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USING REMOTE SENSING TO MONITOR ECOHYDROLOGICAL CHANGES IN GREAT LAKES INTERDUNAL WETLANDS/SLACKS

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ABSTRACT
Secondary interdunal wetlands or slacks develop in the Great Lakes coastal dunes when the wind scours the sand to the water table within a dune. Slacks have a limited geographic distribution and are an imperiled ecosystem along the Great Lakes. Previously we used historic aerial photographs and satellite imagery of slacks at Saugatuck Harbor Natural Area on Lake Michigan’s eastern shore to examine the relationship between the Lake Michigan water level curve and the slack’s extent. Water levels and the nature of the slack’s vegetation were found to be tied to Lake Michigan’s levels, larger pond areas in higher water level years and smaller ponds in lower water level years. We extended these studies along Lake Michigan’s coast to Warren Dunes and Ludington State Parks, Leelanau Peninsula, Crystal Lake and Point Betsie using historic images from 1952–2018. Using QGIS we drew polygons around three types of slack features, wet sand, standing water and slack vegetation on georeferenced photos, calculating perimeters and areas for each feature on each photo. Wetland perimeters and areas were summed annually for each feature. These values were then totaled on an annual basis (wetland extent) and compared to the Lake Michigan water level curve. Overall the wetland extent in Warren Dunes, Leelanau and Crystal Lake reflects the lake level curve, increasing as water levels rise and decreasing as they fall. Wetland extents at Point Betsie and Ludington follow the lake level curve with the exception of 1965 and 1993 at Point Betsie, and 1993–2012 at Ludington. Possible explanations being investigated for these variances include photo quality and/or a rain event(s). Overall this method provides a reliable way to evaluate historic ecohydrological changes in response to fluctuating lake levels. 3-band (red, green, near-infrared) drone imagery has also been used as lake levels rise (2017, 2018, and 2019) to examine the ecohydrological changes occurring in a large slack (>1 ha in size) at SHNA where ridges and pools create a diverse vegetation mosaic. Vegetation quadrat sampling (32 quadrats) was used to ground-truth the image interpretations. Vegetation indices using these data provide even greater detail on the ecological changes in the slack.

Introduction and Site Description

Interdunal wetlands/slacks are found amongst the coastal dunes of Lake Michigan where the wind scours the sand to the water table. These areas tend to be ecologically diverse, albeit rare in occurrence. The Michigan Natural Features Inventory (MNFI) ranks their status as G-2, meaning they are “imperiled and at high risk of extinction due to a very restricted range...”(MNFI 2016).

The hydrology of these slacks is generally connected to Lake Michigan-Huron (DeVries-Zimmerman et al. 2016), but it is also influenced by rainwater and seasonal processes such as evapotranspiration. Lake level data collected for the Lake Michigan-Huron basin since 1860 show fluctuations of ~2m (USACOE 2019). These fluctuations can profoundly change the ecosystem of the slacks as low levels will cause the slacks to dry and higher levels will inundate them.

We initiated ecohydrological studies in a large slack in the Saugatuck Harbor Natural Area (SHNA) near Saugatuck, Michigan in May 2016, investigating the effect of rising lake levels on the slack’s ecology (DeVries-Zimmerman et al. 2016) studies which continue to date. We have also used remote sensing, especially color-infrared satellite and drone images, to study the ecological changes in the dune slack associated with past and current hydrologic fluctuations (Donaldson et al. 2018).

We have expanded these studies to examine how historic lake level fluctuations have affected the ecology of other slacks along the eastern coast of Lake Michigan. Have they responded similarly to those at SHNA, contracting in times of low Lake Michigan-Huron water levels and sometimes drying up completely, only to reappear and expand during times of higher water levels? Or have they fluctuated in presence and size independent of these water levels?

Remote Sensing Survey – Methodology

Using Google earth, we surveyed Lake Michigan’s eastern coast for slacks located within dune complexes that also had usable historic imagery. Historic aerial photographs (Fig. 3) were obtained from Michigan State University’s Aerial Imagery Archive. Satellite images were obtained from Google Earth and NAIP. When possible, we tried to obtain imagery from the same years for the respective sites. However, given the quality of some of the images, this was not always possible, and imagery close in time to the year in question was used. Based on this survey, we studied historic georeferenced images from 1952–2018 at five locations, Warren Dunes and Ludington State Parks, Point Betsie, Crystal Lake, and the Leelanau Peninsula (Fig. 2)

Using QGIS, we drew polygons around three types of slack features (wet sand, standing water, and slack vegetation) and calculated perimeters and areas for each feature on each photo. Wetland perimeters and areas were then summed annually for each of the three features at each location. These values were then totaled on an annual basis (wetland extent) (Fig. 4) and compared to the Lake Michigan-Huron water level curve (Fig. 5).

Figure 3. Historic aerial photograph of coastal dune area at Ludington State park. Lake Michigan is in the bottom left hand corner. Note slack areas (grey) in both open and forested dune areas.

Figure 1. View of an interdunal wetland/slack at Ludington State Park.

Figure 2. Elevation shaded relief map of Michigan’s lower peninsula showing study areas along Lake Michigan’s east coast (MDEQ GeoWebFace Map, 2019).

SHNA Near Infrared-Red-Green Drone Imagery

The 2016 image was obtained from the National Agriculture Imagery Program (NAIP). The 2017, 2018, and 2019 images of SHNA were obtained using a small unmanned aircraft system (a.k.a. drone) equipped with a sensor capturing red (R), green (G), and near-infrared (NIR) spectral bands with ~1 cm² per pixel resolution (2017 and 2018 images) and ~6.25 cm² per pixel resolution (2019 image). The pigment in plant chlorophyll is photosynthetically active, absorbing red wavelength light (700nm) and reflecting near infrared wavelength light (700nm < λ <1000nm) (NASA 2017). Hence, different plant species have different color fluctuations or tonal signatures within an image. These, in addition to pattern, shadow, and texture, can distinguish different vegetation communities and even species within a wetland. The drone was systematically flown over the study area at an approximate height of 60m above ground level. Overlapping images were stitched together in Photoshop to create images of the study area in 2017. The 2018 and 2019 imagery was stitched using Agisoft metashape.

Remote Sensing Survey - Results

Figure 4. Plots of wetland extent (m²) vs year for each of the study sites. Lake Michigan water levels at the time the imagery was obtained are indicated as above average (H), average (A), or below average (L) on the plots.

Figure 5. Historic Lake Michigan-Huron water level curve (International Great Lakes Datum 1985) (USACOE, 2019).

Historic aerial photograph and satellite imagery

The wetland extents in Warren Dunes, Leelanau, and Crystal Lake (Figs. 4A, B, and C, respectively) reflect the Lake Michigan-Huron lake level curve (Fig. 5). Wetland extents increase as water levels rise and decrease as they fall. In Warren Dunes (Figs. 4A, 6), wetland extents showed a small increase even though water levels dropped .5m between 1975–1993. However, despite this drop, lake levels were still above average, keeping the wetlands flooded. Wetland extents at Point Betsie (Fig. 4D) follow the lake level curve except for 1965 and 1993. Wetland extents show a decrease in 1965, reflecting a drop to below average lake levels. However, wetland extents in 1993 are slightly lower than those in 1965 despite above average lake levels at this time. Photo quality and/or a rain event are possible explanations being investigated. Wetland extents in Ludington (Fig. 4E) reflect the lake level curve until 1993–2012 when small differences between wetland extent and lake levels are noted. Again, image quality and/or rain events are suspected as possible causes of these discrepancies. In 2018, wetland extent increases at Ludington as lake levels rose to average and above average levels.

Multispectral NAIP and drone imagery

Lake levels were above average in 2016, expanding the pools on the slack’s northern edge and creating pools in the central slack. In false-color (NIR-R-G) images, vegetation within the slack is pink to light-medium red in color, suggesting an increase in plant vigor and a possible transition to wetland vegetation. Rising water levels continued in 2017, deepening and expanding the standing water areas (black to very dark red colors). The 2017 image shows expansion of wetland vegetation (pink to medium red colors) along the western and southern margins, in the northwest corner and onto an east-west trending ridge. Vegetation quadrat sampling in both 2016 and 2017 confirmed that this area was dominated by facultative wetland to obligate wetland vegetation with different species’ densities creating the pink to red color variations. In 2018, water levels continued to rise above average. The 2018 drone image shows greatly expanded and deepened areas of standing water (black to very dark red) along with larger areas of wetland vegetation (light to dark red). Vegetation density decreases in areas of deepening water, however, as shown by the lack of red textures in black colored areas. Vegetation quadrat sampling confirmed this and also showed a transition from damp/shallow water species to those tolerant of deeper water beginning to occur. Water levels rose to near record highs in 2019. Significant expansion of standing water (black to very dark red colors) occurred with this rise and wetland vegetation (pink to red color variations), especially in the northern part of the main slack, markedly decreased. Mottling of the pink/red areas with black (standing water) indicates that the density of the remaining vegetation has decreased from 2018. Standing water has also increased in blowouts on the north, east, and south edges of the main slack, creating incipient slacks. Quadrat sampling confirmed these interpretation.

Future Work

This work continues the ecohydrological study of an interdunal wetland/slack in a Great Lakes coastal dune system. The remote sensing study of historic images documents the ecosystem shifts due to fluctuating Lake Michigan-Huron water levels wherein the wetland ecosystem expands in response to rising water levels, and contracts, almost disappearing completely, in times of low water levels. The newly collected drone images, in conjunction with quadrat sampling, allow us to monitor the ecosystem shifts in greater detail as the wetland is mapped as a whole feature rather than as discrete sampling points. Vegetation indices, including the Normalized Difference Vegetation Index (NDVI), are being calculated from the drone data to further examine and quantify these changes.

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Figure 7. A. 2016 NAIP color-IR image; B. 2017 color-IR image obtained using drone data collected by Mishigami Group. C. 2018 color-IR image using drone data collected by Mishigami Group. D. 2019 color-IR image generated from drone data collected by Hope College Dune Group.