of the The Massasauga are located within the UNESCO Georgian Bay Littoral World Biosphere Reserve. The Georgian Bay comprises the northwest portion of the Laurentian Great Lakes, separated from Lake Huron by the Bruce Peninsula and Manitoulin Island. The park consists of over 200 islands, of which 16 were inventoried for plant species richness, substrate characteristics, and forest characteristics in July 2016 (Fig. 1).

The Massasauga consists of Canadian Shield bedrock, with evidence of relict bedding and tectonic activity (Cordiner 1977; Sly & Munawar 1988; Larson & Schaetzl 2001). The archipelago was formed by glacial scouring, erosion from glacial meltwater drainages, and post-glacial isolation. Detailed reviews of glacial and postglacial lake level history of the Georgian Bay region are provided in and Eschman & Karrow (1985). The Massasauga islands permanently emerged as dry land 3-4 ka, following isostatic rebound and draining of the higher than present day lake levels associated with the postglacial Nipissing Great Lakes Periods (Larson and Schaetzl 2001). Lake levels for the past 2.5 ka show a stabilized mean of 177 m asl (Eschman & Karrow 1985).

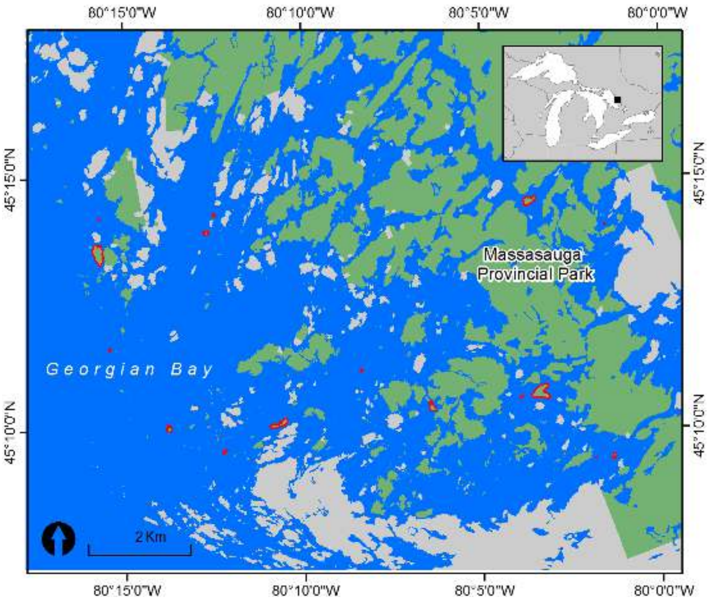

Figure 1. Map of the study area within The Massasauga Provincial Park, Ontario, Canada. The park (green) consists of mainland and approximately 200 islands. The sixteen islands sampled during summer 2016 are outlined in red. (Cartography by the author. Data sources: E. Steinfeld 2016; Esri 2010; Esri Canada 2014; Geography Network Canada 1984.)

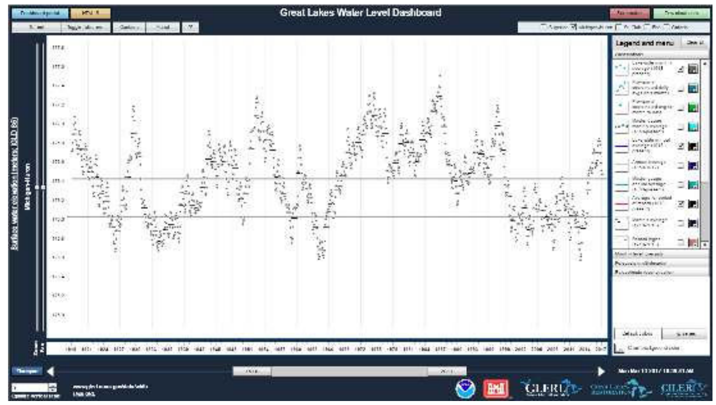

Figure 2. Historic monthly and annual mean water levels for the Lake Michigan – Huron basin, 1918-2017. X-axis displays years and y-axis displays meters above sea level. The black horizontal line shows the average level for the period of record (176.42 m asl). The gray horizontal line indicates the International Great Lakes Datum (IGLD 1985; 176.0 m asl). Black short dash lines designate annual averages. A coordinated network of US and Canadian gauging stations on each lake determines the average water level per month (black dots). For an interactive version of the data, visit https://www.glerl.noaa.gov/data/dashboard/GLWLD.html (Source: Gronewold et al. 2013).

Historic levels in the Michigan-Huron basin show marked fluctuations between approximately 175 and 178 m asl, with chart datum at 176 m asl (Fig. 2). The study area had been experiencing a prolonged low-water stage over the past 15 years with a recent swing to above-average levels. The record high level (1986) was approached with annual mean water levels at 177.5 m asl (Bishop 1990). Since 1998, water levels have fallen below the long-term average of 177 m asl. The January 2013 monthly mean (175.57 m asl) exceeded the previously lowest recorded monthly mean water level of 175.68 m asl from 1964. Current lake levels (February 2017 monthly mean 176.47 m asl; 2016 annual mean 176.7 m asl) remain below the long-term average but are above the historic average (176.42 m asl), indicating an end to the prolonged low-water period.

METHODOLOGY

The Keck team included 1 professor (Diver), 1 graduate student (T. Hill), and three Keck undergraduate students (Steinfeld, Kelly, Bournival). Fieldwork (Diver, Hill, Steinfeld, Kelly) consisted of mapping out sample transects and plots for 16 islands in The Massasauga, commuting to islands via motorboat, data collection via foot, sample prep (e.g. drying soil, creating plant voucher specimens), and preliminary data entry. Participants visited an island together, but then separated into data collection teams. We collected plant species richness data along stratified random transects and tree species abundance, tree diameter (dbh), tree cores, soil depth, soil and habitat characteristics, soil samples, and geographic position within plots in stratified random positions along the transects (Fig. 3). For detailed methods, see Diver (2004).

Laboratory work (Diver, Hill, Steinfeld, Kelly, Bournival) conducted as a team consisted of processing tree core, soil, and plant samples at Wesleyan University in the Earth & Environmental Sciences Department. Tree cores were dried, glued onto wooden mounts, and sanded. All cores in Diver's collection (field years 2000, 2001, 2006, 2011, 2016) were scanned at high resolution (Epson V200) for skeleton plotting and for use in ImageJ (https://imagej.net). Soil pH analyses followed standard soil pH methods (Bickelhaupt and White 1982) using air-dried samples and an Oakton Acorn electrode meter. Unknown plant species were identified using previous field year voucher specimens as well as regional

Figure 3. Collection of soil (E. Steinfeld, left), tree diameter (T. Hill, center), and geographic location (M. Kelly, right) within a sample plot.

taxonomic guides. Data sheet information was transcribed into Excel (Microsoft) and ArcMap 10.3 (Esri). A key finding of a previous Keck project was that obtaining accurate island areas for a region with dynamic water levels is important (Diver 2014, Edgley 2014). However, existing available data reflects island shorelines at high water levels. Therefore, we obtained up-to-date island areas and perimeters from GPS data collected onsite and satellite imagery input into a geographic information system (GIS). Further laboratory analyses were conducted individually at each student's home institution.

STUDENT PROJECTS

Leah Bournival (Mount Holyoke College) *A Dendrochronological Record of Twentieth Century Water Levels in Georgian Bay, Ontario, Canada*. Dendrochronological analyses can offer insights into regional climate histories. Climatic and environmental factors influence the growth of tree rings from inter-annual to millennial time-scales. Tree rings allow for the accurate dating of past climatic and environmental conditions. Bournival tested whether tree-ring analyses can yield information about regional climate variability that can then be correlated to the timing of high and low water-level stages. Islands in the study area undergo harsh growing conditions (e.g. water and temperature stress, limited nutrient availability, restricted root growth space) and decreased anthropogenic disturbance (e.g. logging and fire) due to protected status, which can allow for extensive chronologies of climate variability (Kelly & Larson 1997). Bournival analyzed tree ring widths to establish a chronology and then compared the ring trends and chronology to water-level and climate patterns for the region. Focusing on white pine and eastern hemlock species, Bournival found a poor series intercorrelation for either species yet a strong correlation between annual ring growth and lake level. The lack of strong intercorrelations is likely due to geographic variability in the limiting factors to tree growth in conjunction with an insufficient sample of tree cores to capture the variability. A key finding of Bournival's work is that tree core data (annual ring growth) can be used as an accurate proxy for water level variability in large lakes. Further analyses could analyze annual ring growth of the two species in relation to local precipitation data as well as expanding the analyses to additional tree species.

Matt Kelly (Beloit College) *Dendrochronology and Water Levels as Indicators of Recent Climate Change*. Suggested causes of water-level fluctuations in the Michigan-Huron basin include differential rates of isostatic rebound within the basin, human-driven diversion and depletion of water from the drainage basin, altered rates of groundwater flow, and climatic changes related to annual local precipitation, reduced snowpack in the Lake Superior basin, as well as feedbacks between climate processes and reduced lake ice cover (Schwartz et al. 2007). Kelly focused on precipitation because that is a component of the water budget potentially evident in tree ring records. He examined tree-ring widths as a proxy for regional precipitation and then tested whether tree-ring widths correlate with changing island areas and water levels over the 15-year data record. Two distinct periods of little tree ring growth (e.g., narrow rings) correspond to years with below-average precipitation in the region. Precipitation data did not correspond to water levels during the study period, especially for the recent years of above-average lake levels. As expected, island areas decreased between 2001 (a low-water year) and 2016 (a high-water year). Although precipitation could not be attributed as the main driver of change, a key finding by Kelly is the utility of tree rings in pinpointing recent, short-term climatic and environmental changes in a complex system. Interpretation of the results is complicated due to influences of island connectivity on island area change calculations and isostatic rebound on water level reconstructions.

Ezra Steinfeld (Wesleyan University) *A GIS Approach to the Effects of Water-Level Change on Soil Properties and Tree Species Richness*. Determining the spatial heterogeneity of soil characteristics in relation to the spatial heterogeneity of newly emerged shoreline substrates is important in predicting habitat diversity and, thus, plant species richness patterns on the islands in response to fluctuating water levels. The expectation of the second project objective was that soil properties differ significantly between recently emerged and established substrates, which could play an important role in interisland patterns of plant species composition and richness. Steinfeld digitized established and newly emerged land areas for each of the sampled islands based on field data, lake level data, and orthoimagery (West Parry Sound Geography Network) in a GIS. He then analyzed emergence history in relation to soil pH and other variables. The results indicate that established substrates had deeper soils, more seedlings/saplings, and higher tree species richness as compared to recently emerged shoreline substrates. Steinfeld attributes the differences to water-level fluctuations and the detrimental effect of submersion on soils and soil formational processes. Although the original hypothesis of pH variability with exposure was not supported, a key finding of Steinfeld's work is that soil depth does vary in relation to substrate exposure and is likely a key habitat heterogeneity factor on the islands. The interplay of water level variability, substrate exposure, and soil depth should be analyzed further in terms of implications on insular plant species distributions. Islands with more recently emerged land area may have a greater diversity of habitats regardless of island size, thus contributing to greater species richness on those islands. Emerging shorelines of The Massasauga islands are accessible to plant species establishment either through colonization of new propagules and/or buried seed banks. Future work could take Steinfeld's results and examine whether the spatial variation in non-native plant species (early colonizers) and at-risk shoreline plant species (buried seed banks) in The Massasauga can be explained by substrate exposure or depth.

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