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RISING WATERS, SHRINKING HABITATS: THE INFLUENCE OF FLUCTUATING WATER LEVELS ON THE GEOLOGY AND ECOLOGY OF A GREAT LAKES ARCHIPELAGO

KIM C. DIVER, Wesleyan University
JENNA OTAOLA, Peer Mentor, Wesleyan University

INTRODUCTION

Global and regional environmental change has resulted in water-level changes in the world's oceans and large lakes. The Great Lakes have a history of water-level fluctuations (Figure 1). A prolonged low water stage in the Huron-Michigan basin occurred from 1999-2014, with a record low in January 2013 (175.57 meters above sea level). Subsequent years showed a rapid climb above the long-term average, with near-record high levels in 2020 (177.45 m asl). (Note: the record high of 177.50 m asl occurred in 1986.) In this project, we used field data and satellite/aerial imagery spread over twenty years to analyze the spatiotemporal interplay of water-level fluctuations, shoreline configuration, and island characteristics affecting plant communities on islands in the Georgian Bay of Lake Huron.

Little is known regarding the role of feedbacks between climate patterns, coastline geomorphology, and shoreline vegetation on species richness patterns on islands. The Great Lakes contain the world's largest collection of freshwater islands (Vigmostad, 1999). Many of these islands form dense archipelagos in Lake Huron's Georgian Bay (Ontario, Canada). We investigated spatiotemporal changes in island shoreline configuration and plant biogeography within the Ontario Ministry of Natural Resources' The Massasauga Provincial Park (Figure 2) on the eastern shore of the Georgian Bay and within the UNESCO Georgian Bay Littoral Biosphere Reserve. We hypothesized that the fluctuating water levels influence the area and shoreline configuration of the islands as shorelines and low elevation islands emerge and submerge with these fluctuations. The project had two main research objectives: (1) create accurate island shoreline data for years with field data and the existing low- and high-water years within the 2001-2021 study period and (2) analyze the influence of water level changes on shorelines (e.g., island area, shape), island characteristics (e.g., soil properties, shoreline types), and island ecosystems (plant species richness). The overall objective was to shed light on the applicability of the prevailing model of island biogeography in areas with fluctuating water levels.

STUDENT PROJECTS

This research involved four rising sophomore students, a rising senior near-peer mentor, and one faculty member. The 2001-2021 study period included four

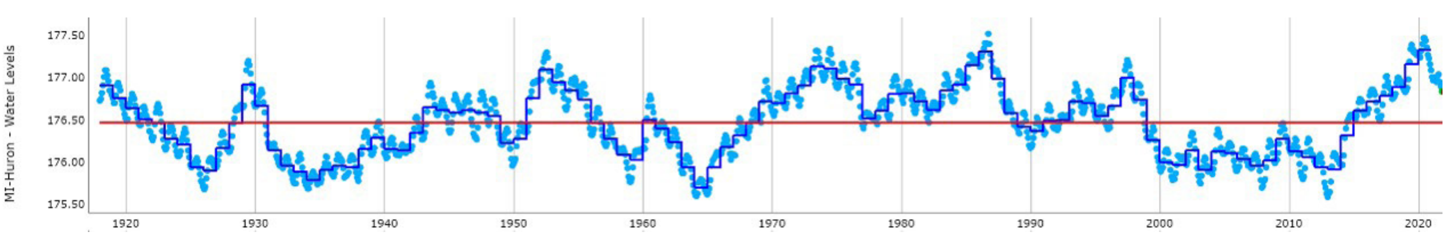

Figure 1. Historical monthly (light blue dots) and yearly (dark blue line) mean water level for the Lake Michigan – Huron Basin, 1918-2021. Note the prolonged low water period of 1999-2014. The vertical axis denotes lake level in meters above sea level (m asl). The red line indicates the average level (176.44 m asl) across the time period. Image source: Great Lakes Dashboard Project (https://www.glerl.noaa.gov/data/dashboard/GLD_HTML5.html).

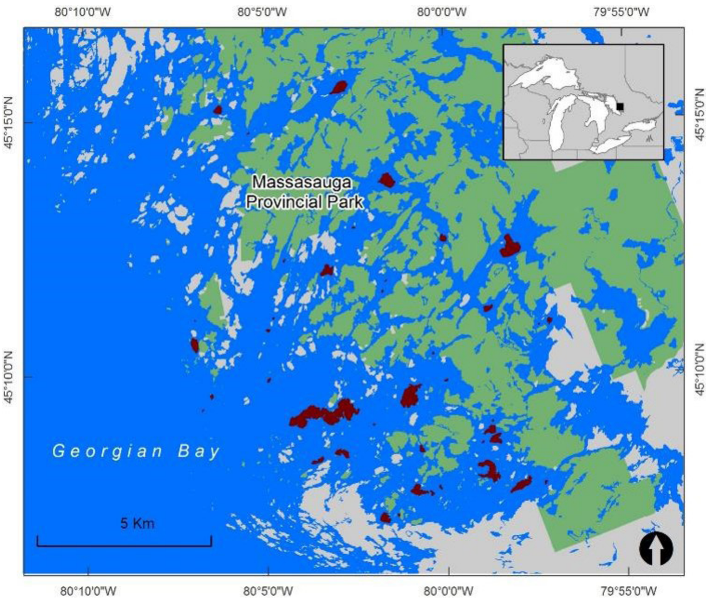

Figure 2. Map of The Massasauga Provincial Park, Ontario, Canada. The park (green and red) consists of mainland and approximately 200 islands. Red islands are park islands sampled during 2001 (n = 34), 2006 (n = 19), 2011 (n = 17), and 2016 (n = 16), for a total of 45 islands.

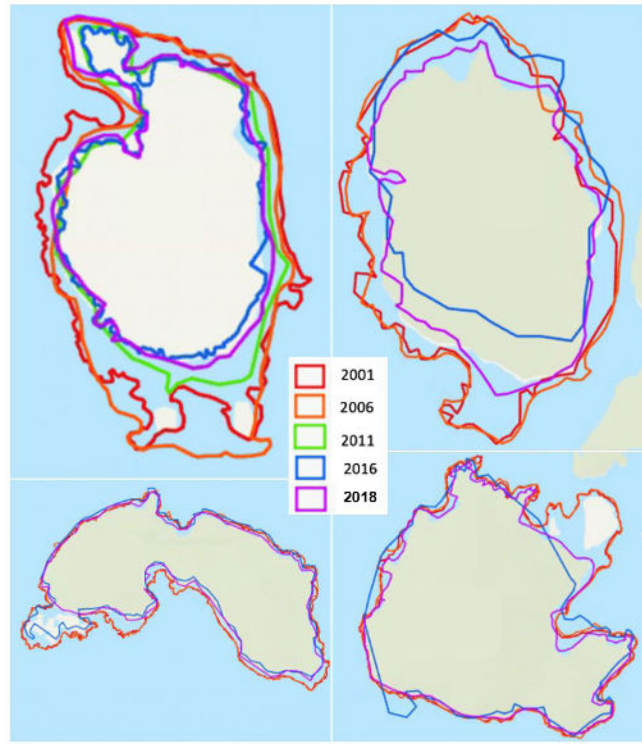

Figure 3. Visual depiction of the island shoreline database for five years and four islands in the database. Note: Islands are depicted at different scales.

years of previously collected field data (2001, 2006, 2011, and 2016) and two additional years of solely remotely sensed data (the 2013 low-water year and 2018, which was the highest water level imagery we could obtain). Average annual lake levels for the study periods were 175.95 m asl (above sea level) in 2001, 176.02 m asl in 2006, 176.04 m asl in 2011, 175.90 m asl in 2013, 176.70 m asl in 2016, 176.87 m asl in 2018, and 177.31 m asl in 2020. Field data included plant species richness, shoreline Global Positioning System (GPS) waypoints, and soils data. Imagery included orthophotos (West Parry Sound Geographic Network) and WorldView-2 (Digital Globe) satellite imagery. Imagery and field data were obtained during the July of their respective year. Together, we created an island shoreline database consisting of island shoreline polygons for each year in the study period (Figure 3). We created the shoreline polygons in ArcGIS Pro v2.8 (Esri) by referencing the GPS waypoints and the aerial/satellite imagery. Individual student projects revolved around issues of global environmental change at a local level.

Relationships between island area and water levels

Veronica Seixas (Hamilton College)

Island area is an important predictor of plant species richness (MacArthur & Wilson, 1967). Fluctuating water levels alter the morphology and area of the islands. Veronica performed t-tests, ANOVA tests, and correlations to analyze statistical relationships between island shape and water level. The percent change in island area was moderately correlated ($r = 0.608$, $p < 0.0001$) with the percent change in water level. A significant difference in island area existed between most of the years, thus indicating that island area does change with water level changes. The results have implications for island biogeography theory, which postulates that island area is a major influence on species occurrence on islands. Islands that decrease in size with high water levels should correlate with less plant species presence. A particular group of plant species, the Atlantic Coastal Plain disjunct species, appear on sandy shores in the region only during low water years and survive as underwater buried seed banks during high water years (Reznicek, 1994). More of these regionally rare species are expected on islands with emerging sandy shorelines. Future research should include additional years of imagery as well as additional islands from other archipelagoes in the lake.

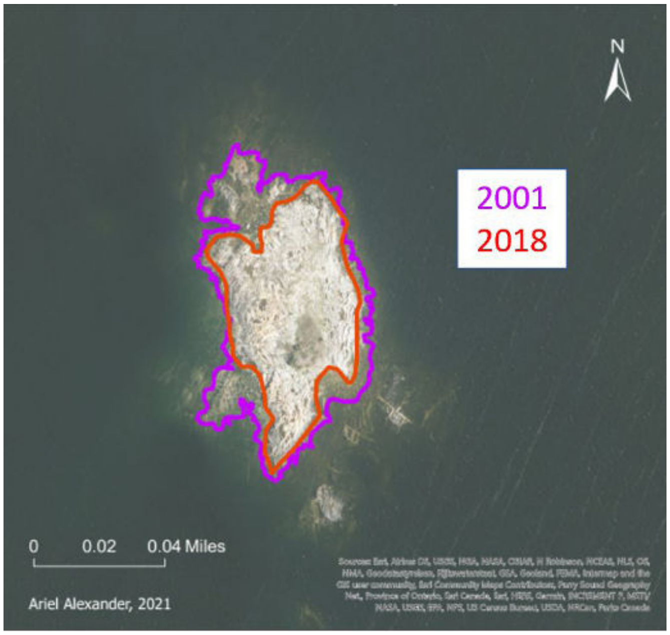

Figure 4. Shorelines for Matches Island in 2001 (purple) and 2018 (red). Results indicate that lower water levels correspond to irregular shoreline shapes and greater diversity of plant species.

Relationships between island shape, soil depth, non-native plant species, and water levels

Ariel Alexander (Carleton College)

Ariel's project had three aims: (1) to determine if island shape and soil characteristics fluctuate based on the water year; (2) to determine if native and non-native plant species richness varies in response to changing island shape and soil depth for the islands of interest; and (3) to determine if certain non-native plant species are recurring due to outcompetition of native species. Island shape was calculated as a function of island perimeter to the perimeter of a circle with area equal to the island. Shoreline shapes did change depending on the water year: shapes were more irregular in low water years than in high water years (Figure 4). Native and non-native plant species were located on islands with a more irregular shoreline. Irregular shorelines might better capture water dispersing plants such as the non-native mossy stonecrop (Sedum acre L.). Soil depth was positively correlated to native plant species richness. With soil depth serving as a proxy for habitat diversity, the results show that islands with deeper soils allow for the presence of both shallow- and deep-rooting plants. The results of the study have implications for park management, especially as related to non-native plant species presence along island shorelines with fluctuating water levels.

Relationships between island elevation, non-native plant species, and water levels

Ryann Busillo (Wesleyan University)

Monitoring the role of fluctuating conditions such as water levels on non-native species is important not only for understanding the complex ecology of the region but also to assist park authorities in managing native plant populations. Ryann used island morphology data (e.g., area, perimeter, maximum elevation) in conjunction with species presence/absence data from the four field years to analyze spatiotemporal trends in non-native plant species over the twenty-year study period. Four non-native plant species not encountered in 2001 were present in 2006. A handful of non-native plant species previously undocumented in the park were encountered in 2011. The non-native plant sheep sorrel (Rumex acetosella L.) was less abundant in 2016 than during previous field seasons. Mossy stonecrop continues to be a prevalent non-native invader of newly emerged bedrock habitats. Species-perimeter, species-area, and species-elevation relationships were not statistically significant for the 2011 field year. Species-perimeter relationships were statistically significant ($p < 0.01$) for the three other field years, with little difference between the strength of correlations for native and non-native plant species for the 2001 and 2006 field years. However, for field year 2016, relationships for native plant species ($r = 0.853$) were considerably stronger than for non-native plant species ($r = 0.674$). Species-area relationships showed a similar pattern to species-perimeter relationships, with the exception of a non-significant correlation for non-native species in 2016. For species-elevation relationships, there was a considerable difference between native ($r = 0.827$) and non-native plant species ($r = 0.687$) during the 2006 field year. The results suggest that non-native plant species might respond differently to water level changes than native plant species. However, further investigation is necessary.

Relationships between shoreline character and water levels

Adalia Rodriguez (Bryn Mawr College)

Shorelines in The Massasauga are varied (e.g., steep cliff, sandy beach, cobble shore) and therefore affect the colonization and persistence ability of plants differently. Adalia used the island shoreline database to quantify the shoreline character and identify any shoreline sections that changed significantly with differing water levels. Of the islands surveyed during field excursions, ten islands were sampled each year. These ten islands were used to compare changes in shorelines. Generally, visual analysis of the shorelines indicated that shoreline change is occurring. For example, qualitative evaluation showed more marshy shorelines in higher water level years than low water level years. However, the results of the statistical analyses were insignificant. This suggests that a combination of higher resolution imagery and more precise measures of shoreline change are necessary to sufficiently examine the degree of shoreline change and any relationship of those changes with fluctuating water levels.

IMPLICATIONS OF THE WORK

A longitudinal study pairing field data with water level data to understand species richness patterns is a novel, but necessary, approach to island biogeography. Analyzing data in The Massasauga over time may elucidate clearer distribution patterns and predictive models of plant species in the park than the ecological snapshot typically derived from island biogeographical research. Results indicate that island areas change significantly with varied water levels and that species richness changes in concert with changes in area, thus it is imperative for island biogeographers to consider water levels and island areas in relation to the timing of fieldwork. Furthermore, studying the island biogeography of this archipelago over an extended time frame will allow for a better scientific understanding of ecological resilience in a system with unstable water levels. Examination of the dynamic terrestrial-aquatic interface in the Great Lakes is pertinent to many of the conservation policy issues in the region today.

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