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A GIS APPROACH TO THE EFFECTS OF WATER-LEVEL CHANGE ON SOIL PROPERTIES AND TREE SPECIES RICHNESS

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ABSTRACT

Seasonal and yearly fluctuations of the water level in Canada's Georgian Bay impact the island systems that make up the Massasauga Provincial Park. In this study led by Dr. Kim Diver, myself and three other students surveyed the plant communities, soil properties, and shoreline boundaries of sixteen small islands in the Park using GPS units. This data, used in conjunction with satellite imagery and elevation contours formed the basis of the GIS map I created to display the information we collected. Each island area was then separated into one of two categories based on the maximum recorded Georgian Bay water-level: recently emerged island areas stand below 177.5 meters asl and long emerged island areas are above 177.5 meters asl. This study determined that soil depth, number of saplings and seedlings, and tree species richness were significantly different on recently emerged shoreline areas compared to long emerged interior island areas. This difference is attributed to the water-level fluctuation of the Georgian Bay and the detrimental effect of submersion on soils and soil formational processes.

INTRODUCTION

Water level fluctuation is an essential aspect of the Great Lakes ecosystem. In the Massasauga Provincial Park (Lake Huron, Canada) the seasonal and yearly lake level changes create a stark contrast between the shoreline areas and central island areas of the archipelago. This project was undertaken to provide a comparison between island areas that have been above water for thirty years at most and island areas that have been above water for approximately eight thousand years (Lewis et al., 1994) . Using ArcMap (ESRI) spatial analysis tools and statistical tests I examined a variety of tree and soil data to explore the differences between recent and long emerged island areas.

FIELD METHODS

From July 4th to July 15th, 2016 Dr. Kim Diver, Tessa Hill, Matthew Kelly, and myself performed surveys of sixteen islands in the Massasauga Provincial park in Ontario, Canada. We classified each island as medium (5-10 ha), small (1-5 ha), or very small (<1 ha) based on the area of the island in question. Islands smaller than one hectare were very small and had three transects perpendicular to the longest axis of the island. Islands larger than one hectare had five transects along the island. We predetermined the bearing for each transect using topographic maps to determine the long axis of each island and the compass bearings perpendicular to those axes. When on the islands, we used our predetermined bearings to lay our transects in as straight a line as possible. However, due to the topography and density of vegetation on some islands, perfectly straight transects were not always possible. Along each transect, spaced at random distances, we laid out 10 x 10 meter square quadrats on small islands and 5 x 5 meter square quadrats on very small islands in which we surveyed the diameter at breast height (DBH) and species composition of all trees present. We also cored some of the larger and healthier trees using increment borers. Any tree with a DBH of less than ten centimeters and taller than breast height was classified as a sapling and its species was recorded. In five, one meter square portions at each corner and the center of each quadrat, any tree shorter

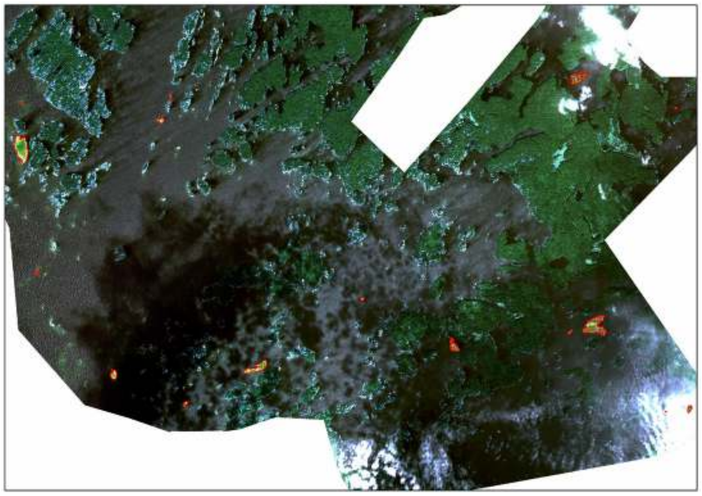

Figure 1: Map of the entire area sampled including all sixteen islands in the study area. Sampled islands are outlined in red and elevation color gradations are included. The image is satellite imagery (Digital Globe) taken July 2016 during our sampling period.

than breast height was classified as a seedling and its species was recorded. At the center of each quadrat we also measured the soil depth in centimeters, took a soil sample and a GPS waypoint. While walking along each transect, we also inventoried plants species richness. We identified each new species observed while walking the transect to create a species accumulation curve to ensure that the species observed along the transects were representative of all the species on the whole island. Finally, we used GPS units (Garmin) to trace the shoreline of every island by walking the perimeter of each island and recording GPS waypoints approximately every five paces. (Figure 1)

ANALYTICAL METHODS

From July 18th to July 29th, Dr. Kim Diver, Matthew Kelly, Leah Bournival, and myself processed the soil samples, tree cores, tree data, and plant species richness data. We created soil slurries with a ratio of five parts water to one part soil to determine the pH of all of our samples, following the methods of Bickelhaupt and White (1982). We mounted and sanded the tree cores and created skeleton plots for each core. We entered all of our plant species richness and tree species composition data into a shared Excel (Microsoft) document. Once all of our samples had been processed and recorded, I created a GIS map in ArcMap 10.4.1 (Esri). I used the GPX to shapefile

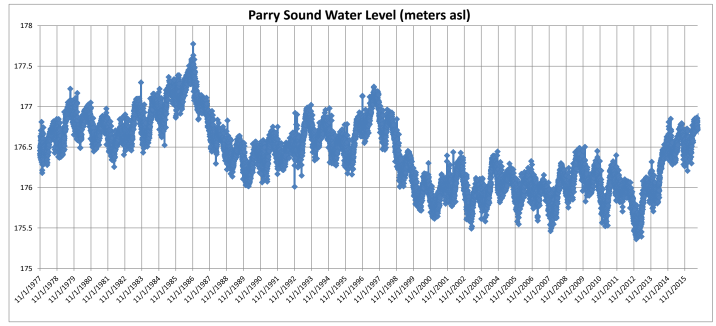

Figure 2: A graph of the daily water level data gathered by the Parry Sound Tidal gauge from November 1st, 1977 to November 1st, 2015. The maximum water level in this time period occurred in 1986 and reached a peak of 177.775 meters asl on November 9th, 1986.

tool in ArcMap to convert all of the GPS waypoints taken in the field to a points vector file. I separated the waypoints into two shapefiles: (1) waypoints representing quadrats and (2) waypoints representing island shorelines. I entered data associated with a specific quadrat into the attribute table for each quadrat waypoint. Data included tree, sapling, and seedling species data, as well as soil depth and pH measurements. I split the quadrats shapefile into multiple shapefiles, each shapefile containing all the quadrats on a particular island. I used the shoreline GPS waypoints as reference, in addition to July 2016 satellite imagery, to create polygons within a shapefile representing each sampled island. I used the editing tool to trace each island by connecting the shoreline waypoints taken in the field. Next, I obtained available water level data (1977-2015) gathered by the Parry Sound tidal gauge (Fisheries and Oceans Canada, Station 11375), which was the closest gauge to our study area. I converted the data from observed water level into meters above sea level (asl) by determining the gauge's baseline water level (176 meters asl) and adding that baseline to the observed water level. (Figure 2) From the Parry Sound water level data and other sources, I learned that the maximum water level in our area of interest for the past hundred years occurred in 1986 and reached a height of 177.5 meters asl. Dr. Diver acquired lidar data (South Central Ontario Orthophotography Project 2013) for southern Ontario from Land Information Ontario. I used the metadata index for the 2 TB lidar dataset to determine which data tiles corresponded to our area of study. Once I identified the relevant lidar data, I used the

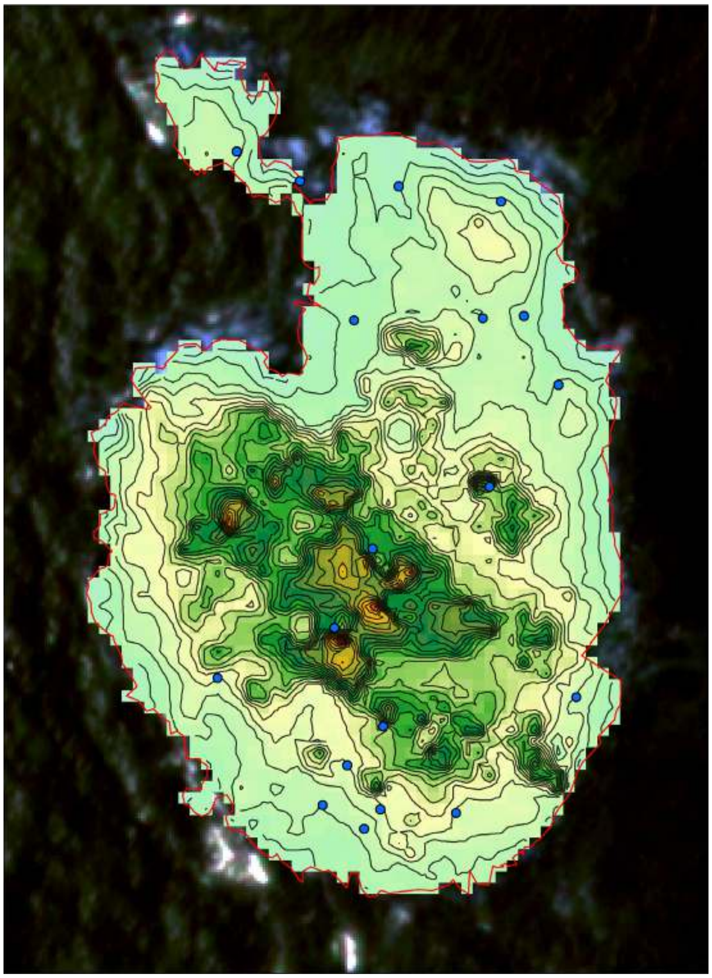

Figure 3: A GIS map of Island 307 in Massasauga Provincial Park. This map includes the island shoreline in red, the sampled areas as blue dots, and the elevation of the island with half meter contours and color gradations. The background is satellite imagery taken of the park in July, 2016.

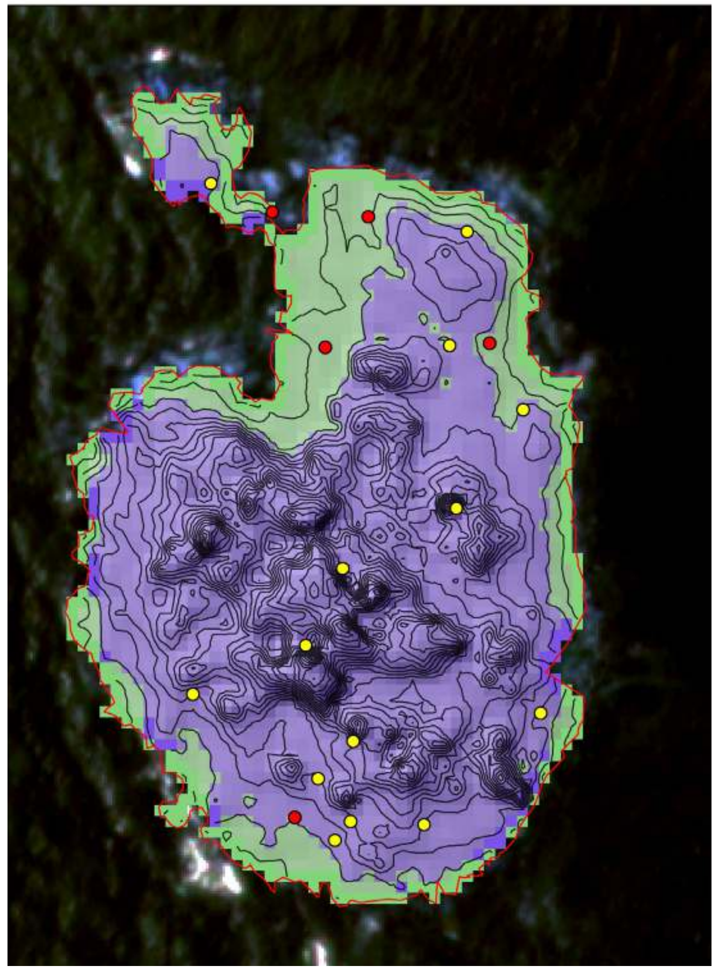

Figure 4: GIS map of Island 307 in Massasauga Provincial Park. This map shows the reclassified raster indicating areas below 177.5 meter asl in green and areas above 177.5 meters asl in purple. Quadrats located on shoreline areas are displayed as red dots and quadrats located on interior areas are displayed as yellow dots. The shoreline at the time of sampling is traced in red, and hillshade and half meter elevation contours are included.

laszip application (www.laszip.org) to decompress the lidar files as well as to spatially reference them with the same projected coordinate system as the rest of the data in my map document (UTM 17N). Finally, I used ArcCatalog to group the unzipped lidar files into a lidar dataset, then added that dataset to my map document. With the high resolution lidar data, I created a detailed raster using the las to raster tool that shows the elevation of the area of interest in half-meter increments. I then reclassified this raster to show only two elevation values; above 177.5 meters asl, and below 177.5 meters asl. The value of 177.5 was chosen because this was the maximum recorded water level for a year in the past one hundred years. As such, this reclassified raster differentiated between shorelines emerged within the past thirty years and island areas that have been exposed since the late Lake Stanley lowstand, between 7.8 and 7.5 ka BP (Lewis et al., 1994). Next, I used the extract by mask tool to limit the area of raster shown to include only the islands we surveyed. I used the shorelines shapefile I created as the mask for both the elevation and the reclassified raster. Then I used the masked elevation raster to create a hillshade raster and half-meter elevation contour shapefile for the islands sampled. (Figure 3) Next, I used the reclassified raster and the extract raster values to point tool to extract the data on whether or not a sampling quadrat was above or below 177.5 meter asl to the shapefile containing all of the quadrats sampled. This allowed me to separate this shapefile into two new shapefiles using the select by attribute feature and the export selection tool. One of these shapefiles contained all the quadrats that were sampled at a higher elevation than 177.5 meter asl, and the other contained all the quadrats sampled at an elevation lower than 177.5 meter asl. (Figure 4) Using these two data sets, I performed unpaired, two-sample t-tests assuming unequal variance to determine if there was a significant difference between the soil depth, soil pH, tree species richness, number of seedlings, and number of saplings between quadrats above 177.5 meter asl and those below 177.5 meters asl.

RESULTS

I undertook this project to determine which, if any, of our sampled variables showed significant differences between recently emerged island areas and areas that have been above the water level for approximately eight thousand years (Lewis et al., 1994). Using ArcGIS mapping tools and unpaired two-sample t-tests assuming unequal variance, I determined that four out of the five tested variables showed significant differences between these two categories of island area. Soil depth, number of seedlings, number of saplings, and tree species richness were all identified as being significantly affected by the emergence state of the sampled area. On average, soil was 7.3 centimeters deeper in long emerged areas than on newly emerged areas. Long emerged quadrats on average had approximately five more seedlings and four more saplings than did newly emerged quadrats. Long emerged island areas also had higher tree species richness values than did the newly emerged areas.

Soil Depth		
	Above 1986 Water Level	*Below 1986 Water Level*
Mean	9.607017556	2.32
Variance	169.162774	53.47666667
Observations	171	25
Hypothesized Mean Difference	0	
df	50	
t Stat	4.119969927	
P(T<=t) one-tail	7.11165E-05	
t Critical one-tail	1.675905025	
P(T<=t) two-tail	0.000142233	
t Critical two-tail	2.008559112	
pH		
	Above 1986 Water Level	*Below 1986 Water Level*
Mean	4.175339815	4.520000029
Variance	0.149834923	0.360799923
Observations	103	5
Hypothesized Mean Difference	0	
df	4	
t Stat	-1.270307616	
P(T<=t) one-tail	0.136418345	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.27283669	
t Critical two-tail	2.776445105	
Seedlings		
	Above 1986 Water Level	*Below 1986 Water Level*
Mean	6.315789474	1.153846154
Variance	259.8879257	32.29538462
Observations	171	26
Hypothesized Mean Difference	0	
df	101	
t Stat	3.106031863	
P(T<=t) one-tail	0.001230806	
t Critical one-tail	1.66008063	
P(T<=t) two-tail	0.002461611	
t Critical two-tail	1.983731003	
Saplings		
	Above 1986 Water Level	*Below 1986 Water Level*
Mean	6.397660819	1.576923077
Variance	69.47622979	28.49384615
Observations	171	26
Hypothesized Mean Difference	0	
df	46	
t Stat	3.933218299	
P(T<=t) one-tail	0.000140329	
t Critical one-tail	1.678660414	
P(T<=t) two-tail	0.000280659	
t Critical two-tail	2.012895599	
Tree Species Richness		
	Above 1986 Water Level	*Below 1986 Water Level*
Mean	2.093567251	0.423076923
Variance	4.038252494	1.213846154
Observations	171	26
Hypothesized Mean Difference	0	
df	55	
t Stat	6.300288363	
P(T<=t) one-tail	2.62244E-08	
t Critical one-tail	1.673033965	
P(T<=t) two-tail	5.24488E-08	
t Critical two-tail	2.004044783	

Table 1: Results of the un-paired two sample t-tests assuming unequal variance run for each of the five fields examined by this study. The P-values shown indicate that the mean differences for soil depth, number of seedlings and saplings, and tree species richness are significant. The mean difference for soil pH does not show significance.

Soil pH showed no significant difference between the newly emerged and long emerged island areas. (Table 1)

DISCUSSION

Constant fluctuations in the water-level of the Georgian Bay drives the existence of at least two distinct categories of land found on the islands of Massasauga Provincial Park. The shoreline areas of these islands are regularly submerged, some parts even on a seasonal scale. The interior areas of these islands are rarely submerged, some areas having been above the water level since the late Lake Stanley lowstand (Lewis et al., 1994). This helps drive the significant difference in the soil resources of these two island land-types. Soil depth is often a reliable metric in broadly determining the length of time soil formation has been occurring continuously in an area. However, sediment transportation caused by the movement of bodies of water such as streams, lakes, or oceans can also account for the buildup or removal of materials in areas influenced by such bodies. Furthermore, submerged areas will be unable to form new soils. As such, the significant difference in soil depth between the two emergence states identified is driven by the thousands of years of uninterrupted soil formation on interior island areas, and by the transportation of sediments via water level fluctuations of the Georgian Bay on shoreline island areas. Although water-level fluctuation directly influences soil properties, I would point to the differences in soil depth as the direct cause of the variation in tree diversity and frequency between shoreline and interior island areas. On many islands, there were shoreline areas populated by saplings that had been killed by elevated water levels. However, since these saplings were dead and outside of the island area surveyed, they were not incorporated into the results of our study. This reveals that water level change does have a direct effect on sapling frequency. However, after the death of these trees, the amount of soil present on emerged shoreline areas will have a greater impact upon future growth than the amount of shoreline area available.

Soil pH was the only environmental factor sampled by quadrat that did not show significant difference in value between shoreline and mainland areas. Considering potential sources of soil acidity might lend insight into this finding. In interior areas, the main influence upon soil pH would likely be the partial decomposition of plant matter, a factor which creates organic acids and lowers the soil pH. In shoreline areas, soil pH would likely be heavily influenced by the acidity released by lichens and mosses to enhance the rate of bedrock decomposition. These earlier successional organisms acquire nutrients and drive soil formation by using protons to help break down bedrock materials. Although these two soil processes are entirely distinct, they both contribute to the acidification of soils and could explain the similarities in soil pH between shoreline and mainland island areas. Another factor influencing the lack of significant difference in soil pH is the reduced number of pH measurements available for statistical testing. For each other observation I tested, zero was an acceptable value. However, even in areas with no soil, a value of zero pH is nonsensical and would completely skew any statistical analysis of pH data. As such, many data collection sites had no pH values associated with them, greatly lowering the number of soil pH values used in the analysis.

CONCLUSION

The Great Lakes experience a great deal of variation in water level. A major goal of this project was to explore the effects these variations have upon the ecological systems of Massasauga Provincial Park. The effects of submersion upon soil formational processes is made apparent in the differences observed between areas above water for no longer than thirty years and areas above water for approximately eight thousand years (Lewis et al., 1994). The difference in soil depth in these two categories of island area provides a glimpse of the effects of water level change, and displays the impact of submersion and soil resources upon tree frequency and diversity.

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