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Short Contributions— GIS Approach to Water-Level Change Project

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Research Advisor: Kim Diver

DECLINING WATER LEVEL IN LAKE MICHIGAN-HURON AND THE EFFECT ON ISLANDS IN THE MASSASAUGA PROVINCIAL PARK, ONTARIO
EMILIE SINKLER,Wesleyan University
Research Advisor: Kim Diver

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POTENTIAL EFFECTS OF WATER-LEVEL CHANGES ON ISLAND ECOSYSTEMS: A GIS SPATIOTEMPORAL ANALYSIS OF SHORELINE CONFIGURATION

KIM DIVER, Wesleyan University

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 (Fig. 1). The lakes have been experiencing declining water levels over the past decade and the trend is expected to continue due to differential rates of isostatic rebound within the basin, human-driven diversion and depletion of water from the drainage basin, and climatic changes related to reduced snowpack in the Lake Superior basin as well as feedbacks between climate processes and reduced lake ice cover.

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). This project investigated spatiotemporal changes in island shoreline configuration within the Ontario Ministry of Natural Resources' The Massasauga Provincial Park on the eastern shore of the Georgian Bay using the mapping and analytical tools of a geographic information system (GIS).

Although the Great Lakes have been experiencing a low-water period over the past decade, existing data on island area in The Massasauga is based on high-water stages of the lake. (Marine navigational charts are updated in a timely manner, but the data are not available for use in a GIS and are not at an appropriate scale for detailed analysis.) Project objectives included (1) creating accurate island shoreline GIS data from aerial photo and satellite imagery for periods corresponding to existing plant species richness inventory data, (2) analyzing the influence of water level changes on shoreline modifications (island area, shape, composition) and island ecosystems (plant species richness), and (3) modeling future changes in island area based on existing long-term water level projections. Objective 1 commenced collaboratively during the summer portion of the project whereas Objectives 2 and 3 were conducted by R. Edgley and E. Sinkler, respectively, throughout the 2013-14 academic year.

Studies of island biodiversity are influenced by MacArthur and Wilson's (1967) Equilibrium Theory

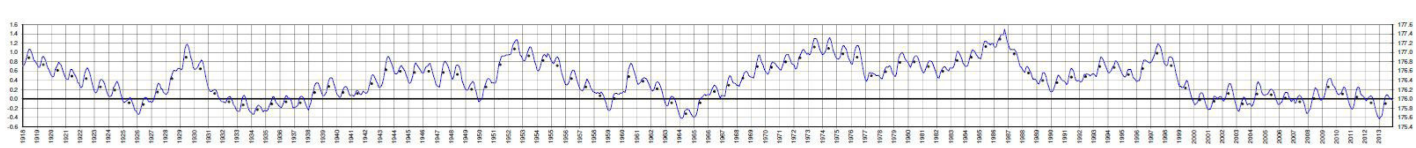

Figure 1. Historical monthly and annual mean water levels for the Lake Michigan – Huron basin, 1918-2013. X-axis indicates years and y-axis indicates elevation relative to International Great Lakes Datum 1985 (176.0 m asl; right) and height (m) above or below chart datum (left). A coordinated network of US and Canadian gauging stations on each lake determines the average water level per month. For an enlarged version of the chart, visit the source: The Canadian Hydrographic Service (http://www.waterlevels.gc.ca/C&A/netgraphs_e.html). For an interactive version of the data, visit http://www.glerl.noaa.gov/data/now/wlevels/dbd/.

of Island Biogeography. The Equilibrium Model predicts that the composition of species on an island changes over time (i.e. turnover) but that the numbers of species remain at equilibrium. The influence of island isolation and island area on immigration and extinction rates, respectively, determines the equilibrium number of species for an island due to the decreased likelihood of extinction on large islands and the increased likelihood of immigration to near islands. An increase in island area and a decrease in island isolation frequently correlate with an increase in species richness. 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). Therefore, islands that increase in size and decrease in isolation (due to increased connectivity of select islands into a single land mass) with low water levels should correlate with a greater number of plant species.

Invasive non-native species cause or indirectly facilitate native species extinctions on a global scale (Rosenzweig 2001). On islands, however, the pattern is less clear (Sax & Gaines 2003) because, although the species richness of an island may initially increase due to the addition of non-native species, a single non-native species may gradually out-compete multiple native species, leading to an overall decrease of species richness. The spatial variation of non-native plant species richness in The Massasauga is unexplained by area, habitat heterogeneity, or isolation. Proponents of an updated model of island biogeography recognize the importance of multiple interrelated variables on the dispersal and persistence of species on islands (Lomolino *et al.* 2010). Emerging shorelines of The Massasauga islands are accessible to establishment either through colonization of new propagules and/or buried seed banks. Non-native plant species are typically early colonizers and efficient reproducers, thereby outcompeting native plant colonizers on newly emerged shorelines. Many of the indigenous species at risk [*e.g.* Atlantic Coastal Plain disjunct species and endemic *Linum medium* (Planch.) Britton var. *medium* (stiff yellow flax)] are shoreline plants vulnerable to disturbance and aggressive competition.

Island biogeography studies typically focus on spatial patterns of floristic species richness at a given point in time, but the number of species on an island can change over time due to environmental, climatic, anthropogenic, or ecological changes (e.g., Larocque *et al*. 2000; Golinski & Boecklen 2006). Base line and repeat plant inventories are necessary to determine the spatiotemporal distribution of native and non-native plant species in the study area. For example, four non-native 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. However, the non-native plant sheep sorrel (*Rumex acetosella* L.) was less abundant than during previous field seasons. Mossy stonecrop (*Sedum acre* L.), a succulent non-native plant species, continues to be a prevalent invader of newly emerged bedrock habitats. Non-native plant species are typically early colonizers and efficient reproducers, thereby outcompeting native plant colonizers on newly emerged shorelines. Analyzing data in The Massasauga over time may elucidate clearer distribution patterns and predictive models of non-native plant species in the park than the ecological snapshot typically derived from island biogeographical research.

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 which approximate 2,000 hectares (ha) of landmass. A total of 43 islands were inventoried for plant species richness, substrate characteristics, and forest characteristics in the years 2001, 2006, and 2011 (Fig. 2).

The Canadian Shield bedrock of The Massasauga consists of the Parry Sound Greenstone Belt (metavolcanic, metasedimentary, and igneous) and the Ontario Gneiss Belt, both of Precambrian origin (Cordiner 1977; Sly & Munawar 1988). The geologic belts show evidence of relict bedding and tectonic activity (*e.g.* folding, stacking, dikes, and lava flows) (Cordiner 1977; van Luit 1987; Larson & Schaetzl

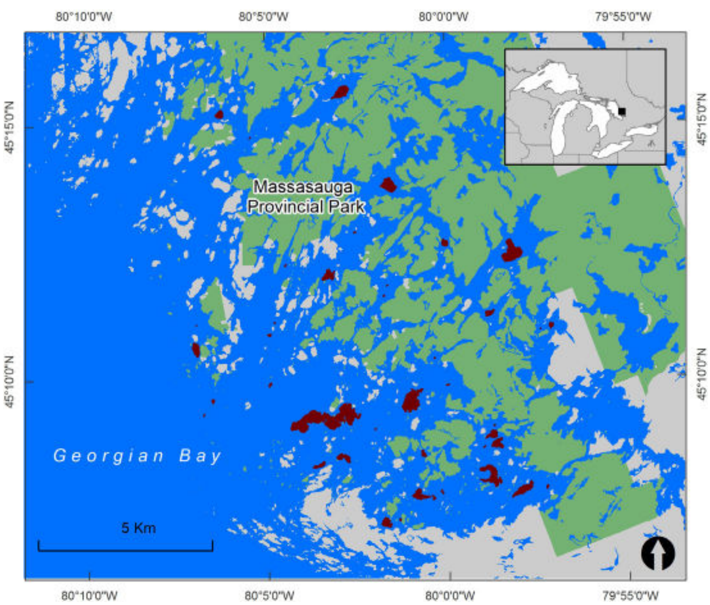

Figure 2. Map of The Massasauga Provincial Park, Ontario, Canada. The park (green and red) consists of mainland and approximately 200 islands. The 43 sampled islands are red.

2001). As part of the Grenville Peneplain, the general profiles of the islands are relatively flat, ranging from a few meters below lake level in depression basins to *circa* 50 m above lake level. Water depths between the islands vary considerably, ranging from less than a meter to depths in excess of 30 m.

The bedrock-dominated topography with thin, discontinuous sediments of glacial till and alluvium is due to bedrock erosion and substrate removal during periods of glacial abrasion and post-glacial lake wave-washing (van Luit, 1987; Larson & Schaetzl, 2001). The Thirty Thousand Island archipelago was formed by glacial scouring of the Canadian Shield, erosion from glacial meltwater drainages, and post-glacial isolation (Hirvonen & Woods, 1978). Detailed reviews of glacial and postglacial lake level history of the Georgian Bay region are provided in Larson and Schaetzl (2001) and Eschman & Karrow (1985). During and following deglaciation, The Massasauga islands periodically emerged and submerged with high and low lake stands. Maximum lake levels during the postglacial Nipissing high lake stand (beginning 5.5 ka) reached 184 m asl, inundating the majority of the islands even those currently greater than 184 m asl due to lagging effects of isostatic depression (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 (Hirvonen & Woods, 1978). (Low elevation islands likely periodically emerged and/or immersed with post-Nipissing lake level fluctuations.) Lake levels for the past 2.5 ka show a stabilized mean of 177 m asl (Eschman & Karrow, 1985).

Historic lake levels in the Great Lakes basin show marked fluctuations between approximately 175 and 178 m asl, with chart datum at 176 m asl. In 1986, the record high level was approached with annual mean water levels at 177.5 m asl (Bishop 1990). Since 1998, water levels have fallen below the long-term historic average of 177 m asl. Current lake levels (February 2014 monthly mean 175.95 m asl; 2013 annual mean 175.90 m asl) are below the historic average and near the lowest recorded annual mean water level of 175.68 m asl from 1964. (Seasonal high levels for the Georgian Bay are typically in July and seasonal low levels are during mid to late winter.) Low elevation islands (< 5 m maximum elevation) and all island shorelines emerge and submerge with these fluctuations.

METHODOLOGY

K. Diver and former research assistants conducted vegetation inventories in 2001, 2006, and 2011 on 34, 19, and 17 islands, respectively, for a total of 43 islands. For field methods, see Diver 2008. The 2013 Keck team included 1 professor (K. Diver) and 3 Keck students (E. Sinkler, R. Edgley, T. Kurtu). The summer portion of the project took place at Wesleyan University in the Department of Earth & Environmental Sciences' GIS Lab. Original analyses of the field data included analyses of the area, shape, and isolation of islands as predictors of the variation in the distribution of total and non-native plant species. However, as stated above, existing GIS data obtained from the Ontario Ministry of Natural Resources reflects island shorelines at high water levels. In order to conduct analyses with accurate data, we acquired satellite imagery (Digital Globe WorldView-2) and aerial photography (Canada National Air Photo Library) captured during water levels states corresponding to the field years (Table 1). We used island polygons digitized from those three

Table 1. Year, source organization, and type of imagery used in the analyses. Three sets of imagery had water levels closely corresponding to water levels that occurred during the fieldwork dates.

Year	Source	Type	Water level (m asl)*	Field year‡
1965	Canada National Air Photo Library	aerial photo	175.94	
1971	Canada National Air Photo Library	aerial photo	176.96	
1983	Canada National Air Photo Library	aerial photo	177.02	
2004	West Parry Sound Geography Network	orthophoto	176.11	2006
2005	Canadian Hydrographic Service	nautical chart	176.09	2001
2007	Land Information Ontario (Forest Resource Inventory)	orthophoto	175.94	
2012	Digital Globe	WorldView-2 satellite	175.86	2011
2013	Digital Globe	WorldView-2 satellite	175.75	

* Annual mean, or monthly mean for imagery with known dates of acquisition

‡ Water level of year of field work corresponding to water level of imagery date

years of imagery as proxies for the three field work years. We obtained water level from the Great Lakes Water Level Dashboard (Gronewald et al. 2013). Additional imagery sets reflecting low and high water level periods were purchased for input into the water level and island shoreline projections model.

All aerial photos were manually georeferenced in ArcMap (ESRI ArcGIS 10.1). Polygons of the 43 islands for each imagery dataset were digitized and their areas calculated. A Microsoft Excel table with the original field data was joined to each new island polygon layer based on the island ID code. Subsequent advanced spatial analyses were conducted individually by the students as pertained to their research objectives. R. Edgley calculated shape and connectivity indices using the geoprocessing and field calculator tools in ArcMap. He also conducted univariate and multivariate ordinary least squares regression models using the spatial statistics toolset in ArcMap. E. Sinkler acquired bathymetry data, created DEM and TIN datasets, and conducted surface analyses in ArcScene in order to model future shoreline configurations and island areas using existing water level scenarios.

STUDENT PROJECTS

Ryan Edgley (California State Polytechnic University) *GIS Approach to Water-Level Change: Potential Effects of Water-Level Changes on Island Ecosystems*. Ryan tested hypotheses regarding the influence of changes in island area, shape, and connectivity on the number of plant species per island. First, larger island sizes are correlated with an increase in plant species richness. Second, using accurate island areas will produce different species–area relationships than the original models using island areas from a high-water year. The results support both hypotheses. The semi-log species–area relationship for total plant species richness (field year 2001) had a regression coefficient of 0.84 ($p < 0.0001$) using island areas from a high-water year (Diver 2004). But using the proper areas, the model is less strong with an R^2 of 0.747 ($p < 0.0001$). Third, islands with a greater increase in island area during low water years should have more non-native plant species because there is more emerged shoreline for those invading plants to take root. The results support this in that 30% of the variation in non-native plant species richness (year 2001 species richness data) is due to the difference in island area (years 1984 and 2001). More non-native plant species were on islands that experiencd a greater increase in size. Fourth, rounder islands (island shape) and less isolated islands (connectivity) will have a greater number of non-native plant species. The results indicate that island shape, ($R^2 = 0.377$, $p < 0.0001$) was statistically significant and our isolation variable (land:water) was not. A key finding of Ryan's work is that knowing the accurate island areas for a region with dynamic water levels is important for understanding the degree of influence that island area has on plant species richness. Anyone studying islands with dynamic interannual water levels (e.g. the Great Lakes, oceans) should obtain island areas for the year of their plant inventories since island area is a key variable in island biogeography theory.

Emilie Sinkler (Wesleyan University) *Declining Water Level in Lake Michigan-Huron and the Effect on Islands in The Massasauga Provincial Park, Ontario*. Emilie modeled future changes in island area based on existing long-term water level projections. Although lake levels fluctuate on daily, seasonal, annual, and long-term cycles, recent studies have indicated that Great Lakes water levels will decline 1 m by 2050

(Mortsch *et al*. 2000). The projection is based on climate change predictions of increased temperatures in the region, increased lake surface evaporation, and extreme seasonal precipitation patterns. Implications of declining water levels on island and shoreline habitats are few (see Schwartz *et al*. 2007). Emilie used bathymetric and elevation data with water level scenario predictions to produce 3D shoreline models. The model projections and maps are useful for recreation and navigation purposes in the region. For example, Emilie's maps indicate that increased connectivity and shallower water depths will cut off mooring bays and reduce navigable waterways in the park. The results are also useful for biodiversity conservation purposes by allowing for predictions of future island biogeography characteristics of the archipelago. Increased connectivity among islands and mainland areas will allow for greater mobility of animals and plants, both native and non-native, throughout the park.

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